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A CONTENT ANALYSIS OF PRESENTATIONS OF ELECTROSTATICS IN SOUTH AFRICAN UPPER SECONDARY SCHOOL TEXTBOOKS

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A Thesis Submitted to the Faculty of Humanities, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy

Johannesburg, 6 December 2016

DECLARATION

I declare that this Thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

_____

(Signature of candidate)

_____day of _____20_____in_____

ABSTRACT

The reality of South African education leaves little doubt that the school science textbook is the primary means by which the 'what is taught and learnt' in science classrooms is determined. Reports from different countries suggest the same trait. The possibility that not all learners' 'naïve ideas' originate in everyday life has also emerged in the literature along with allusions to the quality of textbooks. If school textbooks are to be blamed, even partially, for learners' naïve ideas, a systematic analysis of their subject content becomes requisite.

The present study is a systematic content analysis of presentations of foundational aspects of Electrostatics, in approved South African physical sciences textbooks in use after the first democratic elections of 1994, thus representing and addressing three curricula school education has gone through since. The study was perceived as a first step to an anticipated analysis of the entire topic Electromagnetism to which Electrostatics is part of, given its difficulty as has been widely reported in the literature and its status in school curricula. Using the conceptual framework of the Classical Electromagnetic Theory, six foundational aspects of Electrostatics were demarcated for the analysis, targeting the concept charge, its origins, transfer and conservation, the distinction between conductors and insulators, the attraction between charged and uncharged objects, as well as global perceptions of Electrostatics and its place within Electromagnetism. Categorisation tables with theoretically grounded indicators were developed as the primary constructs against which texts were analysed, but inductive categorisation tables emerged from the texts as well. An additional construct was necessitated and developed, the "Organisation of the science educator's thought", based on the notion of a scientific explanation and the nature of scientific models, for analysing links between macro and micro.

The analysis revealed that the subject matter content of Electrostatics in South African textbooks is of major concern, giving learners no reason to make sense or develop an appreciation for science, physics in particular. In fact it is not science.

The analysis suggests that the long lists of problems revealed, have their origin in two main drawbacks: Firstly, inadequate author understanding of the concept *charge*, disregarded or misused in the texts, and secondly, author unawareness of the inferred nature of science models, affecting purpose of accounts, explanations and reasoning. Furthermore, certain

unprofessional author practices are suggested, such as lack of familiarity with curricula and the content of other topics (not a single link was found), lack of research, and general disregard for learners' difficulties, while misconceptions identified in the literature are all communicated in the texts, most explicitly so. The findings suggest that science textbook authors are in need of training.

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To my supervisor, Professor Samuel Ouma Oyoo, for trusting in me and for seeing the worth of this study from its onset. His encouragement, patience, attention to detail and invaluable insights, meant the world to me and have been deeply appreciated.

To my colleagues and staff of the RADMASTE Centre, who opened my eyes to the world of Science Education. They afforded me unrestricted opportunity to develop and learn and use my creativity in the development of an extensive array of science learning materials and courses, a considerable number of which concentrated around Electromagnetism. Through such activities, I had the opportunity to become first-hand familiar with the world of textbook writing and publishing, an endeavour which was pivotal in this study.

To the many South African physical sciences teachers I had the privilege to work with through my work with RADMASTE. Their enthusiasm and gratitude for any new meaningful knowledge bared the significance and impact of intellectual satisfaction, an experience which was a catalyst for this study.

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LIST OF ACRONYMS

C2005	Curriculum 2005
CAPS	Curriculum and Assessment Policy Statement
CET	Classical Electromagnetic Theory
CT	Categorisation Table
DC	Direct Current
DoBE	Department of Basic Education
DoE	Department of Education
FET	Further Education and Training
GET	General Education and Training
HOS	History of Science
LO	Learning Outcome
NATED 550	National Assembly Training and Education Department 550
NCS	National Curriculum Statement
NOS	Nature of Science
OBE	Outcomes Based Education
PCK	Pedagogical Content Knowledge
R-9	From Reception up to grade 9
RNCS	Revised National Curriculum Statement
SMK	Subject Matter content Knowledge

CHAPTER 1

BACKGROUND AND RATIONALE

1.1 Introduction

The Limpopo textbook crisis of 2012 will be remembered for a long time with dismay (Davis, 2013; Veriava, 2013). What is it about textbooks, the lack of which caused a near upheaval and a hailstorm of allegations in South Africa? Since, statements on their importance and their critical role in learning, and more so in poor environments, have flooded the South African media (e.g. Mpuntsha, 2012). Are these the same learning materials that in the past couple of decades have been met with such apathy and even hostility by educational experts? (Hutchinson & Torres, 1994).

Why did the textbook all over the world survive and prosper, apparently in contradiction to the development of ideas such as constructivism and inquiry learning? Obviously the textbook had a vital role to play then as it has now – it fulfilled certain needs. Hutchinson and Torres (1994) offered an answer since the early 1990s claiming that the importance of the textbook becomes even greater in periods of curriculum change. And change has become almost commonplace in South Africa since independence. According to the authors, the fundamental problem of change is that it disturbs the framework of meanings by which we make sense of the word. Hence, an important requirement in the process of change, if it is to be manageable, is security. This is a call for structure and visibility. Hutchinson and Torres (1994) hold that the importance of a textbook during change is that it provides this *structure* that the teaching-learning interaction requires, stressing the importance of structure to learners' life and the notion that a good lesson is a structured lesson.

There is a simpler explanation, which one meets only too often, but informally in the literature from many different countries: the textbook and especially the science textbook, is the primary source of guidance and information for the teacher and often the only source of

learning for both the teacher and the learner (e.g. Lemmer, Edwards & Rapule, 2008; Mahmood, 2011; Ogan- Bekiroglou, 2007). In many environments it may represent the actual curriculum (e.g. Abd-El-Khalick, Waters & Le, 2008; Green & Naidoo, 2008). Some go to the extent to describe school science with one word, *textbook* (e.g. Wang, 1998). Textbooks persistently have had great influence on what is taught and how it is taught. Paradoxically, little effort has been devoted to their analysis. In more recent years, papers on the characteristics of a 'quality textbook' appear, aiming at textbook evaluation and selection and offering lists of criteria. Such criteria address broadly the quality of textbooks, ranging from philosophical underpinnings and ideologies (Green & Naidoo, 2008) to the more mundane aspects such as curriculum conformity, assessment, teacher support, technical aspects and so on (Lemmer et al., 2008; Mahmood, 2011; Swanepoel, 2010). Regarding school science textbooks, their appearance and structure may have evolved consistently through the era of educational reforms, but unfortunately, the same cannot be said about the science content and particularly the physics content. Research suggests (de Posada, 1999; Guisasola, Almudi & Furio, 2005; Slisko & Hadzibegovic, 2011; Stocklmayer & Treagust, 1994) that the physics content of science textbooks is being trapped in a time warp and is being regurgitated generation after generation of textbooks since the nineteenth century, in almost the same way, to the extent that it has become absolute status quo. The lack of evolution of subject content alone signals that all is not well.

1.2 Reforms in South Africa, the teacher and the textbook

After the first democratic elections of 1994, which marked the end of apartheid, the notion of a national and modern curriculum was embraced with enthusiasm in South Africa. The Curriculum 2005 (C2005) was introduced for the General Education and Training (GET)

band, in September 1997 for implementation in 1998. The new curriculum was outcomes based (OBE) and radically different from the previous one, the NATED 550 (National Assembly Training and Education Department), in both structure and philosophy. It embraced modern ideas, notably constructivism, while learner centeredness, hands-on practical work and continuous performance-based assessment were promoted in the place of traditional instruction and assessment practices (e.g. Rogan & Grayson, 2003). New terminology was introduced, such as, teachers became 'facilitators', pupils became 'learners', textbooks became 'learning support materials' and so on, along with a new vocabulary that included terms such as 'phase and programme organisers' and 'performance indicators'. Although changing the meaning of words, as just mentioned, was seen as critical for breaking the links with the past, Chisholm (2005) asserts that the new vocabulary also served as a vehicle to introduce the heavily assessment-driven reforms that were taking place in the USA, Australia and New Zealand into South Africa. During this period, the role of the textbook was subordinated to the idea that teachers should develop their own materials, incorporating local contexts or aiming at conceptual change.

Soon however it became clear that the system was not prepared for such a fundamental change. According to Khulisa Management Services (cited in Rogan & Grayson, 2003), the whole process of "the implementation of C2005 was hopelessly underestimated and inadequately resourced and supported" (p.1173). Complaints about lack of specific content, inability of learners to read, write and count at an appropriate level, lack of general knowledge and incapacity of teachers to develop own materials could not be ignored. The Curriculum 2005 Review Report (Chisholm, 2000; DoE, 2000), among other recommendations, referred to a simpler use of language that was relatively free of assessment-driven terminology, to the need for content to be brought into the curriculum and

specified, and that textbooks had to be reintroduced as a widely recognised means to bridge the gap between teacher readiness, curriculum policy and classroom implementation.

In response, the Revised National Curriculum Statement (RNCS) for the General Education and Training (GET) band was introduced in 2002 for implementation in January 2004. It addressed grades R – 9 (i.e. reception year to grade 9). Its agenda was shifted from the local, skills-based, context dependent agenda of Curriculum 2005 to a more coherent and explicit body of knowledge. It specifically emphasised the development of high knowledge, high skills. The RNCS was still an outcomes-based curriculum, hence content was specified through Assessment Standards and content frameworks. Yet, once again, lack of a clear implementation plan and poor guidance resulted in widespread confusion, where departments, provinces and districts circulated their own interpretations, and where teachers and department officials would often intermingle RNCS and C2005 (DoE, 2009).

Nevertheless, this confusion did not stop the introduction of the National Curriculum Statement (NCS) for the Further Education and Training (FET) band in 2006, developed along the same principles. The NCS would be the first FET curriculum after independence. It provided far more clarity on content and assessment through provision of national rather than provincial documents to minimise confusion (DoE, 2009). And this time, a detailed content for each Knowledge Area (topic) was circulated in June 2006, the year of its implementation. In the Physical Sciences, conceptual progression and coherence, spiral approach aiming at greater complexity and cognitive demand and *big ideas* were highlighted among others. This was made particularly explicit in physics (DoE, 2006, p.4-5), the content of which was supplemented with new topics, such as *capacitors*, *electronics*, and *LRC circuits*, to render it more contemporary and compatible with regional and international curricula, but on which

teachers had no formal training. The NCS obviously required teachers of sound content knowledge. Its developers were surely aware of the possible inadequacies of many science teachers, but perhaps had hoped that training and time would produce results. Actual training however was deemed by teachers too little and too generic and a fair amount of criticism on curriculum implementation and delivery was reported by the Task Team for the Review of the Implementation of NCS and by UMALUSI's report on curriculum evaluation (DoE, 2009; UMALUSI, 2009). Stances on OBE (Outcomes Based Education) left aside, one may argue that many science and science education experts would have been pleased with the NCS, but the fact is that teachers faced problems. The report of the Task Team (DoE, 2009) refers to change weary, overloaded teachers of compromised confidence. It also mentions an *aversion* to textbooks, which they attributed to Curriculum 2005 when the idea of following a single textbook had become anathema. Taylor (2008) had picked up this aversion among South African teachers, but had attributed it instead to a certain unprofessional attitude. According to the report of the Task Team, GET teachers repeatedly pointed out that textbooks appearing on provincial catalogues are often of poor quality and not very useful (DoE, 2009). Yet the same report stresses the overwhelming plea of teachers for good textbooks. In fact the Task Team considered textbooks of such fundamental importance for the successful implementation of the curriculum that they decided to incorporate them in their report, though not in their mandate, "as one of the most effective tools through which to deliver the curriculum and support assessment…but it can also offer appropriate pacing and weighting of content and assist teachers with lesson and year planning" (DoE, 2009, p.51).

Under their recommendations it is stated: "Textbooks on the national catalogue need to be of excellent quality and offer appropriate content and methodology, as well as assessment support. Subject experts should participate in the evaluation of textbooks" (DoE, 2009, p.54).

Taylor (2008) had recommended in addition that a good textbook would not only assist a teacher with lesson planning and curriculum coverage, but most importantly "provide the most accessible source for learning those parts of the subject that are new to the teacher or which she may have forgotten since her own school or college days" (Taylor, 2008, p.24). And we would argue in favour of this last comment.

Indeed, on 5th November 2009 the Minister of Basic Education Angie Motshega, based on the report and recommendations of the Task Team for the Review of the Implementation of NCS (DoE, 2009), denounced OBE in a statement to the National Assembly entitled "We've signed OBE's death certificate" (Motshega, 2009) and announced the way ahead. Her statement in relation to textbooks was:

> Because there was a very strange anomaly in our system in which the importance of textbooks in curriculum delivery was no longer appreciated, the department has noted the teachers' concerns that the development of learning materials is best placed in the hands of the experts, because it is only people who are experts in their fields of study that are best placed to develop textbooks and learning materials…therefore textbooks are going to be used as an effective tool to ensure consistency, coverage, appropriate pacing and better quality in terms of instruction and content. (Motshega, 2009)

Soon afterward, in 2010, the 'death of OBE' was flagged by the Curriculum and Assessment Policy Statement (CAPS). One CAPS document was produced per subject and these were circulated in their final form by December 2011. The Minister introduced CAPS as "*a refined and repackaged NCS*" (Motshekga, 2010, p.7, cited in Nakedi, Taylor, Mundalamo, Rollnick and Mokeleche, 2012), but at least the Physical Sciences CAPS was rather understood as a new curriculum: "The central pillars of the NCS curriculum have been excised" (Nakedi *et al*., 2012, p.286). Furthermore, Nakedi *et al*. (2012) indicate the significant changes in the physical sciences content (i.e. topics removed and others reshuffled between grades) which

have rendered textbooks written for the NCS obsolete, a factor indicative of a new curriculum. Anyway, considering that CAPS was to be implemented in 2012 (starting with grade 10 in FET, followed by grades 11 and 12 in subsequent years), the production of new textbooks became imperative.

1.3 'New generation' textbooks: A big question mark

The official stance on the long anticipated attention to the quality of textbooks in South Africa is certainly welcomed. However, careful consideration of the relevant statements by the Minister and by the Review Committee (DoE, 2009) may evoke feelings of uneasiness: The textbook is presented as a means for the teacher to deliver the curriculum, to ensure content and assessment *coverage*, to offer appropriate *pacing* and *weighting*, to assist with lesson and year *planning*... (DoE, 2009; Motshega, 2009). Apart from a reference of the Minister, in her introductory statement (Motshega, 2009) that each learner will receive a textbook for each Learning Area (subject), learners do not feature in this whole scenario. Content has been downplayed while conceptual understanding is not even mentioned, not in the report (DoE, 2009) or in the Minister's full address (Motshega, 2009). The emerging message appears to be that the school textbook is to address the teacher. In the South African context however, due to its legacy of apartheid misgivings that still permeate the social fabric, and due to the prior introduction of rather ambitious curricula with no proper implementation plan that left many teachers of 'compromised confidence', according to DoE (2009), this 'focus on the teacher' can be understood. The textbook is perceived as a step-by-step guide for the teacher with less than adequate knowledge and skills. In South Africa there is a vast discrepancy in the range and skills of teachers and this is particularly acute when it comes to mathematics and science teachers (Rogan & Grayson, 2003, p.1174). In 1995,

according to Rogan and Grayson (2003), 60% of South African science teachers had no formal training in these subjects. Reddy (2005-2006) refers to the fact that the majority of mathematics and science teachers in South African schools are underqualified, with less than a year of specialised training, despite the fact that they have accredited teaching qualifications.

Nevertheless, there is the risk that publishers may translate statements on pacing, weighting and planning, in number of pages – 'so many pages per teaching hour' or 'so many minutes per paragraph'. But conceptual understanding is not measured in number of pages and nobody can claim that curriculum coverage alone warrants understanding. In a large scale study involving nearly 2000 physics students in the USA, Sadler and Tai (2001) found that high school physics made little difference to grades obtained in introductory college physics. However, students from high schools that kept rigorous standards, but took their time, or who covered fewer topics in great depth, with teachers that explained problems and concepts in many different ways, performed much better in college. If many of our science teachers lack adequate content knowledge and expertise, and if we have high hopes on the help that textbooks can provide in this respect, it shouldn't be unreasonable to require textbooks free of errors and which include sensible and even in depth explanations and insights and reflect in appropriate ways how science is done. Who the authors of school textbooks are may therefore be a key factor of the quality of science textbooks.

1.4 Physics textbook authors: Do they exist?

In South Africa, physics instruction at school level may be at a disadvantage according to Smit and Finegold (1995), who, in a population study of South African universities, found that the majority of student-teachers, enrolled for a post-graduate teacher's diploma, had a

background in biology and yet they were expected to teach physical sciences at upper secondary school level. Personal experience of the author of this thesis from in-service teacher training in South Africa suggests that within the already small pool of science teachers, it is rare to find a teacher who has some physics background, and this applies to teachers from affluent schools as well. The norm therefore seems to be that physics is taught by teachers with background in other disciplines, at best with some knowledge of chemistry, and whose primary source of information is most possibly the textbook (Green & Naidoo, 2008; Lemmer, Edwards & Rapule, 2008).

If we assume that the majority of textbook authors are primarily teachers, shortcomings in physics are to be expected. However, Gunstone, McKittrick, and Mulhall (2005) and Gunstone, Mulhall and McKittrick (2009) refer to studies in Australia which indicate that even (school textbook) authors with physics or engineering degrees and many years of teaching high school physics experience demonstrate inadequate understanding reflected in their writing. The problems encountered in physics instruction and in textbooks seem to be far more complex than simply a lack of a physics degree. Gunstone, McKittrick and Mulhall (2005) refer in particular to inadequate understanding of the distinction between models and analogies and of the nature of physics knowledge in general. But unexpectedly, they also refer to lack of conceptual understanding of pivotal concepts such as voltage, potential difference and *emf* [1]. These are concepts generally covered under the knowledge area *Electricity and Magnetism*, representing the science field of the *Classical Electromagnetism*, which concerns this study given its difficulty as has been generally reported in the literature (e.g. Furió, Guisasola, Almudí & Ceberio, 2003; Pocovi & Finley, 2003).

[1] Gunstone *et al*. (2005) note that "voltage" is a physics slang expression. It is not a physical quantity and has little conceptual status. It simply means "how many volts". Yet it is found in curricula and hence in textbooks where it is often used interchangeably with the concept of "potential difference".

1.5 The problem with Electromagnetism

Thacker, Ganiel and Boys (1999) argue that unlike mechanics where processes can be directly visualised, in electricity everything seen is actually an indirect manifestation of some hidden microscopic process. Gunstone *et al*. (2009) comment on the extensive literature that points to the fact that student abilities to complete algorithmic and only algorithmic circuit problems are often enhanced by teaching and little else appears to develop. However they also report on something even more alarming: some of the teachers and textbook authors they had interviewed in Australia and whose understanding on DC circuits was a cause of concern, were of the opinion that DC electricity was essentially straight forward. Some teachers indicated that electricity is easy to teach, but students find it hard to learn.

Mulhall, McKittrick and Gunstone (2001, p.576) refer to a workshop devoted to studies of the learning and teaching of electricity, in 1984, where a strong concentration of research in this field was called for, for two reasons: a) electricity is seen as central area of science curricula at all levels of education, primary, secondary and tertiary and b) the concepts of electricity are particularly problematic – they are highly abstract and complex in ways that make their understanding both centrally dependant on models, analogies and metaphors and frequently intrinsically difficult. Since the 1980s, researchers have suggested various approaches for its instruction, involving alternative sequencing of content, teaching and/or assessment approaches, however the results have been consistently disappointing and any gains in understanding seem to be ephemeral. Mulhall *et al*. (2001) points to the lack of agreed consistency among science education researchers, academic physicists, teachers, textbook authors and curriculum developers, about the intended learning outcomes from the teaching of electricity, and in addition, there is no systemic consensus on what models are

appropriate for students at different levels. These concerns are echoed in Viennot's (2008) appeal for the need of a thorough reconsideration of the science content.

However, there are suggestions that problems with Electromagnetism may lie even deeper than this, in the actual physics models used in Electromagnetism instruction, both in schools and undergraduate university. The electric current model used in DC circuits, for example, is archaic (e.g. Simon & Llovera, 2009; Stocklmayer & Treagust, 1994), while in the so-called 'Electromagnetism', different models with conflicting conceptual elements are presented mingled together (Bevilacqua & Falomo, 2011).

The fact that Electromagnetism presentations in school and university curricula are in need of change is not a secret among the physics community and this concern was raised some decades ago (e.g. Booker, 1977). In the West, the two world wars and the great depression during the first half of the 20th century took their toll in physics instruction all over the world. This is supported by Stocklmayer and Treagust (1994) adding how this is somehow paradoxical, considering that the first half of the 20th century was the "golden era" of physics, when such great theories as the theories of relativity and the quantum theories were introduced among other startling developments. Physics instruction did not manage to keep up with the times and it is possible that the disruptions in the writing and publishing of textbooks had a pivotal role to play (Stocklmayer & Treagust, 1994).

Simon and Llovera (2009) make a remarkable claim arguing that teaching and textbook writing being highly creative practices may have played a major role in the shaping of the science of the 19th century, referring to the unification of various physics branches. Thus, scientific disciplines, such as physics and topics such as electrostatics have not been shaped only by research and researchers but also by other factors, including textbooks.

The prospect of change in the treatment of electromagnetism in science curricula would require fundamental restructuring of the topic and of the science curricula. Such a change would seem overwhelming and it would possibly require consensual decisions among educators, researchers and concerned parties from around the globe. Lijnse (1997/98) and Redish (2000) both stress the need for collaboration between physicists and science educators, who both have equal but *different* roles to play in improving a physics curriculum. But their accounts also imply a particular flaw in the lack of doing so, a reluctance to liaise. Redish (2000) attributes this reluctance (among other factors) to the lack of familiarity each party exhibits for the other party's field of research, which are very different, and especially so to the lack of awareness of developments in each other's fields. The lack of literature on the matter of consensual points implies that presently we are not even near such a consensus, also stressed by Mulhall *et al*. (2001) who furthermore highlight the diametrically different positions held by different researchers on how to go about introducing the topic, let alone that changes in schools and attitudes take a very long time to effect, if at all.

This last point is supported by Rogan and Grayson (2003) who maintain, referring to the context of change in South African curricula, that change is not an 'event', it is a 'process'. They stress how the norm is to pay attention to the "*what* of desired educational change, neglecting the *how*" (Rogan & Grayson, 2003, p.1171). And the 'how' refers to the implementation of such changes, which is context specific for a particular school and would require time and as is suggested, introduction in small steps to effect: "Introducing regular small changes can allow teachers to vary their practice, find successful variations and be prepared for further changes. Such a gradualist policy allows for an accelerated evolution of classroom practice" (Johnson et al., 2000, cited in Rogan & Grayson, 2003, p.1175). This last comment could very well apply to a gradual change in electromagnetism curricula and

respective textbooks, allowing thus adequate time for knowledge and expertise among teachers and authors of the topic to develop and evolve.

Hence, a radical change in the science/physics curriculum will be neither fast nor easy, nor is it envisaged in the near future. It must be said however, that innovative textbooks on electromagnetism do exist already and are in use by undergraduate students in some universities (Preyer, 2000; Sherwood & Chabay, 1999). But the issue for the science educator need not be the wait for the 'conceptually superior model'. The mere fact that inadequacies of present models are blamed even partially for learner difficulties, may point instead to inadequacies of the 'normalised' way of presenting science in textbooks and in teaching, as Bevilacqua and Falomo, (2011) and Niaz, (2010) assert. This last insight was one of the pivotal stimuli toward the decision to conduct this study on Electromagnetism.

1.6 Aims of this study

A widely held notion among science educators since the onset of reformed curricula is that science education ought to entail three facets: "*Learning science, learning about science* and *doing science*" (Leite, 2002, p.333). These facets were deemed essential to address the call for "Scientific literacy" for all citizens (Abd-El-Khalick, BouJaoude, Duschl, Lederman, Mamlok-Naaman, Hofstein, Niaz, Treagust & Tuan, 2004; Leite, 2002; Lijnse, 1997/98). They are also embedded in both the NCS and CAPS curricula. The NCS for Physical Sciences (DoE, 2003) elaborates extensively on these facets through three Learning Outcomes (LOs), the scope of which, as shown in Table 1.1, correlates clearly with the facets of science education.

Table 1.1 Correspondence of the LOs of the NCS curriculum with the facets of science education

Learning Outcome (LO) and its scope (from DoE, 2003, p.13-14)		**Facets of science education**
LO1	concerns *doing*, i.e. practical scientific inquiry and problem-solving skills.	Doing science
LO2	concerns *knowing*, i.e. constructing and applying scientific knowledge	Learning science
LO3	is about *being* and *becoming*, i.e. concerns the nature of science and its relationships to technology, society and the environment "it is important for learners to understand the scientific enterprise and, in particular, how scientific knowledge develops" (p.14)	Learning about science

In CAPS for Physical Sciences on the other hand, we find an echo of the Learning Outcomes, remnants from the NCS, under the heading "Specific aims of physical sciences" (DoBE, 2011, p.8), but nevertheless the three facets of science education are implied very succinctly:

> Physical Sciences promotes
> - knowledge and skills in scientific inquiry and problem solving;
> - the construction and application of scientific and technological knowledge;
> - an understanding of the nature of science and its relationships to technology, society and the environment. (DoBE, 2011, p.8)

Hence it should be expected that South African physical sciences textbooks addressing the NCS and CAPS curricula to cater for the three aspects *learning science*, *learning about science* and *doing science*, one way or another.

The important status that science textbooks are given in the South African context has been discussed, in particular that they may be the primary means by which to effect change in the conceptual understanding and attitudes to science of both teachers and learners. Hence, a systematic analysis of their aspects and the messages they transmit becomes vital. To this effect, this study concentrates on the textbook aspect "science content" which relates to the

realms of *learning science* and *learning about science*. The study was perceived as a starting point to an envisioned thorough and systematic content analysis of the entire topic of Electromagnetism in science textbooks. The topic Electromagnetism was chosen due to its inherent difficulties (Bevilacqua & Falomo, 2011; Mulhall *et al.*, 2001), the many difficulties and misconceptions teachers and learners at all levels exhibit vis-à-vis its concepts and processes, as have been reported in the literature (e.g. Duit & von Rhoneck, 1997/98; Furió, Guisasola & Almudí, 2004; Gunstone *et al.*, 2009; Guruswamy, Somers & Hussey, 1997; Mulhall *et al.*, 2001) and the fact that Electricity and Magnetism is the only physics topic which is introduced at all levels of schooling, thus making particularly imperative for the educator to delineate clearly between macro and micro-descriptions of phenomena. Furthermore, scholars from different countries have raised concerns that erroneous ideas on concepts of Electromagnetism may be communicated to the learners by the textbooks themselves (e.g. Gunstone, Almudi & Furio, 2005; Ogan-Bekiroglou, 2007; Pocovi & Finley, 2003; Slisko & Hadzibegovic, 2011). The latter, in the South African context, could have profound consequences for learners, teachers and the country.

Due to the enormity of the task, the analysis of Electromagnetism presentations in textbooks has to be undertaken in steps. This study therefore is the first step, the kick-start to the process, and focuses on the analysis of aspects of *elementary Electrostatics*, the first part and the foundation of this extensive field of Electromagnetism. This is in accord with research, which points to the fact that learner difficulties in Electromagnetism do not originate in the advanced concepts of Electrostatics, *electric field* and *electric potential*, but earlier, in the elementary concepts of Electrostatics (Criado & Garçia-Carmona, 2010). It is also the least researched part of Electromagnetism among scholars as discussed in the "Literature Review".

Hence, the aim of this study is to analyse how the presentations of elementary Electrostatics in the South African physical sciences textbooks (grades 10 to12), in use after the first democratic elections of 1994, address the *learning of science* and the *learning about science*. The third facet *doing science* was not addressed (at least not explicitly) as it is a substantial topic by itself, and it relates better to the context of classroom interactions and practices rather than to textbook analysis. Furthermore, *doing science*, especially as scientific inquiry, has received and continues to receive attention by many researchers (e.g. Abd-El-Khalick *et al.* 2004; Haigh, France & Forret, 2005; Hart, Mulhall, Berry, Loughran & Gunstone, 2000). How Electrostatics is situated in the broad field of Electromagnetism and how it links to other parts of the field from both the curricular and the scientific perspective is discussed in Chapter 2.

1.7 Research questions

1.7.1 Guiding question

The umbrella question of this study is the following:

> "How do the presentations of elementary Electrostatics in the South African textbooks address the *learning of science* and the *learning about science* aspects of science education?"

1.7.2 Specific research questions

The following specific research questions guided the content analysis:

1. To what extent do textbook authors of Electrostatics take cognisance of learners' common misconceptions, common ways of reasoning and the inherent difficulties of the topic elementary Electrostatics?

2. What evidence is there, in the chapters of Electrostatics, of appropriate attempts to enhance understanding of the nature of science and of the foundational aspects of certain concepts or models, by disclosing elements of how scientists work and how scientific knowledge is constructed?

3. To what extent have textbook authors of Electrostatics paid attention to subject content, endorsing rigour and coherent argument, thus reflecting the preciseness and consistency of science?

The above questions may have a seemingly different focus, i.e. the learner, the nature of science and the subject matter content respectively, but their concerns overlap strongly. For instance, portrayal of science as a human activity and coherent argument both take the learner into account, while rigour and ways of reasoning both address the nature of science.

Furthermore, the above hopefully reveal that the term "presentations", as in the title of this thesis, may be understood as attempts of the authors to account for the *what* and the *how* of the subject matter content. Although the *what-how* may be understood as referring to a prescribed section of the curriculum, this need not be the case. It may also concern an aspect, such as a main idea, that an author has chosen to harness as essential to meet a certain target, or it may be a localised point of articulation, such as a 'critical detail' as per Viennot (2008); This is discussed in more detail in section 3.4 of the "Literature Review".

1.8 Structure of the thesis

In this first chapter, a general overview of the educational reforms in the post-apartheid South Africa was presented and the South African science teacher and the textbook were placed in this context. This account was extended towards the shortcomings of physics instruction still in the South African context, and the final focus was placed in particular on concerns surrounding the topic Electromagnetism, the Electrostatics part of which is the focus of this study. The rest of the thesis' structure is as follows:

Chapter 2: A mapping of the organisation and composition of Electromagnetism is presented, based on the consensus understanding of the field by the physics community. This is compared with the structure of the topic "Electricity and Magnetism" and its permutations, as appearing in the three post-apartheid South African curricula, NATED 550, NCS and CAPS. This ought to give an idea of the standing and status of Electrostatics within Electromagnetism in the scientific and curricular contexts.

Chapter 3: Encompasses a detailed review on possible origins of the difficulties surrounding the instruction and understanding of the topic Electromagnetism incorporating informed suggestions from the literature. This is followed by an account of the conceptual framework which guided the analysis of the texts and the guiding principles of this study, as emanated from the literature survey.

Chapter 4: A brief background to the method of qualitative content analysis is given, focusing on its basic ideas, components and procedures. This is followed by an account of the selected texts, and the methodological approach of data collection and their analysis is expounded as was adapted for this study. The chapter concludes with a schema of the overall

work involved in the stages of data collection and analysis (the concern of chapter 5) as well as reporting.

Chapter 5: Represents the main body of this study. It comprises the collection of data and their analysis and interpretation according to the schema conveyed in chapter 4. The selected texts were analysed for six aspects of the topic Electrostatics, the first concerning global ideas/perceptions communicated on what Electrostatics entails, followed by five foundational aspects of the topic, i.e. the concept of charge and its origin, the notions of charged and uncharged objects, the classification of materials according to their electric properties, the processes of transfer of charge and its conservation, and the attraction between charged and uncharged objects due to the process of polarisation.

Chapter 6: Gives an account of the general impressions emanated from the analysis of the texts undertaken in the previous chapter. These are broadly compared with the expectations of respective curricula as well as with related findings from the literature. The large numbers of specific findings per aspect of analysis (included in Appendix E) are consolidated into a few pivotal shortcomings, key ideas communicated or missing from the texts, appearing to be at the source of most concerns. The chapter concludes with possible implications of the findings.

CHAPTER 2

ELECTROMAGNETISM IN SCIENCE AND IN THE CURRICULA

2.1 Introduction

In this study we have sought to analyse aspects from the Elementary Electrostatics part of Electromagnetism presented in South African upper secondary school physical sciences textbooks, which were in use since 1994, i.e. the period of post-apartheid South Africa. During this period, upper secondary education in South Africa has gone through three curricula, namely NATED 550, NCS and CAPS, which is the order in which they were implemented.

NATED 550, although originating in the apartheid era, remained in effect, with some revision, as an interim curriculum up until it was gradually phased out by NCS over a period of three years, from 2006 to 2008. Hence since 1994, NATED 550 remained the curriculum of lengthiest sway in the upper secondary school educational scene. The implementation of the current curriculum, CAPS, begun in 2012 starting from grade 10 and culminating in 2014 with its implementation in grade 12. This was also the order and the years in which CAPS textbooks per grade became available to the public.

The sequence and inclusions of Electromagnetism topics differ in the different curricula. Prior to the analysis of Electrostatics in the texts, it became necessary to include a small section on "Electromagnetism" based on the consensus understanding of the field by the scientific community. In this regard a mapping was formulated of the organisation and composition of Electromagnetism features and aspects, which is presented in what follows. This is followed by a concise presentation of the structure of the knowledge area "Electricity and Magnetism" (and its permutations) as appearing in the South African curricula under consideration, for comparison. The rationale behind this undertaking was to explore the broader understanding of the structure of the field exhibited by curriculum developers and textbook authors and to enable us to look for links, parallels and main ideas.

2.2 Electromagnetism in science

> For a long time electrostatics, under the name *electricity*, was considered an independent physical theory of its own, alongside other physical theories, such as magnetism, mechanics, optics and thermodynamics. (Thidé, 2004, p.2)

Electromagnetism in the NCS and CAPS curricula is represented by the knowledge area "Electricity and Magnetism". Despite the unfortunate separation of the two terms, 'electricity' and 'magnetism', in essence this knowledge area represents the archetypal *Classical Electromagnetic Theory* (CET) or Lorenz's *Electron Theory*, as established at the start of the 20th century (Bevilacqua & Falomo, 2011, citing Lorentz, 1909, p.2). The Classical Electromagnetic Theory takes into account microscopic considerations, incorporating the electron and the existence of mobile charged particles in conductors in explaining electric and magnetic phenomena (Guisasola *et al.*, 2005). According to Bevilacqua and Falomo (2011), the term "classical" indicates that the theory predates Einstein's Special Relativity and Light Quantum theories of 1905.

CET unifies all electric and magnetic phenomena, which in the West, was the result of systematic studies, but also of significant debates between competing schools of thought, for over three centuries prior to 1905 (Bevilacqua & Falomo, 2011). It begun in 1600 with William Gilbert's (1544-1603) publication *De Magnete* (Bevilacqua & Falomo, 2011; Furió *et al.*, 2004), when a clear division between the effects of amber and magnetism was established, and the first classification of objects was proposed into *electric* and *non-electric*, based on whether they could attract others upon rubbing (Furió *et al.*, 2004). At Gilbert's times, *rubbing* was the only known means of electrification of objects and *attraction* was the only observed interaction (Furió *et al.*, 2004).

Guisasola *et al.* (2005) account for nine pivotal models in the history of the development of CET, in an attempt to demonstrate on the one hand the major difficulties scientists encountered in their attempts to explain electric and magnetic phenomena and how they overcame such difficulties, and on the other hand to highlight the ontological and methodological leaps that took place in our understanding of such phenomena. Perhaps the most significant leap in the history of CET, concerning school science education, is the transition from the Coulombian profile, which was based on the Newtonian model of action-at-a-distance, to the Maxwellian profile based on the concept of the field and "action-at-contact" (Guisasola *et al.* 2005, p.327). Yet both of these models are part of CET, along with other conflicting conceptual elements:

> CET is not a simple synthesis, it is in fact based on both discontinuous (charges) and continuous (fields) concepts, on action at a distance (statics) and contiguous action (dynamics), on instantaneous interactions (statics) and finite speed (dynamics), on forces depending only on distance (statics) but also on forces depending on velocity (dynamics), on global conservation of energy with a sharp distinction between potential and kinetic energy (statics) and on local conservation which, through the so-called Poynting vector, blurs this distinction (dynamics), and on the role of potentials as mediators between forces and fields.
>
> (Bevilacqua & Falomo, 2011, p.6)

It is no wonder why learners at all levels demonstrate conceptual difficulties with concepts and processes of electromagnetism (e.g. Furió *et al.*, 2003; Pocovi & Finley, 2002). The difficulties with CET, is one of the reasons why several scholars advocate the use of a historical approach to the topic (and science in general), as discussed in the Literature Review (e.g. Bevilacqua & Falomo, 2011; Furió *et al.*, 2004; Niaz, 2000b; Niaz, 2010; Rodriguez & Niaz, 2004). Guisasola *et al.* (2005) suggest as a matter of a conceptual teaching strategy, that theories of physics should be presented as answers to problematic situations within a socio-cultural context. "Behind the theory of the magnetic field is a long history of difficulties

overcome and of theories reformulated which form part of the physics itself" (Guisasola *et al.*, 2005, p.334).

Table 2.1 was compiled to give a brief picture of what is involved in the parts of Electromagnetism considering its bearing to typical school curricula. It was compiled to agree with the (relevant for school level) equations which summarise CET in "Feynman's table" from "Feynman's Lectures in Physics" (Feynman, Leighton & Sands, 1963, cited in Bevilacqua & Falomo, 2011, p.4).

TABLE 2.1 Organisation and composition of Classical Electromagnetism

<table>
<tr><th colspan="2">ORGANISATION & COMPOSITION OF CET</th></tr>
<tr><td colspan="2">Static situation</td></tr>
<tr><td>ELECTROSTATICS
considers charges in stationary situations,
the electric (electrostatic) fields they produce,
the forces they exert on one another (Coulomb's law),
their behaviour in electric fields
Related items / applications:
Field of conductors;
Capacitors;
DC circuits</td><td>MAGNETOSTATICS
considers currents in stationary situations (steady currents),
the magnetic (magnetostatic) fields they produce,
the forces they exert on one another (magnetic force law),
their behaviour in magnetic fields
Related items / applications:
Solenoids & electromagnets;
Inductors;
Electric motor</td></tr>
<tr><td colspan="2">Dynamic situation</td></tr>
<tr><td colspan="2">ELECTRODYNAMICS concerns electromagnetic induction, the production of electric and magnetic fields from changing magnetic and electric fields respectively, and the effects of fields on moving charges (Lorenz's law).
The fields produced propagate with a finite speed, in vacuum with the speed of light.
Related items / applications:
Generators;
Transformers;
AC circuits;
Electromagnetic waves</td></tr>
</table>

Source: Compiled by researcher, based on "Feynman's Table" of Electromagnetism (cited in Bevilacqua & Falomo, 2011, p.4) and on the content of Electricity and Magnetism appearing in the NCS and CAPS curricula.

As shown in Table 2.1, CET consists of three parts, namely Electrostatics, Magnetostatics and Electrodynamics. Electrostatics and Magnetostatics concern electric and magnetic phenomena which do not depend on time (static situations). The electric and magnetic fields produced by charges and currents respectively, are steady or unchanging and therefore are time independent, and so are the forces acting on charges or currents brought in such *static* fields. Electrodynamics concerns phenomena which are time dependant. Fields produced change with time resulting in electromagnetic fields (a changing electric field produces a changing magnetic field and vice-versa), which propagate with a finite speed, in vacuum with the speed of light.

The comments in what follows expand on some key concepts in Table 2.1.

- The charge, being a property of matter, is always carried by particles. Charge does not exist on its own like some disembodied entity (much like mass).
- The term "charge" (of an object) in Electrostatics means *net charge*. It represents excess charge on objects. The charge of elementary particles can be also understood as a net charge.
- In Electromagnetism, the electric current is considered a distinct entity (Bevilacqua & Falomo, 2011) much like the charge. This might sound counterintuitive to young learners.
- Unlike Mechanics where the basic objects of study are distinct entities, i.e. objects usually modelled as particles, in Electromagnetism we find both distinct and continuous entities. This is the reason why CET is also seen as a wave theory. The basic components of Electromagnetism are charges and currents, which are distinct entities, and electric and magnetic fields, which are continuous entities. The distinct entities are sources of continuous entities (Bevilacqua & Falomo, 2011).

- The Dynamics part of Mechanics deals with forces and their effects on objects, in which case the word "dynamics" can be taken literally to mean "on forces" – the key word is "force". In Electrodynamics, force is not the main player. The word electrodynamics is to be understood as "on dynamic processes", here the key word is "change". In Electromagnetism forces are part of Electrostatics and Magnetostatics as much as they are part of Electrodynamics.
- In Mechanics, forces explain the state of motion of objects (via Newton's laws), hence the concept of force is of highest status. In Electromagnetism, forces do explain the motion of its distinct entities in electric and magnetic fields, but it is the fields that justify the existence of these forces. The concept of the field takes precedence over the concept of the force.
- There is no reference to potentials and energy in Table 2.1 for the sake of stressing the symmetry between Electrostatics and Magnetostatics. The norm in school (and low undergraduate) curricula is to involve these in Electrostatics as a vehicle to introduce current and electric circuits. Electric circuits are a practical application of the electric field and electric potential.
- Potentials may be involved in all three parts of Electromagnetism however, but now we are entering the realm of more advanced studies where not all physicists of the 20th century have entertained similar understandings of the role or relevance of potentials (Bevilacqua & Falomo, 2011). Nevertheless, Feynman's ideas are widely respected by the scientific community and so we can adopt his views on the concept. Feynman stressed the relevance of potentials as basic entities, which in dynamic cases propagate through space with the speed of light, like the fields, and considered them as having physical priority over the fields (Feynman *et al.*, 1963, cited in Bevilacqua & Falomo, 2011). In this sense, regarding Electrostatics, much like electric fields give us a

mechanism to justify the action of a force on a charge, the electric potential gives us a mechanism to justify why a charge would have potential energy.

- In electric fields, a (scalar) electric potential links to potential energy. In magnetic fields, a vector potential links to kinetic energy (Bevilacqua & Falomo, 2011 citing Feynman *et al.*, 1963; Thidé, 2004). The law of conservation of energy holds in both static and dynamic situations, but while in static cases the mechanical distinction between potential and kinetic energy is very sharp, in dynamics this distinction is no longer evident (from "Feynman's Table" in Feynman *et al.*, 1963, cited in Bevilacqua & Falomo, 2011).

2.3 Fundamental ideas in Electromagnetism

On the production of fields:

1. *Charged particles produce electric fields*
2. *Electric currents produce magnetic fields*
3. *An electric field is also produced by a changing magnetic field*
4. *A magnetic field is also produced by a changing electric field*
5. *There are no magnetic monopoles*

On how matter responds to fields:

6. *A charged particle experiences a force in an electric field*
7. *A moving charged particle experiences a force in a magnetic field*

The first five fundamental ideas on the production of fields are represented by James Clerk Maxwell's famous four equations, which unify all electric and magnetic phenomena into one "super-theory" according to Thidé (2004), Maxwell's Electromagnetic theory, to which optics is a sub-field. Early in the twentieth century Hendrik Antoon Lorentz took this super-theory one step further, to the microscopic scale (Thidé, 2004). Maxwell's four equations do

not feature in school curricula as they involve calculus. However, they could be included very easily in the form of verbal expressions as above. Maxwell's equations incorporate a number of laws, of which only Faraday's law of induction is usually introduced to high school learners by name.

The fundamental ideas on how matter responds to fields (ideas 6 and 7 above), are represented by Lorentz's law, $\boldsymbol{F} = q\boldsymbol{E} + q\boldsymbol{v} \times \boldsymbol{B}$ (Bevilacqua & Falomo, 2011; Knight, 2008), which added to Maxwell's four equations form the complete theory of electromagnetism, or what is known as the Classical Electromagnetic Theory (CET). In Table 2.1, Lorentz's law is incorporated under Electrodynamics (effects of fields on moving charges), in agreement with "Feynman's table" from "Feynman's Lectures in Physics" (Feynman, Leighton & Sands, 1963, cited in Bevilacqua & Falomo, 2011, p.4). This is not so much because of its dependence on velocity, but because it is a *true* law - it applies to both static and dynamic situations, as are all the laws of electrodynamics. The two parts of Lorentz's law are not unfamiliar to learners (the second part to NCS learners), but not by name. Ironically the names of Maxwell and Lorentz never appear in school curricula. This is as absurd as learning mechanics without mentioning Newton.

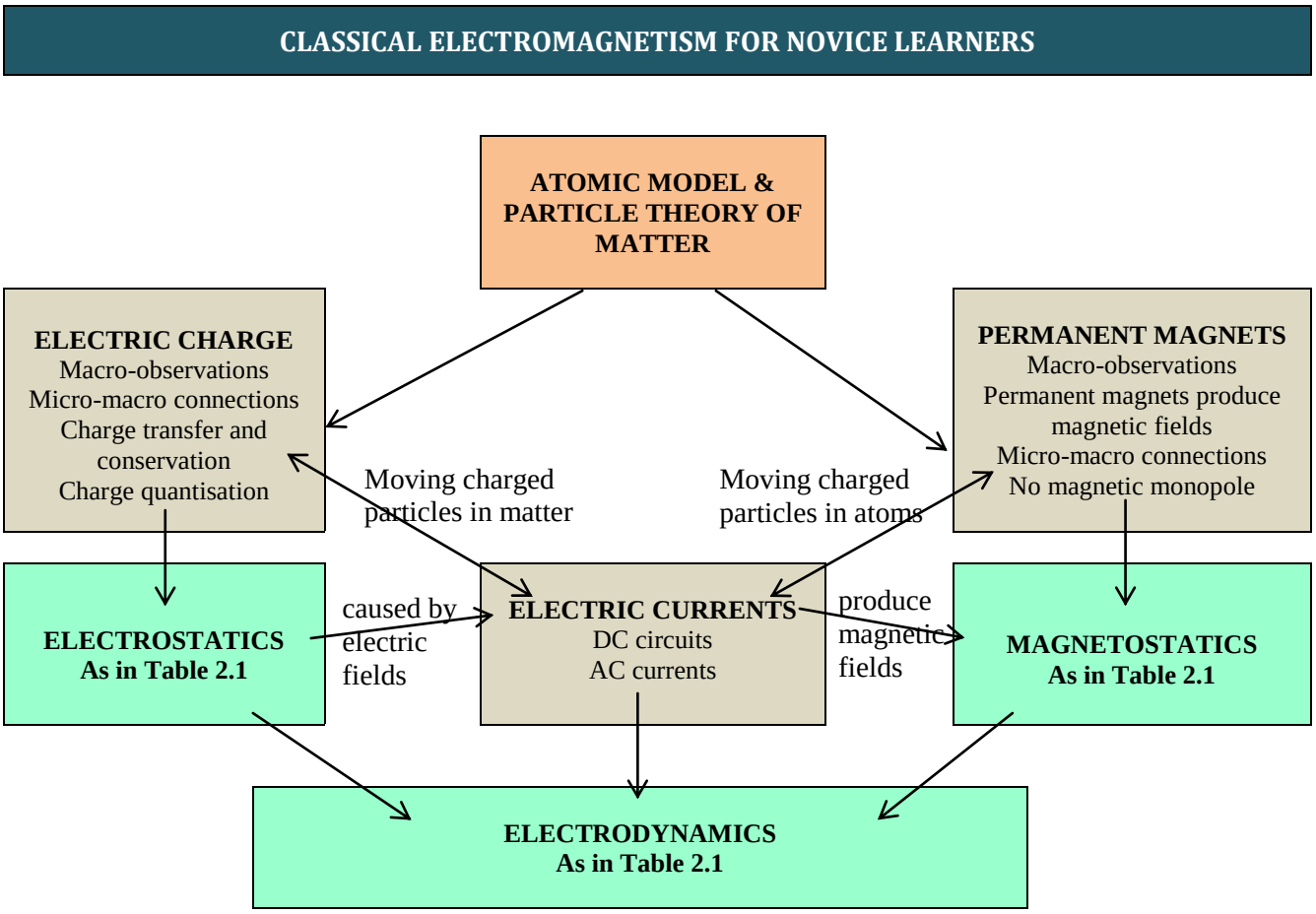
It follows that Coulomb's law cannot be a fundamental or true law because it only applies to static situations. Ohm's law, Kirchhoff's law (not in SA school curricula) and Lenz's law have great practical value, but they are not fundamental either. They can be derived from Maxwell's equations, even though some require the addition of extra empirical concepts, such as resistance.

2.4 Teaching and learning Electromagnetism

Electromagnetism instruction to novice learners however, cannot begin as Table 2.1 suggests. Learners need to know what charge is and how it comes to be on objects before they begin Electrostatics. Learners need to know what currents are and how they come to be before delving into Magnetostatics. Hence Table 2.2 was compiled to supplement the parts of Electromagnetism shown in Table 2.1 with the necessary foundation for its learning. Elementary Electrostatics in Table 2.2 is represented by "ELECTRIC CHARGE". Table 2.2 indicates conceptual paths via which different aspects may be linked together. Electromagnetism is a vast topic and a complex synthesis of models, laws and understandings from different outlooks that developed over a period of time and perhaps are still developing according to Bevilacqua and Falomo (2011). Careless handling can make its contents appear disparate and fragmented only too easily.

The concept of charge and the electric field it produces situates Electrostatics within the broad topic of Electromagnetism as a main constituent that parallels its 'sister' constituent of Magnetostatics, to which it also links via the origins of charge within the atom and via the origins of current within the electric field. Elementary Electrostatics concerns the origins of charge. It sets the foundations for the understanding of the nature of charge, its transfer and behaviours.

Table 2.2 Classical Electromagnetism instruction



Source: Compiled by researcher, considering content of Electricity and Magnetism in the NCS and CAPS curricula.

The links indicated in Table 2.2 are by no means exhaustive and arrows shown are not necessarily unidirectional. We see that micro-macro connections at the start of the topic are critical in bringing the different parts of Electromagnetism to the coherent whole that it is (despite its conflicting aspects). Electric and magnetic phenomena have their origins within the atom. Micro connections can link electrostatics to electric currents, which otherwise might seem contrasting areas of study, and can show that magnets and currents produce magnetic fields which are in fact identical rather than representing 'two ways' of producing magnetic fields. In Electrodynamics, micro considerations explain the induction of currents and give us a way to justify the production of electric fields from changing magnetic fields.

But links, albeit of a different kind, can also be achieved in different forms – by drawing parallels between aspects, by highlighting contrasts, or by the purposeful and clever inclusion of historical incidents at strategic points. Paradoxically (it may seem), it is more contradictions and conflicts that have driven the progress of science forward rather than struck of genius (e.g. Niaz, 2010). These make for perfect material for historical inclusions and what would be a better way to convey the nature of science than through its making? (e.g. Bevilacqua & Falomo, 2011; Leite, 2002; Niaz, 2005; Stuewer, 1997/98).

Before the discussion of the general structure of Electromagnetism in the upper secondary school curricula NATED 550, NCS and CAPS, an attempt is made in what follows to rationalise the use of the terms "Standards" appearing in the NATED curriculum, and "Grades" in the NCS and CAPS curricula.

2.5 On Standards and Grades in the South African curricula

The NATED 550 curriculum for Physical Sciences was actually two curricula, the NATED 550 Standard Grade and the NATED 550 Higher Grade (SG and HG). The HG syllabus included some sub-topics at a more advanced cognitive level than the SG, to cater for learners who wished to know more or who wished to pursue further studies at higher institutions. The same textbooks addressed both curricula, with the HG sections clearly marked. Separate examination papers however were set for HG and SG in Standards 8, 9 and 10. According to UMALUSI''s evaluation in the "2008 Maintaining Standards Report", the Physical Sciences NCS curriculum, in terms of levels of difficulty, was found to be "midway between the NATED HG and SG equivalents in a 50:50 proportion" (UMALUSI, 2009, p.7). The

determination of the levels of difficulty drew on various aspects, according to the report, such as specification, weighting and foci of content and skill topics.

For simplicity in what follows, NATED 550 is referred to as a single curriculum. In any case the distinction between HG and SG did not affect the content of Elementary Electrostatics, which is the focus of this study.

In NATED 550, the upper secondary schooling comprised of the *Standards* 8, 9 and 10 (with Standard 1 being the third year of primary schooling, the previous two being grades 1 and 2). The NATED 550 was a traditional curriculum in the sense that learning *standards* were the basis of the content and skills taught to pupils. The standards were reflected in the aims and objectives, in the content and in other statements described in a "syllabus" (DoE, undated). Consequently, teaching was guided by these standards and progress and achievement of pupils was measured against these standards. The standards set what pupils ought to know and do at each stage of schooling. Hence in NATED 550, stages of schooling were referred to as *Standards*.

The advent of the NCS curriculum in 2006 represented a radically different system of instruction, assessment and academic reporting, as discussed in the previous chapter. It was an Outcomes Based curriculum focusing on what is learnt unlike NATED 550 which focused on what is taught. Learners (no more pupils) would demonstrate achievement of a particular *Learning Outcome* through *Assessment Standards* (DoE, 2003, p. 17) with criteria determined in advance, usually in the form of a rubric, the attainment of which would ensure that learning did take place (hence the term *learner* instead of pupil). For NCS, the upper secondary schooling comprised of the *Grades* 10, 11 and 12 (with Grade 1 being the first year of primary schooling). The choice of the term *grade* signified that there was no longer

distinction between Standard Grade and Higher Grade as in NATED 550, but a common grade in the sense of a *level* "all subjects are now offered at a single level" (UMALUSI, 2012, p.5). The CAPS curriculum which followed soon after, in 2012, abolished the system of Outcomes Based Education (OBE), and in this sense, South African basic education reverted back to 'what is taught'. CAPS maintained however the designation *Grade* for the different levels of schooling.

2.6 General structure of Electromagnetism in South African FET curricula

2.6.1 NATED 550 curriculum

In NATED 550, being a traditional curriculum as discussed above, content was described by a syllabus (DoE, undated) setting the standards of what was to be taught and know. In Standards 8, 9 and 10, representing the upper secondary schooling, the content of Physical Sciences was divided into seven "modules" per Standard, three for physics, four for chemistry, but weighting for physics and chemistry was the same. In physics, each module represented a different topic as a whole, except for Electromagnetism which was dealt with in three modules, but with no specific umbrella name for all electric and magnetic phenomena. Instead, the modules were labelled ***Electricity*** in Std 8, and ***Electrostatics*** and ***Electric Current*** in Std 10 (DoE, undated, p.4; p.36; p. 8 respectively).

Based on DoE, (undated), the contents of the modules concerning Electromagnetism are summarised in Table 2.3, where it can be seen that essentially the modules *Electricity* and

Electric Current involve similar items. This indicates that the module designations do not signify any particular classification of phenomena in the topic.

Table 2.3 Modules concerning Electromagnetism in NATED 550

Electricity (Std 8)	**Electrostatics (Std 10)**	**Electric current (Std 10)**
▪ Electric current ▪ DC circuits ▪ Heating effect of current ▪ Magnetic effect of current (production of magnetic field, solenoids, electromagnets, force on a current carrying wire in magnetic field, motor) ▪ Electromagnetic induction	▪ Static electricity (revision from Std 7) ▪ Force between charges (Coulomb force) ▪ Electric fields (patterns, force on charge, work, potential energy, potential difference, parallel plates)	▪ Electric current (linked to electric field) ▪ Force on a current carrying wire in magnetic field ▪ Force between current carrying conductors ▪ Electric circuits (Ohm's law) ▪ Heating effect, energy, power ▪ AC current

Source: Table compiled based on DoE (undated), p. 4-6; p. 36-37; p. 38-39 per respective Standard

Despite the fact that the NATED module *Electrostatics* does represent the norm in Electromagnetism, the overall picture is that not sufficient reflection has been put into the structure of the topic. Moreover, Magnetism does not feature in any main heading, and yet, aspects of Magnetostatics and Electrodynamics are included in the modules *Electricity* and *Electric Current* (see Table 2.3). Permanent magnets are not mentioned and we are to understand that these have been dealt with sufficiently at a lower level (Std 5). Charge and charging have been also dealt with at a lower level (Std 7), but there is a call (DoE, undated, p.36) for their 'revision' in Std 10 under *Electrostatics*. Revision is not called for in Magnetism.

Upon surveying Table 2.3 we are left with the following overall impressions:

- References to electricity and magnetism are conspicuously unbalanced in favour of electricity, thus encouraging the erroneous perception of electrical phenomena as being more significant than magnetic. Magnetic phenomena are presented implicitly and as playing a peripheral role.
- "Electricity" as an umbrella term in standard 8, involves both electric and magnetic phenomena and so in this context we may assume that for the NATED developers it may signify 'electromagnetism'. Electrostatics however is not part of it. The study of 'electromagnetism' in this sense appears to revolve around the electric current and the study of circuits, an impression that is reinforced by the standard 10 heading and content.
- Although *Electrostatics* appears autonomous and unrelated to the other modules, we do find a call to link electric current to the electric field in standard 10: "to maintain a current in a conductor, an electric field must be maintained in the conductor…." (DoE, undated, p.38), which is missing in the NCS and CAPS curricula.

2.6.2 NCS and CAPS curricula

In NCS, an Outcomes Based curriculum, Physical Sciences knowledge in Grades 10, 11 and 12 was organised around six core *Knowledge Areas*, which could be "used to achieve all the Learning Outcomes (LOs) of the Physical Sciences" (DoE, 2003, p.10). Thus, learning content in NCS was not the goal but the vehicle to achieve the LOs. Learning of content however was expected to take place "This approach allows learners to learn the prescribed core knowledge and concepts by the end of Grade 12, but with increasing depth and breadth" (DoE, 2003, p.10). The Knowledge Areas in NCS could be understood as *broad descriptors* to cluster concepts skills and values (DoE, 2003, p.10), or as *contexts* to develop

competencies (DoE, 2003, p.11), or as themes providing guidelines or a framework (DoE, 2006, p14). When the CAPS curriculum was introduced in 2012, the six Knowledge Areas of NCS were maintained, but became "Topics" (e.g. DoBE, 2011, p.10-11) while the *core knowledge and concepts* of NCS become the *content*. In essence, the DoBE (2011) document is a syllabus. The six Knowledge Areas (NCS) or Topics (CAPS) are the following:

- Mechanics
- Waves Sound and Light
- Electricity and Magnetism
- Matter and Materials
- Chemical Systems
- Chemical Change (DoE, 2003, p.11; DoBE, 2011, p.8)

Hence, in NCS and CAPS, electric and magnetic phenomena are contained within the umbrella of **Electricity and Magnetism**, one of the three Knowledge Areas allocated to physics, the other two being *Mechanics* and *Waves Sound and Light*. In addition, the area *Matter and Materials* integrates physics and chemistry.

Tables 2.4 and 2.5 were synthesised from DoE (2006) and DoBE (2011) respectively to give a brief but holistic picture of the structure of the topic as revealed by the main headings in the two curricula.

Shaded cells in Tables 2.4 and 2.5 represent parts that relate to the topic Electricity and Magnetism, but are included in different knowledge areas.

The faint text in Table 2.5 represents items included in NCS (DoE, 2006) for implementation at a later stage, i.e. after teachers had some form of training intervention, as these items appeared for the first time in a South African curriculum. This never came to be however, because CAPS replaced NCS soon after.

TABLE 2.4 Structure of "Electricity & Magnetism" in NCS

Electrostatics Grade 10. Two kinds of charge, charging by rubbing, conservation of charge, forces Polarisation (in insulators) Conductors and insulators (how easily electrons can move) Grade 11. Coulomb's law (parallel to gravitat. law) Electric field Potential energy and potential (parallel to gravit.) Capacitors (Attention to superposition)	**Electric circuits** Grade 10. Need for closed circuit for charges to flow Potential difference (voltage) (define) Current (define) Resistance – micro (electrons, collisions) Grade 11. Ohm's law Equivalent resistance, internal resistance Series, parallel networks Wheatstone bridge	**Magnetism** Grade 10. Magnetic field of permanent magnets Poles, forces domains – micro (electrons) Earth's magnetic field, compass **Electromagnetism** Grade 11. Magnetic field associated with a current Current induced by changing magnetic field Transformers Motion of charged particle in a magnetic field
		Electrodynamics Grade 12. Electrical machines (generators, motors) Alternating current Capacitance and inductance
	Gr11, under Matter & Materials **Electronic properties of matter** Conduction in semiconductors, metals ionic liquids Intrinsic properties and doping p-n junction and junction diode insulators, breakdown	**Electronics** Grade 12. Capacitive and inductive circuits Filters and signal tuning Active circuit elements, diode, LED and field effect transistor, operational amplifier Principles of digital electronics – logical gates, counting circuits
		Electromagnetic radiation Grade 12. Dual nature of EM radiation Nature of an EM wave as mutual induction of oscillating magnetic/electric fields EM spectrum Nature of EM as a particle – energy of a photon related to frequency and wavelength Penetrating ability

Source: Table compiled based on DoE (2006)

Table 2.5 Structure of "Electricity & Magnetism" in CAPS

Electrostatics Grade 10. Two kinds of charge Excess-deficiency of electrons charging insulators (triboelectric charging) Charge conservation, sharing of charge in conductors Charge quantization Polarisation (in insulators) Grade 11. Coulomb's law Electric field	**Electric circuits** Grade 10. Emf, terminal potential difference Current Resistance (micro), resistors in series, parallel Grade 11. Ohm's law Power, energy Grade 12. Internal resistance Series-parallel networks	**Magnetism** Grade 10. Magnetic field of permanent magnets Poles, forces, field lines Earth's magnetic field, compass **Electromagnetism** Grade 11. Magnetic field associated with a current Faraday's law
Gr10, term 1, under WSL, before E&M **Electromagnetic radiation** Dual nature of EM radiation Nature of EM radiation (meaning wave) EM spectrum Nature of EM as a particle – energy of a photon related to frequency and wavelength	Describe the source of EM waves as an accelerating charge. Use words and diagrams to explain how an EM wave propagates when an electric field oscillating in one plane produces a magnetic field oscillating in a plane at right angles to it, which produces an oscillating electric field and so on. State that these mutually generating fields propagate through space at a constant speed of $3x10^8$ m/s, represented by c Etc **Same as in NCS gr 12**	**Electrodynamics** Grade 12. Electrical machines (generators, motors) Alternating current

Source: Table compiled based on DoBE (2011)

Table 2.4 shows that in NCS the topic Electricity and Magnetism is divided into seven sections with headings which are reminiscent of those in Table 2.2. The main headings provide for both electric and magnetic phenomena and this alone signals a radical departure from NATED. But upon careful comparison of Tables 2.2 and 2.4 we realise that Electricity and Magnetism might not represent the Classical Electromagnetic Theory after all. There are fundamental differences between the two:

- *Electromagnetism* in NCS is just one of the seven sections of Electricity and Magnetism rather than an umbrella for electric and magnetic phenomena. It contains elements of magnetostatics but mostly of electrodynamics.
- *Electrodynamics* is associated with items of which, according to Table 2.2, only generators belong to electrodynamics.
- *Electronics* is not part of electromagnetism, though capacitive and inductive circuits, placed under electronics, are.
- *Electromagnetic Radiation* is to be presented in both its wave nature and its particle nature, so it only partly belongs to electromagnetism.

One can justify the inclusion of electronics and the particle nature of electromagnetic radiation. These are items that perhaps curriculum developers felt ought to be somewhere, and Electricity and Magnetism seemed the most accommodating host. Electronics could of course have stayed under Matter and Materials, where it begun in grade 11 as "Electronic Properties of Matter" (see Table 2.4), but then, capacitive and inductive circuits and filters and signal tuning would not fit in. This brings us to the point of the understanding of the structure of Classical Electromagnetism or lack thereof. Each of the NCS sections *Electromagnetism* and *Electrodynamics* and also *Electronics* lack coherence and are in gross disagreement with Table 2.2. The Physical Sciences Content document (DoE, 2006, p.4-12)

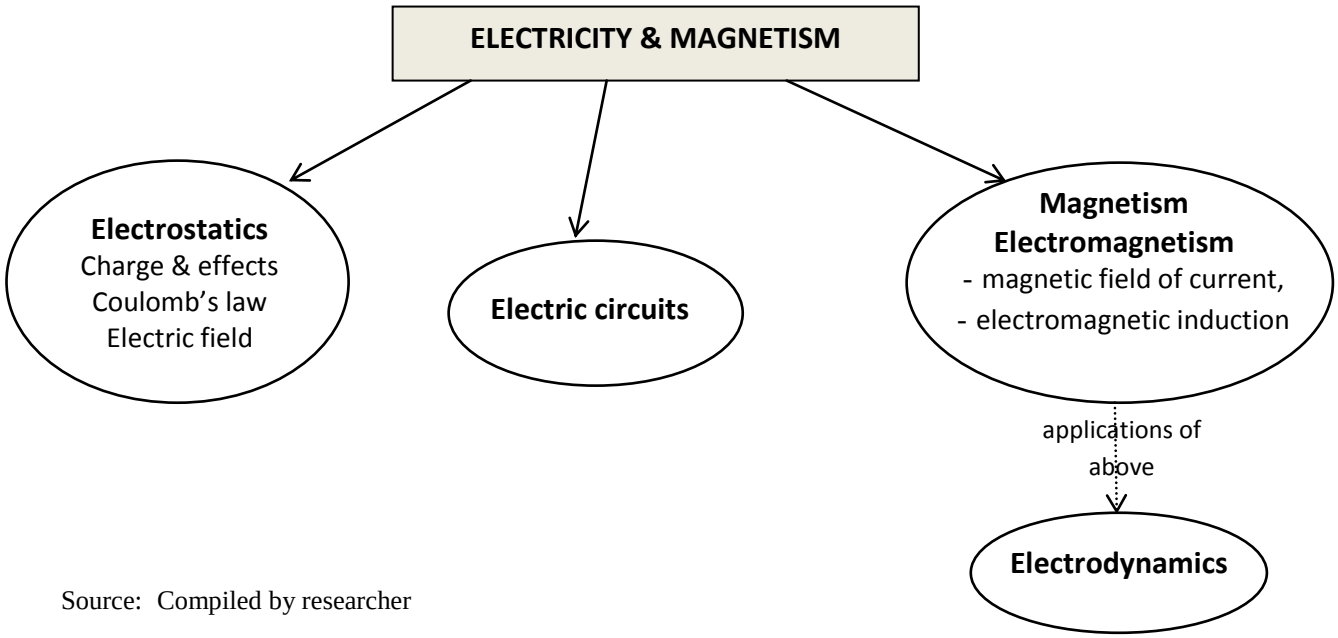
does not provide a rational reason for the presented organisation and grouping of items. Referring to the section *Electromagnetism*, we find the very vague: "In Grade 11 learners learn about various interactions between charges and magnetic fields" (DoE, 2006, p.10), but in *Electromagnetism* in Table 2.5 we see no interactions, even in the case of the moving charge in a magnetic field, the attention is drawn to its motion rather than to the force it experiences. Concerning *Electrodynamics*, we are told: "In Grade 12 the relationship between induced emf and changing magnetic field is used to explain how motors and generators work" (DoE, 2006, p.10). Apart from the fact that an induced emf does not explain how motors work, under *Electrodynamics* we also find alternating currents, which are only meant to be discussed in terms of rms values, and so they belong to Electric Currents, and we also find capacitance and inductance, though capacitors fall under Electrostatics and inductors are nowhere to be found, both of which do not belong in Electrodynamics. According to Table 2.2, what should belong to Electrodynamics is AC circuits, capacitive and inductive circuits and hence filters and signal tuning, which represent dynamic situations. Instead, capacitive and inductive circuits are placed under *Electronics*. Capacitors and inductors are not semiconductor based devices, they are electrical devices. Perhaps curriculum developers felt that capacitors and inductors are part of electronic circuits more often than not. But so are resistors.

Nevertheless, the above comments indicate that in the NCS curriculum, considerable thought had been put in compiling the content of Electricity and Magnetism, despite its misgivings. It certainly brought us steps ahead from the times of NATED. Substantial attempts were made to bring the content closer to our times, lives and experiences, and in sync with modern ideas on science instruction. For example, the Physical Sciences Content document (DoE, 2006, p.4) refers to a spiral approach and stresses *conceptual progression* and *conceptual coherence*. These are to be understood in terms of links across grades and between topics

respectively. But according to Table 2.4, conceptual coherence breaks down when it comes to aspects of the topic where magnetic and electric phenomena merge. The haphazard placement of items in groups on no rational grounds prohibits links and parallels within the topic itself. This is detrimental to the understanding of electromagnetism as a unified field of science.

The focus of the NCS curriculum was the learner and the future. The curriculum offered extra "Comments, motivation and links" in the tables of the Core Knowledge and Concepts to teachers (DoE, 2006), highlighting opportunities were links could be made to other concepts, emphasising big ideas and cautioning on learner difficulties and misconceptions. The content was brought closer to our times through the inclusion of new items, like capacitors, semiconductors and electronics, which were never part of previous South African curricula. The Knowledge Area *Mater and Materials* was meant to reflect the forefront of research of the 21st century, *Materials Science*, where physics chemistry and other disciplines merge (DoE, 2006, p.14). This changed with the advent of CAPS, where the focus became the teacher and the present and which ironically has taken us back in time. Comments on big ideas were removed. Subject matter content was reduced to the level where teachers would be comfortable with without intervention and was reduced even further to fit it in the instructional time allocated for Physical Sciences, which was four hours per week (DoBE, 2011, p.7). The topic Mater and Materials was kept, but its contents were split into chemistry and physics parts. Table 2.5 shows how electromagnetism was affected. The NCS structure of the topic was kept, but new and 'unnecessary' items are gone. The Electromagnetic Radiation was moved from grade 12 in NCS to the start of grade 10 in CAPS without any change in its contents (see highlighted cell in Table 2.5, p.38). This inconsiderate incident alone suggests clearly that little thought was put in the physics content of CAPS. Other mishaps in NCS were carried through unnoticed and unchanged.

The concept-map-type diagram, shown in Figure 2.1, was drawn to give a schematic idea of the organisation of the topic "Electricity and Magnetism" in the CAPS curriculum, which is essentially the same as that of the NCS despite some omissions. This organisation is fundamentally different from that depicted in Tables 2.1 and 2.2.



Source: Compiled by researcher

Figure 2.1 Organisation of Electricity and Magnetism in NCS and CAPS curricula

The above suggest that in all three curricula, NATED, NCS and CAPS, educators involved in the compilation of the electromagnetism content were unaware of any particular structure of the field and hence failed to project its symmetry, links and parallels between electric and magnetic phenomena, as portrayed in Table 2.2. They have developed own divisions of the topic with labels that bear no consequence to their contents. The impression given is that items were grouped into sections on the grounds of convenience rather than on rational classification of phenomena. And this translates to a fragmented presentation. It remains to be seen whether textbook authors have managed to project some unity and sense within the constraints of the curricula.

In what follows, a more detailed review on the possible origins of the difficulties surrounding the instruction and understanding of the topic Electromagnetism is presented and we look at informed suggestions from the literature. This is followed by an account of the conceptual framework which has guided the analysis of the texts as well as the guiding principles of this study, as emanated from the literature survey.

CHAPTER 3

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

3.1 Literature review

3.1.1 Introduction

The literature was surveyed to obtain a global view on concerns raised by scholars on the teaching and learning of Electromagnetism. If we consider Electrostatics as part of Electromagnetism communicating with its other parts, it was thought reasonable that conceptual problems identified in one area of the field may very well affect or be affected by problems in other areas. Hence a broad spectrum of the literature was examined ranging from historical surveys of the understanding of the field to ideas held by learners at all levels. Little was found on the analysis of subject matter content of science textbooks and even less on aspects focusing on Elementary Electrostatics, none of which was from South Africa. The accounts from the literature, in what follows, have provided new insights and/or have contributed to a large extent to the foundations of this study. A number of surveyed papers were a source of inspiration and an 'eye opener' for me. Their impact and bearing is reflected in the guiding principles of this study, in section 3.3. Certain articles, which concerned or linked directly to specific elements of this study, have been expounded in subsequent Chapters and so are not included here. The survey in this chapter has been divided into three sections, each representing some coherent whole in the following order:

3.1.2 *On the nature of science (NOS) and perspectives on the history of physics*: Looks into research done on textbooks regarding consensual aspects of NOS in general, and expands into ways in which scholars have suggested incorporation of HOS to meet different needs, including a better understanding of NOS. A crucial point is introduced, that Electromagnetism cannot be really understood without a

consideration of its origins. History of physics is inside physics. In this sense, *learning science* and *learning about science* cannot be seen as two separate items. The section ends with a summary of crucial points.

3.1.3 *On 'traditional' science models and learners' reasoning*: Contains insights on the standard current model used in circuit electricity, its origins and its drawbacks in terms of explanatory power, in terms of the difficulty it presents to link electrostatics with current electricity and in terms of promoting unscientific reasoning.

3.1.4 *Content knowledge for teaching*: Offers an eminent perspective on teachers' knowledge, highlights essential consensual points among the science education researchers of the 21st century and offers insights on the importance of precise science content.

3.1.2 On NOS and perspectives on the history of physics

> More than any other single aspect of science, the textbook, has determined our image of the nature of science and the role of discovery and invention in its advance.
> (Thomas Kuhn, 1970, in "The structure of Scientific Revolutions", cited in Guisasola *et al*., 2005, p.143)

Researchers in science education consider textbooks as resources that support teachers to deliver science instruction and meet curriculum standards (Chiappetta & Koballa, 2002). But the reality is that textbooks are treated as the curriculum, as mentioned in the introduction. They determine what is taught and learned, the sequence of content, teachers use them to organise and deliver instruction and assign homework (e.g. Green & Naidoo, 2008). In the case of the presentations of history and nature of science (NOS), the impact of textbooks becomes significant, just as in reformed curricula history and nature of science are deemed vital. Abd-El-Khalick *et al*. (2008) report that little research has been done in assessing how

NOS is represented in commercial textbooks and on the response of publishers to such reforms. The authors refer to some studies that have broadly analysed aspects of NOS and these always concern biology and chemistry books. In a study they undertook, Abd-El-Khalick *et al*. (2008) have assessed ways in which NOS was presented in chemistry textbooks, in terms of accuracy, completeness and manner, over the past 40 years. The result was disappointing. The treatment of NOS in textbooks showed either no change or decrease in the quality of presentations, despite the reformed efforts during the past 40 years, which were particularly strong and most widely publisised in the early to mid-90s. Among the analysis of their findings, Abd-El-Khalick *et al*. (2008) report that a chronological analysis within series of textbooks, suggests a strong *author effect* as compared to a *publisher effect*. This could be expected, as authors are much more likely to impact the content and treatment of NOS or lack thereof than publishers. However, authors seem to ascribe to certain views of NOS and 'stick to them', even over the course of several decades.

> Authors seem to be totally dissociated both from the discourse of national and international reform documents in science education, as well as from advances in philosophical, historical and sociological scholarship and thinking about the nature of the scientific enterprise. (Abd-El-Khalick *et al*., 2008, p.850)

There is much controversy among philosophers of science and educationists as to what 'the scientific method' is and in fact whether there is one (e.g. Abd-El-Khalick *et al*., 2008; Blachowicz, 2009; Rodriguez & Niaz, 2004; Silva, 2011). According to Blachowicz (2009), the origin of the step-by-step algorithm: observe, hypothesise, test and its variants, is attributed to John Dewey's "How we think" published in 1910. Dewey presented this pattern as one that characterises any careful, thoughtful inquiry (despite the fact that it was referred to as a 'scientific method', while authors of science textbooks quickly appropriated it in a way that restricted it to the natural sciences. Nevertheless, Blachowicz (2009) argues that any

formal or logical approach to an analysis of the methodology of inquiry will produce some sort of idealised scheme, with various distinguishable stages and steps. "So too, in scientific inquiry, there are many stops and starts, reversals, jumps, and simultaneous intuitions; but this does not mean that such reasoning must be tied to a purely naturalistic account and never distilled into a logical form" (Blachowicz, 2009, p.307). In contrast, Pickering (1984), cited in Rodriguez and Niaz (2004), presents an argument against the traditional step-by-step method, which is perhaps far more important for its implications in textbooks: The role of the scientist in the traditional scientific method is *passive*, scientists do not appear as genuine agents, but rather as passive observers of nature - the facts of natural reality are revealed through experiment and the experimenter's duty is to simply report what s/he sees; the theorist accepts such reports and supplies apparently unproblematic explanations of them. This characterisation of the scientific method approximates a *caricature* of what scientists actually do (Rodriguez & Niaz, 2004).

3.1.2.1 HOS enhances understanding

Bevilacqua and Bordoni (1998), introduce a new hypermedial project that deals with an historical and conceptual approach to physics. Their project, the *Pavia Project Physics*, addresses high school learners and teachers and university students. They call their methodology a historical methodology. Characteristically they claim: "we are not interested in adding the history of physics to teaching physics, as an optional subject; the history of physics is "inside" physics*"* (Bevilacqua & Bordoni, 1998, p.451). In Niaz (2005) we find the same expression for chemistry: "History and philosophy of science is "inside" chemistry" (Niaz, 2005, p.4). Bevilacqua and Falomo (2011) offer a number of case studies on electromagnetism and an intelligible insight on the topic and its presentation in standard textbooks and advanced textbooks. They do not accept the notion that electromagnetism

presentations in textbooks, whether standard or advanced, typify "normal science" as per Kuhn (1962). A point they try to make is that scientific debates and continuous scientific revolutions are an essential component of cultural wealth and not an indication of truth overcoming error. This they justify by comparing the interpretation and exposition of Classical Electromagnetism in five advanced textbooks written by five great scientists of the twentieth century, Planck, Sommerfeld, Pauli, Landau and Feynman. The different approaches of these 20th century books are still embedded in competing 19th century ideas. (For example Feynman in his *Lectures* revives Weber's idea of delayed action at a distance and introduces delayed potentials.) Moreover, this example according to the authors, demonstrates the deep understanding that great scientists have of the evolution of their discipline and of the debates between competing research programmes. Standard textbooks on the other hand, typically used in high schools and first years of university, clash and mix different theories with each other and give a false image of science. Thus Bevilacqua and Falomo (2011) question whether this lack of clarity is the reason for the students', teachers' and learners' difficulties. They argue that the Kuhnian concept of *normal science* should be questioned and an analysis of *extraordinary science* with its historical debates should be considered instead.

Niaz (2010) seems to support Bevilacqua and Bordoni's (1998) and Bevilacqua and Falomo's (2011) conviction regarding Kuhn's 'normal science' in textbooks, emphasising the complete lack of understanding, revealed from textbook analysis, of the role played by presuppositions, contradictions, controversies and speculations in scientific progress, and that despite the reform efforts, students still exhibit naïve views on the nature of science. Niaz (2010) is in favour of a Lakatosian perspective, citing Lakatos (1970), which would enable students to understand that scientific progress is subsumed by a process that involves conflicting

frameworks, i.e. based on processes that require elaboration of rival hypotheses and their evaluation in the light of new evidence. In Niaz (2005), about facilitating the conceptual understanding of students, Niaz offers an example of a simple strategy that would provide a rival/conflicting situation, and that is to provide students with the correct response along with alternative responses (i.e. relating to designing interactive teaching experiments). In a series of other papers, Niaz and other authors undertake the historical reconstruction of developments that lead to important milestones in science and highlight the associated controversies and conflicts. For example, the story of the oil drop experiment (Niaz, 2000b; Rodriguez & Niaz, 2004), Thomson's cathode ray experiments etc. (Niaz, 1998), the history of the photoelectric effect (Niaz *et al*., 2010), the kinetic molecular theory of gases (Niaz, 2000a) etc. Based on these historical reconstructions, the respective authors in each case developed a set of criteria, which they consequently used to evaluate over twenty freshman/college chemistry and physics textbooks on their portrayal of the history and philosophy of science. In all cases, the results obtained showed that textbooks overall lacked a history and philosophy of science framework – historical elements were largely ignored or distorted. Most textbooks emphasised experimental details portraying scientific progress as a *rhetoric of conclusions*, based on irrevocable truths. Such portrayal lacks the conceptualisation of the *heuristic principles* that lead scientists to design and interpret their experiments (Niaz, 1998).

3.1.2.2 Diagnosing conceptual problems

The previous papers offered a perspective on the role of history of science as inevitable for conceptual understanding through awareness of the ways science works and progresses with particular emphasis on competing views. Other papers offer different perspectives on the use of history. Pocovi and Finley (2003), much like the articles discussed above (e.g Rodriguez &

Niaz, 2004), develop a reconstruction of the historical evolution of the field view. They use this historical reconstruction to evaluate two physics textbooks in terms of reasons given for the introduction of the field and on whether these reasons are scientifically accurate, coherent and complete - not historically but epistemologically. Thus, the historical framework in this case serves to compile *credible evaluation criteria*. Nevertheless, at the end of the paper, the authors do indicate that some historical insertion on past ideas of the field may result in some gain in understanding, in terms of awareness of *what the field is not*. In an earlier paper, Pocovi and Finley (2002) concentrate on a historical sketch of Faraday's ideas on the lines of (electric and magnetic) force, looking at the ontological status of these lines in Faraday's writings. They found that Argentinian university students after receiving instruction, possessed similar ideas to those of Faraday's (i.e. that lines had some physical existence, they were responsible for transmitting the electric action, they could move and they could be cut by a moving conductor and so on). Thus they assert, "historical problems and solutions may provide a *framework for the investigation of students' understanding* that is richer than just the comparison to current knowledge" (Pocovi & Finley, 2002, p.461). The authors support the notion that some of the conceptual problems faced by students in understanding physics have parallels with the problems early scientists had to overcome while shaping a new physical idea. According to Viennot (2008), in her review of education research in the eighties and nineties, such notion of parallelisms had already been introduced by researchers since the early 1980s (Also in Seroglou and Koumaras, 2001). This may imply that learner difficulties with certain science concepts may well be of an ontological and epistemological type, rather than due to preconceptions. This is illustrated in Furió and Guisasola (1998), who argue that a historical study of the main qualitative leaps that took place in the construction of a theory, such as the 'electric field' theory, may help to diagnose conceptual difficulties. In their study they examined the conceptual profiles (i.e. Coulombian and Maxwellian) used by

high school and university students and found that most favoured a reasoning based on the Newtonian model of action at a distance (i.e. the Coulombian profile). Students demonstrated ontological and epistemological difficulties in reasoning with the idea of the field (i.e. the Maxwellian profile). The authors point to the qualitative leap that took place in passing from the Coulombian electricity to the Maxwellian electricity. This was due to the ontological change that took place in the 19th century concerning the new forms of perceiving charge and particularly charge interactions. These forms represent a radical departure from the Newtonian mechanistic view of the universe. Once students learn about the Coulomb force with its quantitative study of electric interactions, they must account for a new way of seeing and reason about electric interactions through the electric field, i.e. a linear accumulative presentation of electrostatics with such lack of consideration for the discontinuities among conceptual profiles. At a later paper, Guisasola *et al*. (2005) proposed a set of criteria based on history and epistemology of science, which they used to analyse physics textbooks as regards the image they provide on the theory of the magnetic field. Their finding, despite the increasing number of studies into the nature of science in science education, was that textbooks fail to adopt the results of such research. Much like Bevilacqua and Bordoni (1998) and Niaz (2005), Guisasola *et al*. (2005) assert that the history of physics is intrinsically contained within physics itself, hence they suggest employing teaching strategies which would present the theories of physics *as answers to problematic situations* within a socio-cultural setting.

3.1.2.3 Attempts to introduce HOS in science curricula

Seroglou and Koumaras (2001) present a framework for the classification and comparative presentation of various proposals on the use of the history of physics in physics education, 1893 being the year of the earliest reference available. The proposals are classified in

dimensions based on the objectives of physics teaching of the past 30 years or so, i.e. in *cognitive*, *metacognitive* and *emotional/affective* dimensions, while they leave out the *practical* dimension (as proposals for the use of history of science on this objective have not been reported). This framework was used to map the changing and evolving aims, the current trends and the various factors influencing the teaching and learning of physics education over the years. The authors point to the gradual shift in the focus of research interest since 1965 from the cognitive to the metacognitive dimension. This is in agreement with the trends emerging at the time on the teaching of the nature of science and the interrelation of science and society. This is in contrast to the methodology trends at the beginning of the 20th century that aimed at showing the 'magnitude' of physics as a science. Seroglou and Koumaras (2001) stress how each new curriculum seems to be informed by preceding proposals and on how each new curriculum forms the backdrop of subsequent research. Leite (2002) too develops an historical account of the different attempts to introduce history of science in science education, during the same period, but she does so descriptively highlighting similar trends. The account was used to develop a checklist for analysing the historical content in science textbooks. Leite's checklist consists of eight dimensions focussing on the historical information included, its role in the textbook, the consistency of the book in terms of history of science and on bibliography suggested. Seven of these dimensions are not content dependent as regards specific historical inclusions and may be used for the analysis of any science topic. But the eighth dimension relates to the *correctness and accuracy of the historical information* and hence, specific markers must be developed for it for each content topic to be studied. Leite (2002) used the checklist to analyse the historical content in Portuguese science textbooks, pointing to the fact that Portuguese science textbook writers are not compelled by syllabi to give importance to HOS. The results of the analysis revealed

that the historical content included in the texts was hardly adequate to give learners an idea of science and how scientists work.

3.1.2.4 HOS and the culture of the physics discipline

> We are in real danger of having constructed a society fundamentally dependent on science and technology in which hardly anyone understands science and technology. This is a clear prescription for disaster.
>
> (Sagan, 1989, cited in Stuewer, 1997/98, p4)

Stuewer (1997/98) maintains that physicists value the history of their discipline and foster historical studies both intellectually and financially. But he points to a paradox: Despite the natural alliance between historians and physicists, collaboration between the two to improve physics instruction at all levels is very small. Stuewer (1997/98), representing the point of view of historians, uses the expression *complete neglect* of the history of physics. And if history of physics comes into play it is only anecdotal, represented in a more or less linear path from one historical event to the next. Logical and not historical considerations dominate physics courses, as in any examination 'logic should pay off while history probably will not' (Stuewer, 1997/98, p.2). This attitude is attributed to the goal of physics, and according to Klein (1972), cited in Stuewer (1997/98, p.2), "characteristic of the physicist is to want to get at the very essence of a phenomenon, to strip away all the complicating features and see as clearly and directly as he can what is really involved". The maxim of the physicist is logicality and simplicity, while the maxim of the historian is illogicality and complexity. The question now posed by Stuewer (1997/98) is whether the common use of history does more harm than good. Considering that textbooks and teachers treat the history of science, if at all, in a linear manner, some messages conveyed implicitly could be for example: a) Physics progress is almost programmed…start the machine and in the near future it will have produced a new discovery, or b) Physicists are people (mostly white males) of superhuman

intellectual capacities; physics is not for ordinary mortals, such as young and inexperienced learners and students… (There is no room for mistakes and there is no room for ordinary mortals). An 'accurate' portrayal of the HOP however, would send very different messages and Stuewer (1997/98), through a number of characteristic examples, makes this point very vivid. Stuewer (1997/98) asserts that if this was the case, students would understand a few aspects of the nature of science as practiced by real scientists/physicists, like the nature of scientific creativity, how strongly political events can influence the development of science, that progress depends on many people rather than one, that the relationship between theory and experiment is far from simple and straightforward, that even great scientists such as Einstein, Millikan or Compton can be confused, dead-wrong in their theoretical views or misread their experimental data, and so on, but students could also learn about the extraordinary lives of some physicists (which hardly match the stereotype of the narrow scientist confined to his/her lab). Stuewer (1997/98) concludes that history of physics and physics are mutually exclusive but both are necessary (*complementarity*), in order to give students a full understanding of the nature of physics as an intellectual and human activity. Broadening the physics literacy of citizens through a more realistic, more approachable image of physics, would not only attract more students to the discipline, but it would improve the cultural climate for physicists and their research, who depend upon (a scientific literate) government support for their livelihood. Although Stuewer (1997/98) may seemingly have the physics community at heart, the points made are very relevant to physics/science instruction at school, especially at senior level. Reformed curricula and trends such as "Scientific literacy" and "Science for all" (e.g. Abd-El-Khalick *et al.* 2004; Leite, 2002; Lijnse, 1997/98) are common in many countries and both the South African NCS and CAPS have encouraged inclusion of history of science (HOS).

3.1.2.5 Summary of pivotal points in this section

The following brief statements are based on the literature presented in this section and have been chosen for their impact on the foundations of this study. They are reflected implicitly or explicitly in section 3.3, of the 'Guiding Principles of this study', p.73-74.

- Scientific debates and continuous scientific revolutions are an essential component of cultural wealth and not an indication of truth overcoming error. Such debates may still be present in the case of classical electromagnetism, a 19th century theory, as evidenced by its different interpretations in advanced science textbooks written in the 20th century, described in Bevilacqua and Falomo (2011). In addition, the standard model of the electric current presented to learners/students, is in fact a 19th century fluid model disguised with later terminology, like 'electrons' and 'current', as for example in Stocklmayer and Treagust (1994). In such cases, commonly used expressions such as: "ideas currently held by the scientific community" become obsolete.
- The classical electromagnetic theory is not a simple construction – it consists of incompatible concepts. Perhaps this is a reason why it cannot be really understood through a 'normalised' view that ignores its foundational aspects. "How and why important physicists have conceptualised such antagonistic concepts in electromagnetism and how it happened that these antagonistic concepts have been joined together?" (Bevilacqua & Falomo, 2011)
- Despite reform efforts, textbook analysis reveals complete lack of understanding on the role of presuppositions, contradictions and controversies and students have naïve ideas on the nature of science (Niaz, 2010).
- Several authors have found evidence to support the notion that some of the conceptual problems faced by students in understanding physics have parallels with the problems early scientists had to overcome while shaping a new physical idea (e.g. Pocovi &

Finley, 2002). Hence, learners' difficulties with certain concepts may well be of an ontological and epistemological nature rather than due to preconceptions. Thus a historical reconstruction of a theory may help diagnose such difficulties (e.g. Furio & Guisasola, 1998).

- According to Stuewer (1997/98), only 0.04 % of learners leaving school each year will do physics at a creative research level (e.g. PhD). Thus, the image of physics and physicists that the remaining enormous percentage of population retains from school and university has immense implications for the welfare of the nation and for the continued support of physics. Leite (2002) emphasises that if there were no other reason to include history in science education, the case of scientific literate citizens alone would be a strong enough reason. But the kind of historical material used and the way it is used is what determines the type of image of science, scientists and scientific practice given to students.

3.1.3 On 'traditional' science models and learners' reasoning

It is not surprising that most of the research on learner misconceptions and difficulties on electricity /electromagnetism have been concentrating on electric circuits or DC electricity. The typical model presented to high school learners and most university students is that of a 'flow' of electrons between two points at different potential (i.e. due to the influence of a potential difference applied across a wire), and in which it is the electrons that transfer energy to a load through collisions. Hart (2008) refers to this model as "the electron transport" model, others simply call it the 'standard' or 'traditional' current model (e.g. Stocklmayer & Treagust, 1994). Considering that at least in South African curricula high school learners are

introduced to the metallic bond, it is reasonable to expect that a mechanism based on microscopic considerations (such as implied by the electron transport model), would be in place to analyse electric circuits and other electrical phenomena (such as polarisation). The reality however is that the electron transport model is very limited and it cannot provide a coherent account of how energy transfers via electrons in the circuit. In addition, it encourages inappropriate reasoning (as explained further down). This may have implications in arguments found in textbooks or given by teachers and may result in a wrong impression on the consistency of science. Gunstone et al. (2009) provide evidence that concepts such as energy and voltage are poorly understood and are in fact confused, by both teachers and textbook authors. There is no evidence in the literature on consensus among scientists and educators on how to use the traditional current model for best advantage (or even with what to replace it). This is supported by Hart (2008), who acknowledges that the ontological assumptions of the models suggested in school curricula have received little attention. She moreover gives a good account of the problems associated with electric circuits and the electron transport model, which she considers 'not a good teaching model', as well as some criticisms on common analogical models found in books or used by educators. However, her main contribution is to demonstrate how a model, whether consensus (i.e. a science model) or not can be "used more *knowingly* for important education ends" (Hart, 2008, p.529). In the same paper, she helps a group of teachers to focus on the transition from one model to another, highlighting the nature of science. Hart (2008) holds that despite its short comings, the electron transport model remains the most appropriate starting point for beginning students of any age.

Stocklmayer and Treagust (1994) point to the problems associated with this model of the electric current and of the analogies that usually accompany it in textbooks of all levels.

Stocklmayer and Treagust (1994) remark that textbooks from 1891 to date reflect little change in their presentation of DC circuitry, and the current model that today's learners are required to grapple with, is in essence a fluid model predating Faraday. It is not surprising that this model has been the subject of much research. Stocklmayer and Treagust (1994) marvel at how we press young students into learning a fluid-like model and expecting them to conceptualise the nature of electronic action. Stocklmayer and Treagust (1994) pose the question on whether we should start again, by developing the ideas of Faraday and Maxwell and present a totally different view of electricity to students (with the setting up of an electric field that causes electron movement). Indeed, suggestions for such a new model do exist in literature, as in Sherwood and Chabay (1999), (also see Preyer (2000) for comprehensive diagrams) whose model has the added advantage to offer a unified treatment of electrostatics and circuits. This unification is not evident in the traditional model of the electric current. The Sherwood and Chabay approach (Chabay & Sherwood, 1995) describes circuit behaviour directly in terms of charge and electric field, focusing on the atomic structure of materials, linking micro to macro, and thus local and sequential reasoning, the scourge of the traditional model, finds no place. This approach is already in use in a number of universities. Thacker *et al*. (1999) investigated and compared the understanding of two groups of students on the understanding of simple DC circuits. One group had used a traditional textbook on electricity, while the other had used a text emphasising microscopic processes (e.g. Chabay & Sherwood, 1995) requiring students to explain their reasoning. The analysis of the students' performance revealed superior qualitative understanding of the second group. In fact the authors comment on the striking difference in argumentation of the two groups. Given the difficulties arising by the use of the traditional model of DC circuits and especially due to sequential reasoning, other authors have also suggested alternative models, like Barbas and Psillos (1997), whose model is often cited in the literature. Their model takes advantage of the common reasoning

of students, by adopting a causal approach to the quasi-stationary state of a circuit (i.e. from the moment we close the switch up to the establishment of a steady current in the whole circuit), while linking electrostatics and circuits as well. Barbas and Psillos (1997) propose their model for school instruction in mind, possibly as a 'preparation' for the introduction of a model such as Chabay and Sherwood (1995) at university.

Viennot and Rainson (1999) agree that a unified treatment of electrostatics and electric circuits can be introduced by emphasising causal aspects and transient currents, but she warns, provided that the superposition principle has been mastered. The principle of superposition holds for systems in which several factors evolve at the same time, in both electrostatics and electrodynamics situations, hence its understanding is essential for reaching a unified view of the two. Her research suggests that this principle is far from obvious to learners or students and thus she advises on the need to work on it in static situations before analysing electric circuits. According to Viennot and Rainson (1999), the reasons for the difficulties on this seemingly simple principle, are associated with tendencies of students to a) ignore a cause if no effect is visible, b) to associate a cause with only one effect, forgetting other effects and c) to consider only one cause for a given effect. Such reduced causal reasoning does not favour a systemic approach.

Staying in the topic of causal reasoning, Koumaras *et al*. (1997) investigated similarities and differences in structure and meaning of learners' conceptions of steady state and evolutionary tasks in electricity. An evolutionary task refers to a system undergoing change with time (for example a battery going flat over time). The results showed that most learners employed causal structures in their predictions, but two models were identified: A give-model was applied to steady-state tasks and a take-model was applied to evolutionary tasks. For

example, in the steady state task, learners reasoned that a battery (the agent) gives 'current' and the effect is that a bulb glows. In the evolutionary task however, the learners reasoned that the bulb (the agent) takes current and the effect is that the battery goes flat. The authors point to the semantic differences in the switched role of devices. This finding conflicts with studies highlighting that the battery is conceived by learners as a device which provides 'current' at constant rate, a model essential in several constructivist curricula. The message the authors send is that the reasoning of learners is as important as their initial ideas. It also points to the widespread lack of evolutionary tasks in standard school teaching.

Besson (2004) gives a comprehensive overview of causality in science and science education research from different philosophical perspectives, noting the trend among contemporary educational researchers to re-establish the value of causality in learning science. The paper highlights differences between common reasoning, which tends to align with contingent causes, and scientific reasoning, which requires the identification of efficient causes. Besson (2004) highlights three aspects of causal reasoning used by students in physics, for their implications: a) confusion between efficient and contingent causes (i.e. produce and trigger causes), b) tendency to displace causes, skipping intermediate objects and c) difficulty in connecting local causes and global effects. These aspects are all interrelated. Duit and Rhoneck (1997/98) highlight the types of major reasoning employed by learners and students in electric circuits, namely, the *local* and *sequential* reasoning. Such reasoning was identified in other fields as well, but it is particularly evident in electric circuits (e.g. Viennot, 1997/98; 2008). The local reasoning refers to concentrating upon a point in the circuit and ignore happenings elsewhere. Reference to the splitting of current in parallel connections, found so often in textbooks, is an example of local reasoning. The notion of a battery supplying a constant current independent of circuit connections is another example of local reasoning.

The sequential reasoning refers to situations where the students analyse a circuit in terms of 'before and after' current 'passes' a place. Duit and Rhoneck (1997/98) also alert to the fact that students show a tendency to argue in terms of current only. The current in a branch is not seen as a consequence of the voltage across the branch. In fact there is a tendency, even after instruction, to consider voltage as having almost the same properties as current. (Note that authors use the term voltage and potential difference interchangeably). In electric circuits, according to Viennot (1997/98; 2008), the sequential reasoning consists of thinking of the current as starting from the battery, then meeting various devices or junctions (episodes) along its way up-stream, where occurrences might take place (like current being used up or split), while there is no reaction in the down-stream part of the circuit. Different variables are dealt with individually and sequentially in a story-like series of cause-effect links, though they should be seen as changing simultaneously. Viennot (2008) based on literature findings, adds that such fundamental ways of reasoning appear even more resistant to change than isolated conceptions. More disturbingly, the sequential reasoning is still present at the end of studies at university, in fact, "sequential reasoning adapts itself to new knowledge, but does not disappear in so-called *experts*" (Viennot, 2008, p.3).

3.1.4 Content knowledge for teaching

Shulman (1986) proposes three categories that could distinguish the content knowledge required in teaching: a) subject matter content knowledge (SMK), b) pedagogical content knowledge (PCK) and c) curricular knowledge. SMK would refer to the *amount* and the *structure* of knowledge in the mind of the teacher, pointing out that for different subject matter areas, the structure of knowledge is discussed differently. Shulman (1986) elaborates particularly on the structure of content knowledge. "To think properly about content

knowledge requires going beyond knowledge of the facts or concepts of a domain. It requires understanding the structures of the subject matter" (Shulman, 1986, p.9). Citing Schwab (1978), Shulman (1986) refers to two types of structures of a subject, the *substantive* and the *syntactic* structures. The substantive structures are the different ways in which the discipline can be organised around its basic concepts and other constructs. This can be understood as approaching a topic from different angles. An able teacher should recognise alternative ways of organisation and select appropriately, based on the circumstances and pedagogical grounds. The syntactic structure is the set of rules/ways in which truth/falsehood or validity/invalidity is established (what is legitimate to say or not say in a discipline). It follows that a teacher ought to have a sound subject matter content knowledge. In fact Shulman (1986) is adamant that the SMK of a teacher be at least equal to that of a subject matter major.

> The teacher need not only understand *that* something is so; the teacher must further understand *why* it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied…understand why a particular topic is particularly central to a discipline whereas another may be somewhat peripheral. (Shulman, 1986, p.9)

The second type of teacher knowledge Shulman (1986) refers to, is the pedagogical content knowledge (PCK), which can be understood as subject matter knowledge *for teaching*. This includes the ways of representing and formulating the subject that make it comprehensible to others. Hence, it includes the most useful forms of representation of regularly taught topics, "the most powerful analogies, illustrations, examples, explanations, demonstrations…" Shulman (1986, p.9) in addition stresses that PCK also includes awareness of what makes learning a topic to be easy or difficult, of conceptions or preconceptions of students and of knowledge of strategies to overcome them. Finally, the curricular knowledge, underlies

among others, the ability of the teacher to relate the content of a given topic to the content of other topics/issues of other classes (lateral curriculum) or to topics of the same subject taught in earlier years or that will be taught in the future (vertical curriculum). In South Africa, the average teacher may be far from the teacher Lee Shulman had envisioned, but we should require textbook authors to be of this high standard.

Viennot (2008) has done a most insightful probe of what has been done and what can be learned from the past 30 years of research into science education. She stresses how diverse theories during this period have contributed to rather consensual points:

> Thus, it seems useful to hold an approach to learning which excludes a purely transmissive model without excluding the central role of the teacher, which considers the virtues of experiments without falling into new empiricism, which excludes a dogmatic view of science without imposing a dogmatic relativistic epistemology, which puts learners 'in context' without getting paralysed by an absolute and permanent need to simulate social activities. (Viennot, 2008, p.12)

One aspect that implicitly pervades Viennot's (2008) account is the oversight by the research community of the importance of precise science content. In an earlier paper she had proposed that science and physics in particular should be valued "for the beauty of its theories: for their unity, conciseness, predictive power and consistency" (Viennot, 2006, p.400). This statement was not proposed for its general connotations on the nature of science, nor as the only reason for valuing science. It was proposed for its tacit call for thorough attention to content matter. Subject content is an essential aspect overlooked by researchers in science education (Viennot, 1997/98), whether in South Africa or elsewhere. We would argue in agreement with Viennot (2008) (and Ogborn, 2008) that insistence on rigour and careful, coherent argument could also be a contributing factor to learners' pleasure to learn, and moreover, this does communicate an essential feature of how scientists work. Attention to content could

manifest in conceptual understanding and even in a sense of purpose. Intellectual satisfaction is surely a tacit aim of any science curriculum, yet it has not been perceived by researchers as a motivating factor.

Viennot (2008) emphasises the need to strike a *balance* between a small number of consensual basic principles like the above and a thorough and fine-grained attention to content specific aspects. She addresses a notion based on mutual consideration of both students' ideas and content analysis. To this effect, she suggests two important aspects to be considered at the designing of teaching sequences: the notion of *spotlight* and that of *critical details*, as explained below. A consensual point among researchers in education is to take learners' conceptions into account, an aspect essential in bridging common knowledge to the target one. Another widely shared viewpoint is that learners should not be left on their own to negotiate their knowledge, if conceptual change is to be reasonably expected (Viennot, 2008). This implies and calls for guidance, which means knowing what it is that the learner should understand. Viennot (2008) urges, that a *choice* must be made *from the start* of a teaching sequence (teaching unit) as to what to *spotlight* in the science content (i.e. spotlight refers to aspects of the content that have been chosen as central for the comprehension of the target knowledge). Hence, the *what* and the *how* of teaching should be linked in the light of learners' common conceptions and ways of reasoning. Yet, here as well, thorough content analysis is crucial, this time in the unrecognised details that need but often escape attention. For example, there are strategies in physics that at first may be seen as mere details, but which may be giving a poor impression of the consistency of physics. Viennot (2006; 2008) herself provides an example from optics and the 'ray' box and which has been much criticised - not as an inefficient teaching technique, but because it gives a distorted idea of what the model of a light ray may be. Such *critical details* (Viennot & Kaminski, (2006);

Viennot *et al.*, 2005) of the teaching practice are very well localised points of articulation between the *what* and the *how* without attention to which intellectual coherence is lost.

Apart from an emphasis on (subject matter) content, Viennot's (2008) and Shulman's (1986) arguments converge to a number of points. For instance they both suggest taking the student as a point of departure. But even Viennot's notion of *spotlight* echoes Shulman's reference to the *substantive* structures of knowledge. Spotlight implies awareness of different forms of concept organisation in a discipline, i.e. the substantive structures, and the need to select a form of organisation based on pedagogical grounds and (learner) circumstances.

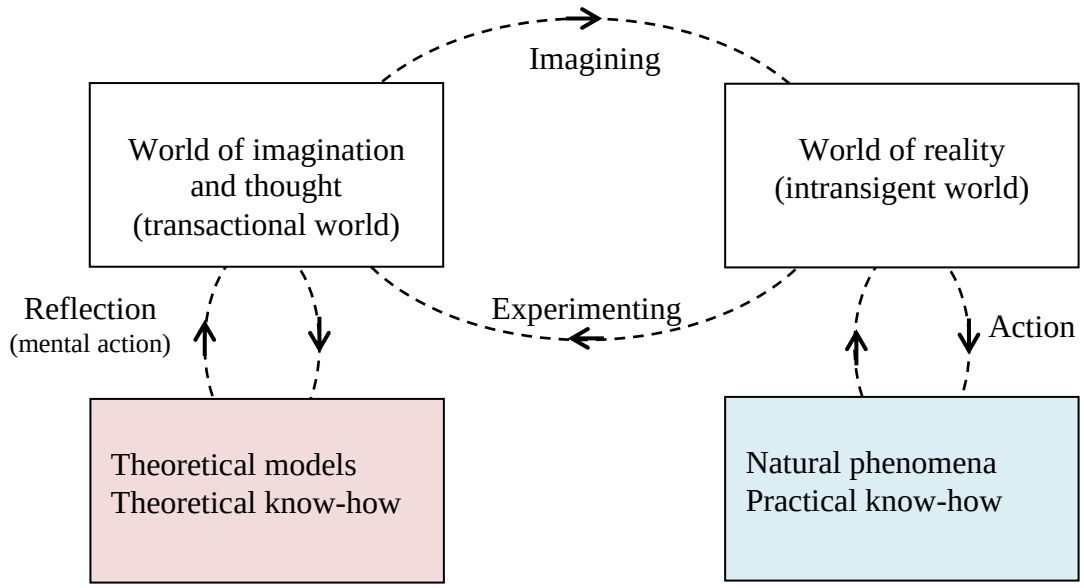
3.2 Conceptual framework

Three items served as the Conceptual Framework of this study. The first one is the framework of Electromagnetism as understood by the scientific community, presented in sections 2.2 and 2.3 of this thesis. The second one concerns the "Construction and Organisation of Scientific Knowledge" by Ogborn (2008), presented in summary in what follows. The third one, the "Organisation of the Science Educator's Thought", is a construct of this author, which was inspired by Ogborn (2008). It is a construct necessitated by and developed during the first steps of the analysis of this study. This is expounded in section 3.2.2 further on.

3.2.1 Construction and organisation of scientific knowledge

It sounds like a paradox, but centuries of development of scientific knowledge has shown that the primary means to understand reality is imagination. Science is reality re-imagined,

Ogborn (2008) proclaims. The scientific entities or *imaginings*, once imagined "are taken seriously as actual constituents of the physical world, existing and able to act or be acted upon in their own proper ways without regard to what we may wish or expect." (Ogborn, 2008, p.1). But in forming imaginings scientists are not free, the imaginings must survive this attribution of reality or else they are discarded. Hence, Ogborn (2008) presents the scientific thought as a dialogue between the world of imagination (the transactional world) and the world of reality (the intransigent world), referred to in Figure 3.1. Ogborn uses this figure to illustrate what guides the scientific mode of thought and what is involved in the construction of scientific knowledge, a brief description of which is given below (adapted from Ogborn, 2008, p.2-4):



Source: Ogborn (2008), p.2

Figure 3.1 Organisation of scientific thought

a) *The need for imagination*: Why is a stone hard? Surprisingly little can be read straight off the face of reality. Imagination is essential if we are to understand how things come to be what they are. We need to imagine how things are 'inside' or 'behind' the

surface and tell the story. Hence, a scientific explanation is a story. The story of how some imagined entities have acted to produce the phenomenon to be explained.

b) *The need to constrain imagination*: But the imaginings are not wishful-thinking. In scientific mode we try to imagine the world in such a way that our explanatory story about how things turned out to be the way they are "cannot be faulted".

c) *The need to experiment*: Since we aim at "cannot be faulted", our imaginings must be tested. If we want to see the behaviour of an imaginary entity acting alone we have to limit and control the actions of entities that might disturb or interfere with it. In doing so, we deform the natural state of affairs, we fool nature. We have to, because reality is too complex and messy and something rarely happens twice in the same way.

d) *The need for knowledge to experiment*: Since we need to control some entities, we need to know a good deal about them or else how can we control them? But we need not know everything. We can shield against a magnetic field for example, even if we do not know its origins. So experimental work does need some knowledge to get it off the ground, bit by bit.

e) *The need for practical know-how*: We can cook, we can navigate, we can make glass and smelt metal. In fact much of what we know is 'practical know-how' and this is an essential input into the doing of science. Not only we use it to get an experiment off the ground, but above all it can inspire us, it can be a source of imagination itself[2]. In the last case the meanings of the imaginings (imagined ideas and concepts) derive from action rather than definitions (from the practical active know-how that underlies them).

[2] Gardner (1999), from the technologist's perspective, elaborates on this point very vividly, by investigating the links between science and technology (the practical know-how) using historical examples and marvelling at how textbook authors consistently persist in presenting technology as application of science.

f) *The need for imagination to discipline itself*: As implied in point b, scientific imagination is constrained by projecting imagined entities onto reality and living with the consequences of this confrontation. But from the moment we constructed the imaginary entities and attributed certain nature and behaviours to them, we also triggered necessary inner consequences, within our imaginings. If we imagine, for example, an organism breading at constant rate (ascribed behaviour), it follows that its population will increase exponentially (necessary consequence). Hence, scientific imagination must also be constrained by its own inner and necessary consequences, or else there will be no integral consistency to our imaginings.

g) *The need for theoretical know-how*: Investigation of the necessary inner consequences of different imagined entities (theoretical entities) has generated a stock of theoretical models. These can be used or even investigated for their own sake. And sometimes in the process, new models are generated (e.g. chaos theory). All this work has resulted in a body of theoretical know-how, which is to the imaginative choice what practical know-how is to the practical choice. The theoretical know-how feeds the scientific imagination, which has now new resources and language for thinking about how things might be. The imaginings become more flexible and efficient and even more adventurous. Once again, the meanings of the imagined ideas and concepts derive from action, but this time from mental action.

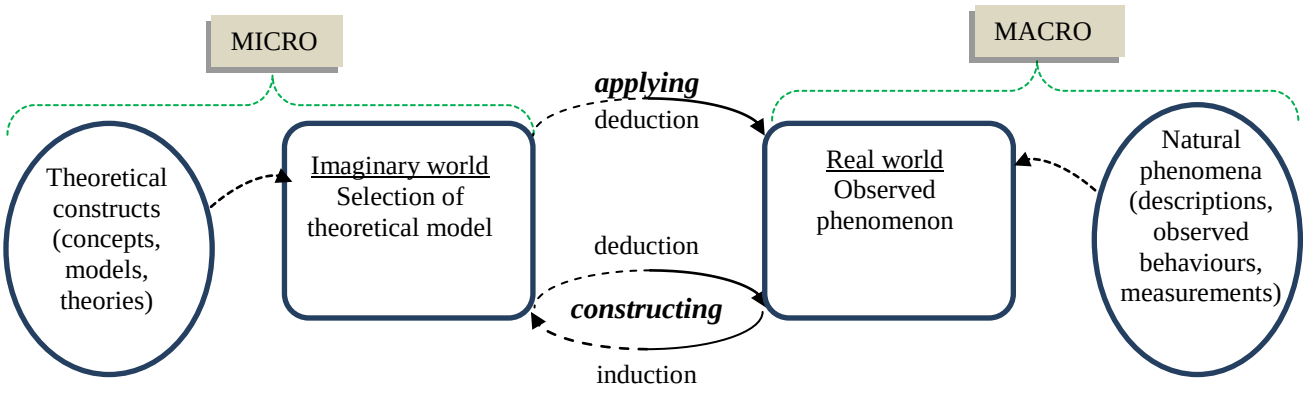
In short, science provides synthetic descriptions of as many as possible aspects of the world, endowed with as great as possible explanatory and predictive power. Concepts, models and theories are being constructed and successively refined, constrained by the necessity of integral consistency and their confrontation with the intransigent world of 'brute' reality (Ogborn, 2008; Viennot, 2008). Hence, scientific entities are mind constructs that exist in the

world of imagination where we *pretend* they are real. It follows that learning science cannot be achieved by mere memorisation of definitions and 'facts'. It requires understanding and handling of relationships between essentially abstract (constructed) concepts. At times, it requires acknowledging that some concepts cannot be understood at all by a mere definition and outside their context of use. An objective of *learning science* is conceptual understanding, which allows transfer of an explanation of a phenomenon to different relating situations. Furthermore, if a learner is to have an idea of what science is, elements of the way scientists work and how scientific knowledge is constructed should be part of these objectives (*learning about science*). Such objectives are generally present in reformed curricula, as is the case with the post-independence South African curricula, as has been explained under the "Aims of this study".

3.2.2 Organisation of the science educator's thought

Ogborn's (2008) notion of the "Organisation of the scientific thought" represented schematically in Figure 3.1, portrays the interplay between the word of imagination in the mind of the scientist and the world of reality as a continuous back and forth dialogue. Figure 3.2 was composed for the needs of this analysis. It represents a construct instigated by Ogborn's (2008) notion, as a suggestion for the organisation of learning and teaching science. The labels "macro" and "micro" appearing in Figure 3.2, address the context of Elementary Electrostatics where micro-considerations for the explanation of phenomena are of significance. Whereas Figure 3.1 represents how scientific knowledge is constructed and organised according to Ogborn (2008), Figure 3.2 may represent how *existing* scientific knowledge is organised for teaching and learning. In this sense, Figure 3.2 represents the "Organisation of the Science Educator's Thought". The advantage of this construct is that it

delineates clearly the worlds of imagination (micro) and reality (macro) in the mind of the educator, and indicates directions between the two when learners are expected to apply or construct scientific knowledge.



Source: Compiled by researcher

Figure 3.2 "*Organisation of the science educator's thought*" for linking micro to macro

In section 3.2.1 it was argued that a prerequisite for scientific imagination in order for it to measure up against confrontation with reality, was integral consistency. Then a scientific explanation would be the story of how some imagined entities would have acted to produce a certain observed phenomenon. If all was well with our imaginings, the story told should leave no doubt, meaning that it should lead to one interpretation. The story, in the case of Elementary Electrostatics, would be a micro-macro connection. *Micro* can be understood as considerations of the aspects (behaviours and attributes) of the players of a theoretical construct, such as the atomic model. A micro-macro connection would then reflect how the players of the atomic model have acted to produce a certain *macro* observation, like the 'appearance' of 'charge' on objects. This story-telling or micro-macro connection is an example of "applying" scientific knowledge, as denoted in Figure 3.2 by an arrow directed from micro to macro.

The aim of the micro-macro connection is to *explain* a real world phenomenon beyond doubt. The condition 'beyond doubt' is achieved by *deductive* inferences, which in electrostatics should be no problem, as the theoretical constructs involved are well established and powerful. So powerful in fact that in the science community we often ignore their imaginary nature and we refer to them as if 'real'. But when we teach young learners we need to be more careful. The distinction between model and reality has to be clearly articulated or else learners will confuse what is reality and what could be perceived as reality. An educator needs to make learners aware that the players of the micro world, such as atoms and electrons, exist in a cosmos to which we have no access, not because they are too small to see but because their cosmos is a creation of our imagination.

The "applying" path could be also understood as corresponding to the Kuhnian concept *normal* science (Kuhn, 1962). Within the context of learning and teaching, normal science would typify the expected norm in textbooks as has been pointed out by several scholars (e.g. Bevilacqua & Falomo, 2011; Niaz, 2010) and hence much of the everyday classroom discourse.

The loop at the bottom of Figure 3.2 labelled "constructing", represents the facet of science education in which learners are afforded the chance to experience or learn about the process of constructing scientific knowledge. But this is not a straightforward venture and in the learning-teaching context there exists much debate among science education scholars and philosophers of science on how to go about. It can range from the traditional algorithm of scientific inquiry "observe, hypothesise, test" and its variants, criticised for triggering a portrayal of scientific progress as a *rhetoric of conclusions* (e.g. Rodriguez & Niaz, 2004), to what Bevilacqua and Falomo (2011) would call *extraordinary* science, which incorporates

historical accounts of debates on conflicting frameworks and rival hypotheses, thus emphasising *heuristic principles* as well. The trend among scholars of the 21st century is to favour a historical approach (e.g. Erduran & Dagher, 2014; Niaz, 2010) portraying science as a human endeavour influenced by the context of the times.

Whether a science educator chooses a hands-on approach or an historical approach to expose learners to the construction of scientific knowledge, the distinction between imagination and reality or between micro and macro in the case of Electrostatics still needs to be kept in mind. A hypothesis or prediction would involve the deductive path from the imaginary to the real, whereas inferences drawn from observations and results (testing/experimenting) would involve the inductive path from the real to the imaginary. In the case of hands-on work, the type of inferences, deductive and inductive, learners can draw will determine the trustworthiness of their conclusions and their acceptance from other learners in the class. If learners are exposed to historical accounts of conflicting frameworks, as for example the Millikan – Ehrenhaft controversy relating to Electrostatics (e.g. Niaz, 2000b), distinction between the theoretical construct (imaginary) and suggested conclusions from measurements (real) would help learners to appreciate the credence of heuristic principles when it comes to interpreting reality. And what a better way to get a feel of how scientists think and work and even fight!

3.3 Guiding principles of this study

This study of the Elementary Electrostatics as part of Electromagnetism in the South African science textbooks was guided by four notions, grounded on the Literature Review and the Conceptual Framework. Within these notions, the aspects of science education *learning of*

science and *learning about science*, referred to under the "Aims of this Study", are reflected clearly. The four notions are given below:

A. The body of scientific knowledge consists of mind constructs. A scientific explanation is a story which attempts to make the reason for the occurrence of a phenomenon obvious
B. That science and physics in particular, should be valued for the beauty of its theories, for their unity, conciseness, predictive power and consistency
C. That learner ideas should be respected and that attention to their difficulties and reasoning should be taken into account
D. That history of science is an integral part of science. It can convey a full understanding of the nature of science, it can portray science as a continuous quest and as a human activity and it can promote both interest and conceptual understanding. A linear or simplistic use of history however, could cause more harm than good.

Table 3.1 illustrates how these guiding principles correlate closely with the specific research questions in section 1.7.2. The correlation of guiding principles and research questions portrayed in Table 3.1 is only indicative, as there is far more overlap across aspects of the two. For instance, portraying science as a human activity (D) and coherent argument (B), do take the learner into account (question 1). This has been pointed out earlier in section 1.7.2, in relation to overlapping concerns within the research questions themselves.

Table 3.1 Correlation of guiding principles and specific research questions

Research questions	Guiding principles
1. To what extent do textbook authors of Electrostatics take cognisance of learners' common misconceptions, common ways of reasoning and the inherent difficulties of the topic elementary Electrostatics?	C. Learner ideas should be respected and attention to their difficulties and reasoning should be taken into account. A. The body of scientific knowledge consists of mind constructs.
2. What evidence is there, in the chapters of Electrostatics, of appropriate attempts to enhance understanding of the nature of science and of the foundational aspects of certain concepts or models, by disclosing elements of how scientists work and how scientific knowledge is constructed?	A. The body of scientific knowledge consists of mind constructs. D. History of science is integral part of science. It can convey a full understanding of the nature of science, it can portray science as a continuous quest and as a human activity and it can promote both interest and conceptual understanding.
3. To what extent have textbook authors of Electrostatics paid attention to subject content, endorsing rigour and coherent argument, thus reflecting the preciseness and consistency of science?	A. Scientific explanation is a story which attempts to make the reason for the occurrence of a phenomenon obvious. B. Science and physics in particular, should be valued for the beauty of its theories, for their unity, conciseness, predictive power and consistency.

CHAPTER 4

RESEARCH DESIGN METHODOLOGY AND PROCEDURE OF DATA COLLECTION

4.1 Overall research design

The overall research strategy of this study can be regarded as a *case study* approach, involving a number of South African FET physical sciences textbooks. However, as regards the part of the study that concerns the CAPS textbooks in particular, the study can be regarded as a *population study*. This is because all the CAPS approved textbooks in circulation at the time of the analysis, according to the Department of Education, had been considered.

A *content analysis* approach was adopted as a method of collection of data as well as for data analysis. A combination of deductive and inductive qualitative content analysis procedures were employed to analyse the sections of Electrostatics in the selected textbooks. A brief background to the method of content analysis with relevant explanations is given below.

4.2 Content analysis

Krippendorff (1980) suggests that content analysis as a research method is a systematic and objective means of describing and quantifying phenomena. Elo and Kyngäs (2008) add that it is also known as a method of analysing documents. It makes it possible to distil words into fewer content-related categories. Berg (2007) suggests that it is a process by which a coding scheme is applied to field notes or data. Stemler (2001) citing Holsti (1969) refers to a broader definition of content analysis that is not restricted to texts, as "any technique for making inferences by objectively and systematically identifying specified characteristics of messages" (Stemler, 2001, p.1).

Wang (1998) reviewed content analysis techniques conducted on 31 school science textbooks during the period 1989 to 1996. The results suggested a wide number of content analysis

approaches, mostly quantitative. He found that most of the researchers had fragmented uses of content analysis as a textbook study method, whether quantitative or qualitative. Elo and Kyngäs (2008) point to the fact that although content analyses are commonly used in nursing studies, only 15 methodological papers concerning content analysis have been published in their journals from 1988 to 2005; most in the 21st century. The fact that a homogenous understanding of this method does not seem to exist, is also reflected in Kohlbacher's (2006) literature review, where as he upholds, originally the term referred only to those methods that involved directly and clearly quantifiable aspects of text, and as a rule on absolute and relative frequencies of words per text or surface unit.

4.2.1 The origins of qualitative content analysis

The longest established method of text analysis is the so-called "classical" content analysis. This is traditionally a quantitative method operating within a system of categories and is essentially a "coding operation", with coding being the process of transforming raw data into standardised form. Consequently, its assessments are typically based on frequency analysis. This classical method of text analysis was dominant in the first half of the 20th century triggered by the onset of an ever expanding mass communication (Kohlbacher, 2006; Mayring, 2000).

Kohlbacher (2006) refers to strong criticisms against the classical content analysis, despite the reliability of this method, which begun in the 1950s (sparked by Berelson's book "*Content analysis in communication research*" published in 1952) by researchers who claimed that quantitative orientation was a superficial analysis that neglected the quality of texts, did not respect latent content and contexts and ignored different possibilities of

interpretation. Quantitative research proponents responded by calling their qualitative counterparts journalists, soft scientists whose work was unscientific, exploratory and subjective and so on. Kohlbacher (2006) refers to the heated disputes between supporters of the quantitative and qualitative research designs as the "paradigm war" (Kohlbacher, 2006, p.2).

It was such criticisms however that triggered attempts to exploit the advantages of both approaches, by seeking synergy and complementarity rather than rivalry between the quantitative and qualitative camps. Kohlbacher (2006) indicates that such efforts have led to the appearance of mixed method approaches and the use of triangulation. And in addition, it was such criticisms that have prompted advancements of qualitative methods and that led to the development of qualitative approaches to content analysis.

4.2.2 Qualitative content analysis

In Kohlbacher's (2006) wide-ranging paper, he explores and discusses the use of qualitative content analysis in case study research. The basic introduction to qualitative content analysis as an interpretation and analysis method for text documents (and other material) below, will be largely based on Kohlbacher's (2006) paper. The principal focus of Kohlbacher (2006) is on the main points of Philipp Mayring's approach to qualitative content analysis, developed in the 1980s, with references to Krippendorff (2004). Mayring's and Krippendorff's works have become standard literature on content analysis, the former's particularly on qualitative content analysis. The main idea in Mayring's (2000) approach is "to preserve the advantages of quantitative content analysis as developed within communication science and to transfer and further develop them to qualitative-interpretative steps of analysis" (Mayring, 2000, p.1).

4.2.3 Basic ideas of qualitative content analysis

Mayring (2000) defines qualitative content analysis as "an approach of empirical, methodological controlled analysis of texts within their context of communication, following content analytical rules and step-by-step models, without rash quantification" (Mayring, 2000, p.2). Hence, the strength of qualitative content analysis is that it is strictly controlled methodologically and that the material is analysed step-by-step.

In this study, most aspects of the research questions required a step-by-step ongoing analysis of texts, or at least rendered themselves to the formulation of some operating schema of categories. Hence, the qualitative content analysis method was the most appropriate[3]. However certain aspects, especially relating to the third research question required a more exploratory analysis style, but still theoretically and empirically grounded. For example, certain characteristic excerpts or localised points of articulation were selected to comment upon extensively. It was in such instances where trends and aspects of content warranted the description *critical detail* (see section 3.1.4, under Literature Review). And critical details ought to be elaborated upon individually. Another example was a holistic exploration of main ideas that filtered through the texts under Electricity and Magnetism. The main ideas students in schools or universities retain from a topic has been identified in the literature as a problem. Bagno and Eylon (1997) for example, found that most high school students considered Ohm's law as the most important idea in electromagnetism. Working with coding rules would

[3] The method of **discourse analysis** has also been considered as a possible alternative qualitative approach to content analysis within the context of textbook analysis. Bondarouk and Ruël (2004) disclose how discourse analysis also encompasses inductive-deductive development of categories and an operationalization scheme, evoking the coding agenda of content analysis. However, discourse analysis focuses on communication processes within their socio-political, cultural and even historical dimensions. Thus, the emphasis is placed upon both the *production* of the discourse and its reception by the audience (Kumaravadivelu, 1999; Lupton, 1992). Alba-Juez (2009) in addition, highlights that "Discourse analysts are interested in the actual patterns of use in *naturally-occurring* texts" (p.18). Hence, although written texts can be perceived as a type of discourse, textbook texts are by no means 'naturally occurring', nor have we the means to know the (socio-cultural) context and conditions of their production. In addition, this is not the concern in this study.

be a restriction here. In any case, as Kohlbacher (2006) contends, argument is more important than procedure.

4.2.4 Instrumentation

The core and central tool of any content analysis is its system of **categories**, developed right on the material, by employing a **theory-guided** procedure. This way, the aspects to be filtered from the material are defined. The interpretative, but rule guided process of assigning categories to text portions is crucial for qualitative content analysis, whether inductive or deductive, as argued in section 4.2.5.

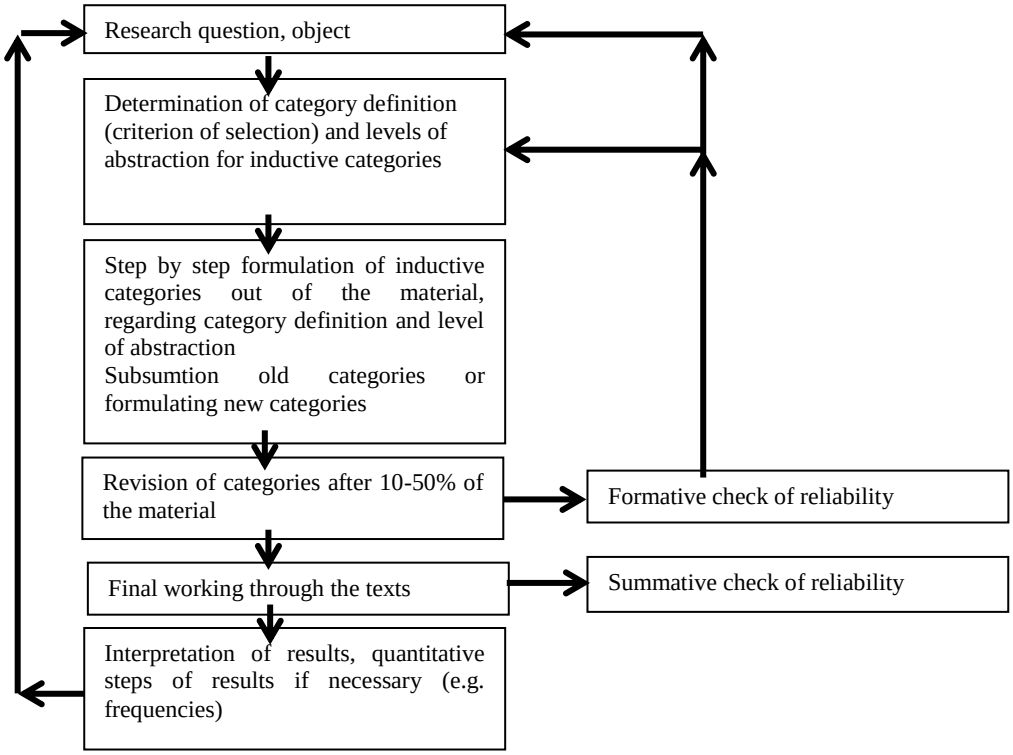
The rule-based approach of qualitative content analysis provides for a systematic treatment of the empirical basis and ensures reproducibility of the analysis to a certain extent. It is this kind of systematics that distinguishes content analysis from more interpretive, hermeneutic processing of texts (Mayring, 2000). Table 4.1 displays the components of content analysis for a qualitative oriented procedure of text interpretation. It has been compiled using the 'basic ideas of content analysis' described in Mayring (2000) and Kohlbacher (2006). Points a, b, c and h in Table 4.1 refer to components of quantitative content analysis that we wish to preserve in qualitative content analysis, as representing the advantages of the method.

Table 4.1 Components of qualitative content analysis

Central points	Explanations and comments
a. Fitting the material into a mode of communication	Determine parts of the text where inferences shall be made: To aspects of the communicator? (experiences, opinions, feelings) To the situation of the text production? To the socio-cultural background? To the text itself? To the effect of the message?
b. Systematic, rule-based analysis	Material to be analysed step-by-step following rules of procedure, devising material into content analytical units.
c. Categories in the centre of analysis	The aspects of text interpretation, following the research questions, are put into categories, which were carefully founded and revised within the process of analysis.
d. Subject-reference instead of technique	Instead of being a set of techniques for text analysis, the connection to the concrete subject of analysis is a very important point in qualitative content analysis. The procedures of content analysis cannot be fixed, but have to be adapted depending on the subject and its context.
e. Verification of the specific instruments through pilot studies	Due to the subject reference, fully standardised methods are abstained from. Hence the procedure must be tested in a pilot study. Inter-subjective verifiability is a case of point here.
f. Theory-guided analysis	Technical fuzziness of qualitative research needs to be balanced by theoretical stringency. Hence, the state-of-the-field of the respective research subject as well as subjects closely related are required to be taken into account and integrated into the analysis.
g. Inclusion of quantitative steps of analysis	Quantitative analyses are important when trying to generalise results. This notion of triangulation to argue in favour of integration of qualitative and quantitative methods is not limited to content analysis, but has been raised by many researchers.
h. Quality criteria of reliability and validity	The procedure has the pretension to be inter-subjectively comprehensible, to compare the results with other studies in the sense of triangulation and to carry out checks for reliability.

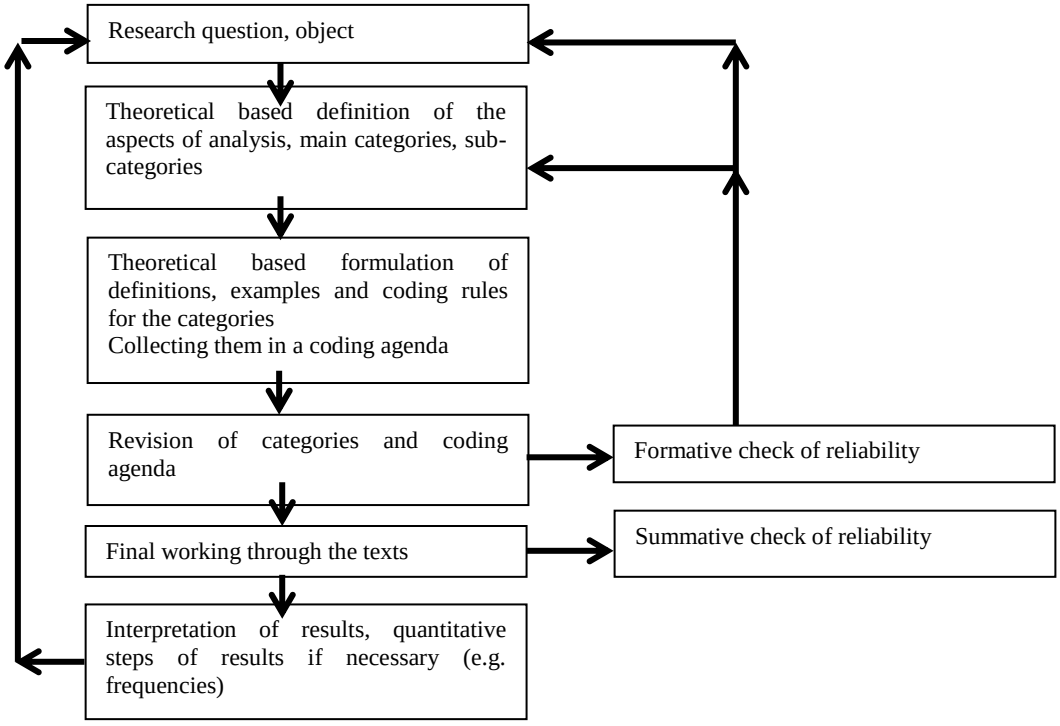
Source: Adapted from Mayring (2000) and Kohlbacher (2006)

Figure 4.1 Step model of inductive category development



Source: Mayring (2000), p.4

Figure 4.2 Step model of deductive category application



Source: Mayring (2000), p.5

4.2.5 Procedures of qualitative content analysis

> How categories are defined…is an art. Little is written about it.
>
> (Krippendorff, 1980, p.76)

Among the number of procedures developed for qualitative analysis, Mayring considers two as central in developing a category system and finding the appropriate text components as a result, described in sections 4.2.5.1 and 4.2.5.2.

4.2.5.1 Inductive category development

The classical content analysis provides little insight as to where categories are derived from or how the system of categories is developed (Mayring, 2000). But in qualitative approaches, such aspects of interpretation, the categories, are crucial and must be formulated in terms of the material and as close to the material. This resulted in the inductive category development. The main idea of this procedure is to formulate a criterion of definition, derived from the theoretical background and research question, which determines the aspects of the textual material taken into account. Following this criterion the material is worked through and categories are tentative and deduced step-by-step. Within a feedback loop, those categories are revised, eventually reduced to main categories and checked in respect to their reliability, as illustrated in Figure 4.1, (Mayring, 2000).

4.2.5.2 Deductive category application

This approach works with prior formulated, theoretically derived aspects of analysis (categories), bringing them in connection with the text. The qualitative step of analysis consists of a methodologically controlled allocation of a category to a passage of text. The main idea here is to give explicit definitions, examples and coding rules for each deductive

category, determining exactly under what circumstances a text passage can be coded with a category. Those coded definitions are put together within a coding agenda (and Mayring (2000) provides such an example of a coding agenda), as illustrated in Figure 4.2.

Mayring (2000) notes however, that the research questions and the characteristics of the material should be given priority in the decision about adopted methods. For example, the procedures of qualitative analysis would be less appropriate if "the research question is highly open-ended, explorative, variable and working with categories would be a restriction, or a more holistic, not step-by-step on-going of analysis is planned" (Mayring, 2000, p.8).

4.3 Selection of textbooks for analysis

4.3.1 Selection criteria

According to NCS and CAPS curricula, grades 10 to 12 constitute the Further Education and Training band or FET. For simplicity in what follows, grades 10 to 12 or the NATED equivalent of standards 8 to 10 may be referred to as FET. The following factors were considered upon selecting textbooks for analysis:

a) *Approved textbooks*: At the onset of this study it was envisaged that a number of about three physical sciences textbooks per grade and per curriculum (NATED 550, NCS and CAPS) would be selected for analysis, covering the period of post-apartheid South Africa. Thus, selected textbooks would be addressing FET level (grades 10 to 12 or standards 8 to 10). Selected textbooks ought to be approved, i.e. appearing on the catalogues of provincial or national departments of education of each curriculum era. In the years preceding CAPS, textbooks would be approved by provincial departments and each publisher could submit

more than one series to each provincial department. Hence, there were relatively many textbooks in circulation. This was not the case with CAPS, where each publisher could only submit one series and the selection and approval was done on a national level.

b) *Continuity across grades*: Ideally, for the sake of continuity, groups of grade 10-12 books addressing a particular curriculum would be part of the same series, but we also had to acknowledge that this might not always be possible. In CAPS especially, approved books for a certain grade might have not been necessarily produced by the same publishers as the approved books of adjacent grades. Furthermore, even within the same textbook series it is not uncommon to have different authors writing the corresponding chapters (of the same Knowledge Area / topic) for the different grades.

c) *Widely used textbooks*: Concerning this study, the number of textbooks sold or used in classrooms was never meant to constitute a strict selection criterion, but a preferred one, since it would reveal what the majority of our learners have been exposed to in terms of the questions of this research. Whether the number of the most widely used textbooks is also an indicator of quality or not, depends on the criteria used by teachers when selecting textbooks, as according to Lemmer *et al*. (2008) this is usually their responsibility. Lemmer *et al*. (2008) investigated the selection criteria used by 16 South African grade 7 natural science teachers when selecting textbooks during the time of RNCS. The criterion of utmost importance for all teachers was the alignment with the learning expectations/requirements of the curriculum and that learning outcomes and assessment standards should be indicated for all activities. Regarding content, most teachers did not consider vital aspects such as in-depth presentation of topics, increasing sophistication across grades, nature and historic developments in science, important ideas, interconnectedness across strands and treatment of alternative conceptions. In terms of instruction, aspects such as ‘science as a human endeavour’, critical thinking and making sense among others were not referred to. Lemmer *et al*. (2008) stress the

need for educator training courses on textbook evaluation and selection. Wang (1998) had also stressed the same need ten years earlier in the USA and in fact emphasised the urgent need for the development of a '*teacher friendly* content analysis method' to be part of teachers' training. Wang (1998) marvelled at how little effort had been devoted in analysing curriculum materials during teacher training, especially textbooks, which according to the Third International Mathematics and Science Study (IEA, 1996) form the basis of about 50 % of teaching time for all teachers around the world.

4.3.2 Textbooks sourced for this study

The selected textbooks are listed in Appendix B. The last column of the table displayed in Appendix B, labelled "Code name", indicates the code of each series by which textbooks are referred to in the analysis. As mentioned earlier, the target since the inception of this study had been to source three series of FET textbooks, if possible, per curriculum. Series rather than ad-hoc textbooks had been sought after for the sake of continuity across grades. This target has been largely met, as shown in Appendix B. Furthermore, all selected textbooks represent approved titles that have appeared on provincial or national catalogues of each curriculum era.

NATED textbooks

The three NATED textbook series were donated by colleagues who in the past had worked for many years as physical sciences teachers and who fortunately had retained these textbooks. This was indeed fortunate because sourcing old textbooks proved to be a lot harder than anticipated. The SPS standard 9 book could not be sourced, but according to the NATED 550 curriculum, and as can be seen in Table 2.3, electromagnetism sections are only

addressed in standards 8 and 10. This may make standard 9 textbooks on the list appearing unnecessary. However, standard 9 books were also examined for possible links to electromagnetism, considering that several models employed in electricity are introduced under the chemistry sections of standard 9 (e.g. bond models and the structure of the atom).

NCS textbooks

The NCS textbooks of the "Study & Master" series (indicated in what follows as S&MN) were already in my possession since the times of NCS in the late 2000s. The books were handed out to me by the publisher during an in-service training of physical sciences teachers and curriculum advisors in the Limpopo province. The NCS Oxford series (indicated as OXFN) came to my possession a lot later, middle of 2014. It was donated by a teacher from a Limpopo school, whom I knew through a different series of in-service teacher training, and whose school by that time when CAPS was in full swing, made no longer use of the older NCS textbooks. The three NCS version of the Siyavula series (indicated as SIYAN) could be accessed electronically as e-books through the website of the DoBE and also from www.everythingscience.co.za. During the course of 2014, a printed version of a Grade 12 NCS Siyavula textbook was donated to me by a Gauteng school, and this replaced the corresponding e-book, as shown in Appendix B.

Considering that the inception of this study begun during a transitional period between two curricula, NCS and CAPS, it was particularly hard to get hold of NCS textbooks, let alone whole series. During this period, few NCS textbooks were printed, bookshops would run out of NCS textbooks and schools would hold on to their NCS textbooks since they were still in use. Nevertheless, I consider the three selected series of NCS textbooks appearing in Appendix B to be quite adequate and representative of the NCS era, as these series appear to

have been widely used by South African schools. It must be noted that the remark on the wide use of these textbooks is entirely based on professional experience. No official statistics on the number of sales per textbook could be sourced and publishers, when contacted, were very reluctant to divulge such information. However, my lengthy experience with in-service teacher training and the considerable numbers of teachers and schools that I have had contact with over the past decade (primarily from Gauteng, North West, Mpumalanga and Limpopo provinces), suggest that the selected series were indeed among the series used widely by schools.

CAPS textbooks

The CAPS FET textbooks for grades 10 to 12 have all been purchased one by one over three consecutive years, starting from 2012, as they became available in bookstores. Hence the list of textbooks as appearing in Appendix B was completed by the middle of 2014. Regarding the implementation of the CAPS curriculum, the DoBE had only approved a small number of textbooks per grade. Hence, at the start of the CAPS implementation, the collection of CAPS textbooks was not a matter of selection, but rather a matter of obtaining them all. To these we added the CAPS versions of the Siyavula series, as e-books, as they became electronically accessible per grade following the CAPS implementation over the period from 2012 to 2014. These can be sourced through the website of the DoBE (and www.everythingscience.co.za). Another two printed Siyavula CAPS-version textbooks for grades 10 and 11 became available in 2014, donated by the same Gauteng school that also gave me the grade 12 Siyavula NCS-version. Upon inspection of the chapters on “Electricity and Magnetism”, the Siyavula e-books and printed books are identical with the exception of the page numbering.

The inclusion of the NCS series S&MN and OXFN, which have their counterparts in the CAPS list of approved textbooks, was a matter of chance rather than a matter of intention. CAPS textbooks were approved grade by grade in consecutive years and we had no means of anticipating the approved titles. Nonetheless, we did anticipate that tracking the progress of a series through consecutive curricula could yield interesting trends or other aspects.

4.4 Ethical issues and Ethics clearance

Regarding the attainment of an "ethics clearance" in order for research in humanities to proceed, one has to consider the distinct difference between working with *humans* and working with the *work of humans*. This study falls in the latter category because it does not involve human participants. It is concerned with the analysis of textbooks, which are public documents and as such, they do not represent individual people nor do they disclose confidential information (as per "Benchmarks for Ethical Research", Horn *et al*., 2015, pp.9-15). Because this study cannot be classified as research with humans (human research), an ethics clearance was not therefore necessary. Nonetheless, ethical issues were not ignored during the analysis of the texts and the reporting of findings, and great care was taken to avoid disparaging reporting style.

4.5 Methodological approach of data collection

The study was guided by the components of qualitative content analysis as displayed in Table 4.1, bearing in mind the research questions.

In accordance to section 1.6 "Aims of this Study", inferences were made to the aspect *science content* of the texts and to the effect of their messages. This addresses ***point a*** in Table 4.1

(p.82 of this thesis): "*Fitting the material into a mode of communication*", implying determining facets of the text where inferences would be made.

4.5.1 Preparation and organisation phase

Becoming familiar with the texts:

The first objective and priority of a content analysis is to become most familiar with the texts/data, reading through the materials several times. Elo and Kyngäs (2008) advise becoming 'immersed' in the data, as no insights or theories can emerge without the researcher becoming completely familiar with them. Initially not all textbooks were available, as discussed earlier. Nevertheless, the process begun with the NATED series, two NCS series (SIYAN and S&MN) and most of the CAPS grade 10 and 11 textbooks from the list in Appendix A. In addition to these, two more NCS textbooks from different publishers were in my possession, one grade 10 the other for grade 11. However, once the complete NCS Oxford series became available, they were removed from the list in favour of the complete series.

The chapters on Electricity and Magnetism in the available textbooks were studied fastidiously, reading through the material several times, starting from the NATED and followed by the NCS and CAPS textbooks. Engaging with the books in the chronological order in which curricula were introduced was thought to be the reasonable way to go for ascertaining possible progression in aspects concerning this study. In the process, and already from the first round of reading, problematic expressions in texts were underlined and comments or notes were placed at the margins or diagrams. 'Texts' is to be understood as the whole material where inferences would be made, including the figures. In addition, separate

and copious written notes were taken per book, either on aspects that commanded attention or on insights that might have surfaced, sometimes very tacitly, as reminders to consider or to research or to think further. This stage was very time consuming and the many notes taken were not used as such in the actual data analysis and reporting. Yet this process, far from being a waste of time, was instrumental in a) ameliorating our memory, thus enabling parallels and comparisons between texts, b) bypassing difficulties arising from differences in authoring style and superficial features of the books, c) gaining a preliminary holistic picture of trends, authors' understandings and handling of topics, d) exposing dominant aspects in need of attention per topic and thus e) giving me insights on how to proceed with the formulation of categories and the process of analysis.

In this initial phase, all topics of Electricity and Magnetism in the textbooks from all FET grades were read carefully, as well as relevant sections from the knowledge area Matter and Materials and/or chemistry sections. This was done for two reasons. The first one was to look for continuity and possible links and parallels between topics and between grades, whether these were intentional or unintentional from the part of the authors. The second reason was that in the inception of this study the initial aim was to analyse as many aspects of Electromagnetism in the texts as possible. Due to my work experience I had already several ideas on where problematic areas lied in different topics. However, once the actual fine-grain analysis of the texts begun, far more areas of concern were revealed than initially anticipated. It became obvious that each topic, in fact each aspect, was in need of substantial scrutiny. As a result, this study concentrated on the analysis of Elementary Electrostatics, seen as the first step to an anticipated broader analysis of Electromagnetism. Elementary Electrostatics is foundational to the rest of Electromagnetism, yet it has been largely overlooked by scholars.

4.5.2 Procedure of data collection

The endeavours of becoming familiar with the texts and the first trials on categorisation matrices, resulted in some valuable insights on the characteristics of the materials and provided indicators on how to proceed. Such indicators were largely followed in the data collection, analysis and interpretation phase of this study, which took place as follows:

Aspects of analysis were allotted per section of the topic Elementary Electrostatics and its categories and subcategories were designated based on the context and characteristics of that particular section. The rule-based approach for the data collection took place using as guidelines the basic ideas of content analysis described by Mayring (2000) and Kohlbacher (2006) in Table 4.1. This was done bearing in mind that the procedures of content analysis cannot be fixed, but ought to be adapted to the texts. In the following, the process of data collection is described and related to the guidelines in Table 4.1 (p.82):

- *Categories in the centre of analysis* (addressing ***point c*** in Table 4.1, implying formulation of categories):

  Both deductive and inductive categories were formulated depending on the texts and each aspect of analysis. Deductive categories contained theoretically founded definitions, explanations or descriptions, referred to collectively, in what follows, as ‘definitions’. Inductive categories consisted of text based accounts, characterisations or particular understandings found in texts, if any, and if they were in discord with the theoretically based counterparts. This was a slight departure from the approach initially envisioned, in which an inductive procedure would take precedence, while theoretically based definitions would be a supplement if necessary. The decision to give more prominence to

deductive categories was necessitated from the fact that texts were found overall to be very brief, superficial, similar and haphazard. In this case, inductive categories could compromise the outcomes of this study due to lack of substance. If this study was to be of value to other authors, educators and curriculum developers, it should be more than a criticism, it should provide the missing substance, it should provide check-points and it should provide rational accounts of order of concepts and processes, opportunities for links, parallels and inclusions and reasons. Deductive categories would better serve this purpose due to the relative control they would afford.

- *Subject-reference instead of technique* (addressing ***point d*** in Table 4.1, implying need for adaptation to context for concrete connection to texts):

  The formulation of categories needed not be restricted to a particular format. The format was dictated by the idiosyncrasies of each topic, the aspect of analysis and the connection with the texts. (Refer to comments under point *d* in Table 4.1, p.82.) This concerned primarily the generation of inductive categories, but not only.

  In the case of deductive categories, the criterion of assigning text to a theoretically grounded definition was not based on whether the text was in accord with the definition but on whether the author had attempted to address the definition, even if this was done partially or unsuccessfully. Examples from the texts were added, long enough as to maintain a context for meaning. In addition, comments or notes were placed next to each example to point out aspects in need of attention.

Concerning the deductive categories, no use was made of codes. Due to the nature of the texts, and the analysis of texts per section, coding became unnecessary. Instead of assigning codes to the texts, texts were assigned directly to definitions in the

categorisation tables. Categorisation tables were formulated in such a way as to accommodate all textbooks concerned, as shown schematically in Figure 4.3.

Figure 4.3 Example of typical categorisation table for deductive categories

Category (I)	**Book A**	**Book B**	**Book C**	**Book D**	**Book E**	**Etc.**	
Definition 1	see (1)						
Definition 2		see (2)					
Definition 3							
Etc.							

Examples (excerpts from books)	**Comments**
Example (1)	On example (1)
Example (2)	On example (2)
Etc.	

Source: Compiled by researcher

Although there was no need to be restricted to a specific format of categorisation table, the format of the table shown in Figure 4.3 proved to be quite effective and advantageous and was used almost consistently. The top part of the table featuring the 'definitions', reveals a picture of the state of affairs in textbooks, the intentions of the authors, sometimes revealing trends across curricula or across series of textbooks, and it also allowed for quantitative results if necessary. But the actual fine grain analysis of the texts was performed on the examples at the lower part of the table. The examples allowed to scrutinise the handling of particular aspects individually and collectively, to look for common or unique features and notions, and were the source of formulation of inductive categories if needed be.

Inevitably during the development of categories, 'definitions' were revised. Certain categories were subdivided while new categories emerged as in an inductive procedure.

Inductive and deductive strategies in the development of a category system are often combined, and the two should not be regarded as mutually exclusive, but rather as complimentary (Schilling, 2006). This process was quite intricate, and a second coder with expertise in physics and science education had to be involved from the early stages for the sake of reliability.

- *Systematic rule based analysis* (addressing ***point b*** in Table 4.1, p.82, devising the material into content analytical units, i.e. selecting units of analysis):

  According to Schilling (2006), a meaningful unit would be a segment of text that is comprehensible by itself and contains one idea, episode or piece of information. Shilling had in mind sentences or short expressions that could be allocated a single code in a coding process. However, Elo and Kyngäs (2008) advise that units of analysis must be large enough to be considered as a whole and small enough to be kept in mind as a context for meaning during the analysis process, without adhering to any particular restrictions. This last notion was more applicable to this study. The extent of the units of analysis differed within the data and one had to use some judgment on a meaningful unit. Units of analysis were mostly sentences or paragraphs which often included diagrams. In certain cases, analytical units could be half a page depending on the textbook. In general, as mentioned earlier, texts were very brief and so it was easy to include entire analytical units as examples in the categorisation tables. There were also cases were bits and pieces of text from different pages had to be collected to form an idea of what the author understood and conveyed on certain concepts.

4.5.3 Schema of overall work

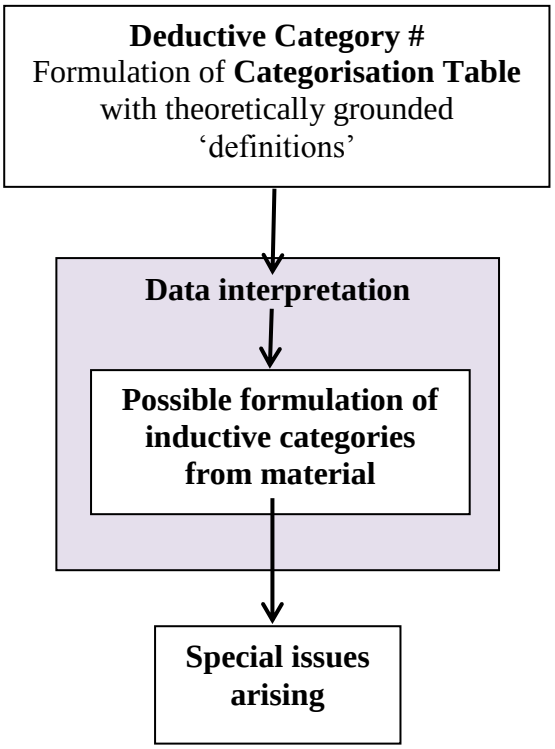
Figures 4.4, 4.5 and 4.6 were composed to represent the overall course of work that steered this study, from the data collection and analysis to the reporting and conclusions. Figure 4.5 represents an overview of the analysis of the texts, encompassing the data collection and their interpretation, giving an idea of the complexity of the process and the extent of work involved, but in a form hopefully easier to the eye. Broad aspects of analysis were allotted to the topic Electrostatics, six in total (not all are included in Figure 4.5), based on the characteristics and the context of particular sections, as discussed under "Procedure of data collection" (p.93). Apart from the first aspect of analysis (on the left of Figure 4.5), which concerned global understandings of the topic, each aspect of analysis entailed the formulation of one or more theoretically grounded categories, referred to as "Deductive Categories" in Figure 4.5. Each of these categories was the basis for the formulation of a *Categorisation Table* (CT) of the type shown in Figure 4.3 (p.95), with theoretically grounded 'definitions'. The categorisation tables were the primary means of date collection from the texts.

The completion of each categorisation table with relevant data was followed immediately by the interpretation of the data. This process is illustrated in Figure 4.4, which represents a basic 'cell' of the analysis of the texts. The basic cell reflects the work entailed per deductive category. If during interpretation particular understandings of authors emerged, these were followed up by a fine grain analysis and/or were used to formulate inductive categories, followed by further interpretation and analysis of issues arising. Once the process of analysis in one cell was completed, the analysis of the next cell would commence, indicated by the dashed lines in Figure 4.5. Finally, the summary of the findings from each aspect of analysis were drawn together to a summative report, as shown in Figure 4.6, where trends were

highlighted and crucial aspects that emerged from the texts were discussed holistically in conjunction with the research questions.

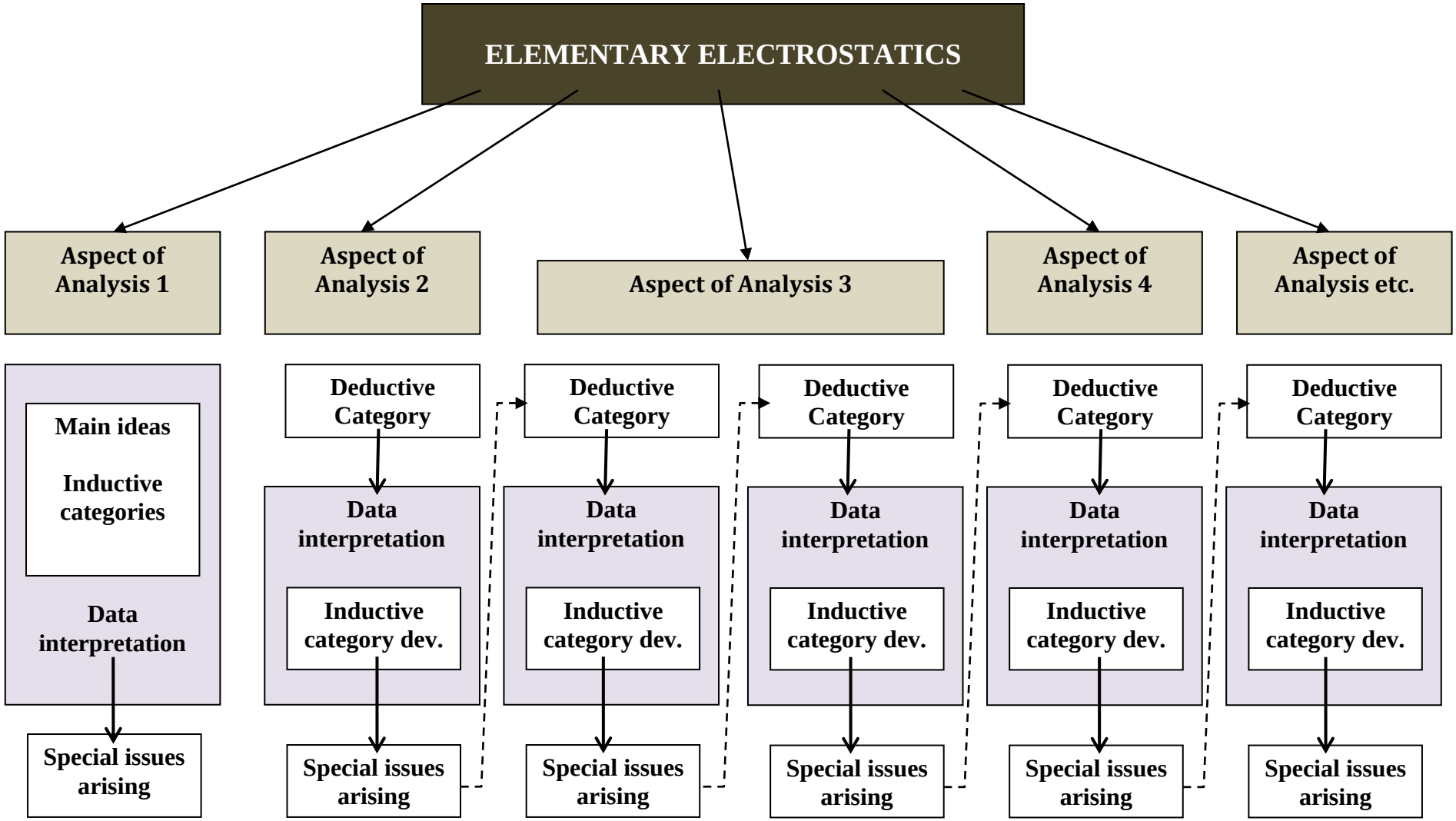
Although tedious and time consuming, this approach was found to be of particular value. The step-by-step approach would often enable the researcher to pick-up implicit understandings or misunderstandings of authors which would affect their handling of content elsewhere in the texts. Hence, the approach allowed for predictions of problems further on in the texts or even other topics, and permitted the tracing of unscientific notions to their roots. Moreover, the approach exposed pivotal points, "critical details" according to Viennot (2008), points that often escape attention and yet they are crucial for intellectual coherence, essential for conceptual understanding.

Figure 4.4 Basic 'cell' of analysis and interpretation



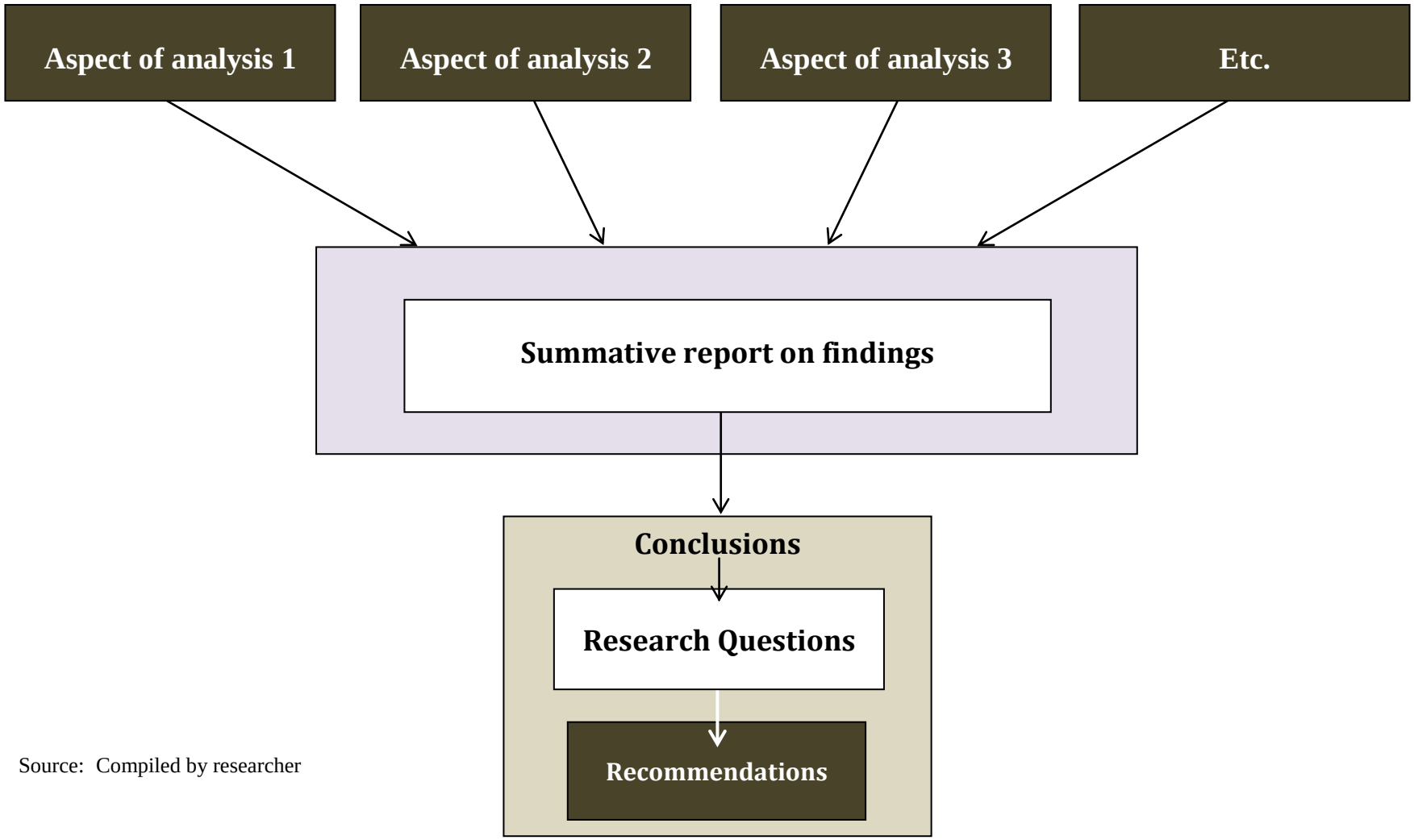
Source: Compiled by researcher

Figure 4.5 SCHEMA OF WORK A: Data analysis



Source: Compiled by researcher

Figure 4.6 SCHEMA OF WORK B: Summative reporting



Source: Compiled by researcher

CHAPTER 5

DATA ANALYSIS AND INTERPRETATION

5.1 Introduction to the analysis of Elementary Electrostatics

5.1.1 Introduction

> Unlike mechanics where processes can be directly visualised, in electricity everything seen is actually an indirect manifestation of some hidden microscopic process. (in Literature Review, based on Thacker *et al*., 1999)

Considering that to young school learners the basic phenomena of electricity are neither as familiar nor as obvious as those of mechanics, it becomes imperative to place large emphasis on such phenomena. Thus, it makes sense that instruction of electricity to novice learners should start at the very beginning with simple but careful observations of the behaviour of charged objects and the charging process. This approach is indeed endorsed by South African curricula. Such initial endeavour should build a practical know-how that would lead to the development of an empirical / descriptive model in terms of *charge* and *force* – let us call it the 'macro-charge' model – with no need for reference to *atoms* and *electrons*. It would be the initial stage of introduction to electricity (an analogous approach would apply to magnetic phenomena). Besides, a substantial theory of electricity did exist by early nineteenth century when little was known about the atom and before the introduction of electrons (e.g. Furió *et al.*, 2004). The expression "charge/electricity flows", the convention "positive" and "negative", the distinction of materials as conductive or non-conductive in terms of "allowing" or "not allowing" flow of charge, the view of the charge as something fluid called *electricity*, originate in this pre-electron (and pre-field) era. For young learners, the step-by-step built up of a macro-charge model via simple practical experiences could provide invaluable first insight on the construction of scientific knowledge and a first taste of

scientific reasoning (just a realisation for the need of careful, systematic reasoning would be invaluable). This, provided that learners have been explicitly alerted and motivated and know that they aim towards developing a basic model and ultimately a theory of electricity. Learners would certainly appreciate a justification and a purpose for what they are expected to engage with.

The macro-charge model however, although it allows for certain predictions, tells us nothing about the nature of charge and the process of charging. It relies on descriptive terms (e.g. charge, charging, discharging, neutral, etc.) and observed patterns of behaviour, thus leaving many questions unanswered. If we are to continue building a theory of electricity, sooner or later we have to employ imagination:

> Little can be read straight off the face of reality… We need to imagine how things are 'inside' or 'behind' the surface and tell the story… of how some imagined entities have acted to produce the phenomenon to be explained.
>
> (adapted from Ogborn, 2008, as appears in the Literature Review).

It follows that for the next stage of learning electricity more contemporary views of the atom can be employed and learners should be guided to explain observations of electrostatics phenomena by establishing micro-macro connections. Taking into account that protons and electrons are considered basic charged particles of matter, it is readily justifiable that all previous observations ought to be explained in terms of protons and electrons and the freedoms they are afforded within the atom. It is at this stage where the concept of 'charge' may be understood as an inherent property of matter, and questions such as 'why do charged objects attract uncharged?', 'how can charge be transferred?' and 'why do conductors and insulators behave differently?' can be answered. Whereas introduction of elementary micro-macro connections in electrostatics may or may not have been initiated in junior high (or

earlier), depending on the context of each school and curriculum, in senior secondary (FET) level such connections ought to be prevalent and this ought to be discernible in textbooks. Or else, how can we establish the basis for a meaningful theory of electricity and soon after of electromagnetism if seemingly disparate concepts and behaviours are not unified by encountering them at the atomic level where they originate?

5.1.2 Electrostatics in the textbooks

In light of the above, the Electrostatics sections in the available FET textbooks were systematically analysed. Data were collected using a primarily qualitative content analysis procedure. The details of the textbooks addressing Electrostatics, 17 in total, are listed in Appendix A. The same textbooks are also listed in Table 5.1 below, but in the code form in which they will be quoted in this analysis. Textbooks are listed under the curricula they correspond to. In NATED, the entire Electrostatics is assigned to Standard 10 (equivalent to grade 12). In NCS and CAPS, electrostatics is divided among grades 10 and 11.

Table 5.1 Codes of Physical Sciences textbooks addressing *Electrostatics*

NATED	NCS	CAPS
SPS (1987)		PLATC (2011) PLAT11C (2012)
SS (1989)	OXFN* (2008) OXF11N (2009)	OXFC* (2011) OXF11C (2012)
BJ (1987)	SIYAN (2010) SIYA11N (undated)	SIYAC (undated) SIYA11C (undated)
	S&MN (2005) S&M11N (2006)	S&MC (2011) S&M11C (2012)

Notes: * The letter N denotes an NCS textbook and conversely C denotes a CAPS textbook.
The full names of the textbooks can be found in Appendix A.

It is the part of Electrostatics designated by NCS and CAPS to grade 10 that will primarily concern us in this chapter, and which we refer to as "Elementary Electrostatics". It deals with the origins and nature of the charge and explains how charge transfers from object to object. This is the part considered by the same curricula to be a *qualitative* look at electrostatics (e.g. DoE, 2006, p.11), as opposed to the *quantitative* look that follows in grade 11. However, we would favour the notion that elementary Electrostatics concerns the benchmarks for a sound understanding of Electricity through its origins within the atom. We consider this part of electrostatics to be of paramount importance for further understanding of electromagnetism as a coherent whole. Hence in what follows, particular care has been taken in its analysis, in terms of attention to detail.

5.1.3 A note on the meaning of "Electricity"

Scientific language is famed for its preciseness, conciseness and consistency. Preciseness and consistency in particular should be strictly adhered to in science instruction to young and novice learners, as concepts used carelessly can only cause confusion and multiple and unwanted interpretations. But in Electromagnetism discourse and already from the onset of its instruction we are faced with practices that seem to contradict the above qualities of scientific language. Concerning the term *electricity*, we talk about current electricity, static electricity, electricity can kill you, paying for electricity, electricity in nature, electricity in wires, studying electricity… So what is the true meaning of electricity?

The term *electricity* has been around for centuries and during its history it has acquired a multitude of meanings. In the 19th century, the word was being used by most scientists to mean electric *charge* (Beaty, 1996a & 1999). But by the end of the 19th century, perhaps because of the advent of electrical companies selling 'electricity', the word acquired the extra

meaning of *energy* and *power*. Or perhaps because these were the times of the unification of different sciences via the concept of energy to the single discipline we now call physics – if the caloric fluid was an energy transfer, so perhaps was the electric fluid. During the course of the 20th century electricity acquired further meanings in everyday language. In scientific practice nowadays, the word 'electricity' is used predominantly to mean a *field of study* or groups of electrical *phenomena*, but in casual discourse other meanings are also prevalent, such as *force*, *current* and *potential difference*. Some are found in abundance in primary school textbooks and not only. One could argue that the word electricity has lost its meaning and perhaps it should be replaced by something more suggestive, 'Electricism' for example, analogous to 'Magnetism' or 'Electrics' analogous to 'Mechanics'. But the word *electricity* is so much ingrained in the (English) language of science that most possibly is here to stay, much like the word *heat* which is still in use though it has been branded obsolete and unscientific (e.g. Driver *et al*., 1994; Summers, 1983).

5.2 ASPECT OF ANALYSIS 1: On Authors' Perceptions of Electrostatics and Static Electricity

5.2.1 Introduction

In scientific discourse "electrostatics" and "static electricity" are both in use, though "electrostatics" is by far the preferred term. "Static electricity" is usually met when denoting effects exhibited by charged objects. For example, hair standing on end after combing is (an effect of) static electricity. No particular reason for the preference of electrostatics over static electricity was found in the literature and one has to speculate. Static electricity is certainly an older term, from the times when the nature of the charge and the concept of the field were unknown and when it meant static charge. Perhaps as our knowledge of electromagnetism evolved by the end of the 19th century, the term Electrostatics has been seen more fitting and compatible with the terms Magnetostatics and Electrodynamics. Electrostatics did not concern just charges, but charges and electric fields. Regarding our SA school curricula, NATED is the last curriculum referring to "Static Electricity", and it does so as a heading under the module Electrostatics. This implies that static electricity is subordinate to electrostatics and so it has a different meaning. NCS and CAPS have omitted the term.

To the effect of the said aspect of analysis, data from the textbooks listed in Table 5.1, have been examined. Categorisation Tables (CT) 1 and 2 have been developed using an inductive procedure and summarise perceptions of the authors on Electrostatics and Static Electricity. Most grade 10 textbooks begin the chapter by offering a 'definition' of Electrostatics and in most NCS and CAPS textbooks this is the only introduction to the chapter. The S&MN

(2005) and S&MC (2011) textbooks disregard Electrostatics and begin by elaborating on Static Electricity, which is in dissonance with the NCS and CAPS curricula. BJ (1987) does not offer any comment on either terms, but then in NATED, elementary electrostatics is supposed to be presented as a revision from standard 7, and BJ (1987) does so by means of a set of questions for learners to answer.

Categorisation Table 1 CATEGORY: Perceptions of *Electrostatics*

Electrostatics is: (Definitions/perceptions)	**Examples**	**Gr/Std 10 Textbooks *** (& page No)
The study of charges at rest.	**Electrostatics** is the branch of physics which deals with charges at rest. *SPS (1987, p68)* **Electrostatics** is the study of **charges** that are not moving. *PLATC (2011, p134)*	**SPS** (1987, p68) **PLATC** (2011, p134) **SIYAN** (2010, p305) **SIYAC** (undated, p254)
▪ The study of static electricity ▪ The study of effects charges at rest have on each other ▪ The study of forces between charges at rest.	**Electrostatics** is the study of static electricity. We try to find out the effects that charges at rest have on each other. The study of the forces between stationary (static) electrical charges is known as electrostatics.	**SS** (1989, p52-53)
A phenomenon	…the phenomenon of electrostatics has limited applications…	**SS** (1989, p74)
The study of interactions between charges <u>mainly</u> at rest	E**lectrostatics** (or static electricity) has to do with the interactions of **charges** that are mainly stationary.	**OXFN** (2008, p60) **OXFC** (2011, p154)
A theory?	In this chapter we will look at some of the basic principles of electrostatics as well as the principle of conservation of charge.	**SIYAC** (undated, p254)

* BJ (1987) does not include any comments

Categorisation Table 2 CATEGORY: Perceptions of *Static Electricity*

Static electricity is: (Definitions/perceptions)	**Examples**	**Gr/Std 10 Textbooks** (and page No)
Phenomenon, charge? unclear	Static electricity occurs naturally, especially in dry weather. For example, when you put on a jersey made from synthetic wool, it crackles. If you put on the jersey in the dark, you can sometimes see sparks. This is because the jersey has become electrically charged, and electricity sparks and crackles when it discharges.	**S&MN** (2005, p90) **S&MC** (2011, p190)
Charge acquired by rubbing	(charge acquired by rubbing)…we now call this charge static (stationary) electricity.	**S&MN** (2005, p91) **S&MC** (2011, p190)
Same as electrostatics	E**lectrostatics** (or static electricity) has to do….	**OXFN** (2008, p60) **OXFC** (2011, p154)
Electrostatic electricity is electricity at rest	Electrostatic electricity is electricity at rest. However, as we have seen with lightning, the charge can build up to such an extent that there is a sudden discharge. This is very dangerous….	**OXFN** (2008, p65)
Electricity originating from friction	Electricity which originates as a result of friction is called **static electricity**.	**SPS** (1987, p68) **SS** (1989, p52)
Electricity at rest	**Static electricity** is electricity at rest. In other words, there is no movement of electric charges.	**SS** (1989, p53)
Build-up of electricity that can discharge and flow Implies electricity from friction	…The build-up of static electricity as you walk over artificial fibres discharges itself as soon as you touch a good conductor and the shock that you feel is the flow of electricity between your body and the conductor….Lightning is a discharge of static electricity built up…some substances can be charged by friction…So in this chapter we look at electricity at rest…	**SS** (1989, p52)

5.2.2 Interpretation of data in CT1 & 2 and issues arising

5.2.2.1 Vagueness, impreciseness and inconsistency

Categorisation Table 1 (CT1) reveals that all textbooks present Electrostatics as a branch of science that studies charge at rest or something (effects, forces…) relating to charge at rest. SIYAC in addition refers to electrostatics as consisting of principles, though the principle of conservation of charge is not one of them: "we will look at some of the basic principles of electrostatics as well as the principle of conservation of charge" (SIYAC, undated, p.254). In all textbooks there is vagueness and ambiguity as to what exactly is the subject of study of electrostatics and variations of perception not only appear in different textbooks but also within a textbook itself (SS offers three takes on electrostatics). Because of this vagueness of subject, the attention of the reader is drawn to the 'staticness' of charge which thus becomes a major characteristic of electrostatics, "Electrostatics is the study of charges that are not moving" (PLATC, 2011, p.134). The prominence of the staticness of charge is reinforced by textbooks referring to Static Electricity. In this case, CT2 shows that for the majority of authors Static Electricity means 'static charge' rather than a certain class of effects. In OXFN (2008) we find two takes on Static Electricity, one as being the same as Electrostatics (i.e. branch of science) and the other as being static charge. We also note the tendency of authors to replace the scientific term *charge* with the ambiguous term 'electricity'. Such practices do not reflect the preciseness and consistency of science and confuse the learners who are driven to produce own interpretations.

Thus overall, recounting CT1 and CT2, the first ideas that texts communicate to the learners are something along the lines that "static electricity is a special type of electricity where static

charge is produced by rubbing/friction. Charges at rest exhibit certain effects and their study is called electrostatics".

5.2.2.2 Static electricity is restricted to charging by rubbing

As CT2 reveals, the authors of S&MN (2005) and S&MC (2011), and of SPS (1987) and SS (1989) present static electricity as static charge originating from *rubbing* or *friction*, an idea which is sustained throughout corresponding chapters. Later on, under "Distinction between conductors and insulators" we meet this idea again in two more CAPS textbooks, PLATC (2011) and OXFC (2011) (refer to CT5). According to Furió *et al.* (2004), this pre-Newtonian idea originates in the turn of the 17th century and is associated with William Gilbert, who proposed the first (and we can now say primitive) classification of materials into *electric* and *non-electric* (e.g. metals) based on whether they became charged/electrified when rubbed. Already by mid-18th century this distinction of materials was no longer in favour among scientists, yet it appears that this is not the case with South African textbooks of the 21st century. Furió *et al.* (2004) found that students aged 17 to 21 interpreted electrostatic phenomena using elements of pre-Newtonian ideas. The textbook analysis so far suggests that this might be the case with textbook authors as well.

Considering that today's learners are exposed to further electrical processes at school, other than rubbing, the 'restriction' of static electricity being associated with only rubbing/friction invites unwanted understandings: It may imply that objects charged by different means do not exhibit electrostatic effects, or that they have a different type of charge or that electrostatics concerns only insulators, or that objects can only be charged by rubbing, etc. It may also imply that rubbing and friction *produce* charge rather than enabling separation or redistribution of existing charge between two objects, which conflicts with the law of

conservation of charge. Some textbooks (SS, 1989 and OXFN, 2008) even refer to a charge *build-up* followed by a sudden *discharge*, which gives an even stronger impression of creation and disappearance of charge. Presentations of the processes of charging will be revisited in detail later on. First indications of a transition from charging 'by friction' to charging 'by rubbing' also becomes evident as we move on from NATED 550 to NCS and CAPS textbooks.

5.2.2.3 Staticness of charge

For today's scientist, 'static charge' means *excess* charge, whether it moves or not. It is the excess or unbalanced charge on objects that causes certain effects. The expression 'static charge' may be seen as conformity rather than something to be taken literally. However, textbooks communicate the idea that 'static charge' is charge at rest and as a consequence of this state, the "staticness" (Beaty, 1998), it exhibits certain phenomena. This is a misconception. None of the authors has referred to charge *imbalance* or charge *separation* or something reminiscent to justify the occurrence of electrostatics phenomena. OXFC (2011) and SIYAC (undated) textbooks do mention *net* charge within the chapter but very inconspicuously and inconsistently (discussed in the analysis of Aspect 2 later on). All textbooks refer to 'static charge' or 'static electricity' as the cause of electrostatics phenomena, without taking care to stress that this is in fact excess or unbalanced charge on objects. The prominence and erroneous role given to the notion of staticness of charge is not to be taken lightly because for learners it is a source of multiple, unwanted interpretations or understandings. Are we to understand that if stationary charge starts to move all effects disappear? Are we to understand that a piece of wire, the mobile charge of which can be modelled as stationary, exhibits electrostatic effects? Is it possible for a current carrying wire to exhibit electrostatic effects? If we take the staticness of charge for granted we end up with

the wrong answer to all such questions. A current carrying wire can certainly exhibit electrostatic effects due to excess charge. It is an unfortunate tradition that we call excess charge 'static charge' and authors and curriculum developers need to become aware of it. Only the OXFN (2008) and OXFC (2011) textbooks have made some allowance for movement by including 'mainly': "**electrostatics** (or static electricity) has to do with the interactions of **charges** that are mainly stationary" (OXFC, 2011, p.154). There is no explanation for this allowance, but it is presumably to justify sparks and lightning, but which is left to the learners to figure out.

5.2.2.4 Static versus current electricity

A further possible erroneous message that may be promoted and can be attributed to the staticness of charge is that 'static electricity' and 'current electricity' are two opposed fields of study (Beaty, 1998). This notion further leads to the belief that static electricity is of little use, unlike current electricity: "In the previous chapter we studied electricity at rest, now we study electricity on the move!... As we saw…the phenomenon of electrostatics has limited applications…" (SS, 1989, p.74). Little such authors are aware of more contemporary ideas where 'static' charge on the wires actually causes the electric current (e.g. Sherwood & Chabay, 1999; Preyer, 2000). Indeed none of the authors who have included applications of electrostatics have included something reminiscent of a link between electrostatics and electric currents or electronics (NCS). Photocopying machines and smoke precipitators, presented as staple electrostatics applications in NCS textbooks, do not have the same appeal and gravity as generators or the national grid or information technology. Hence, electrostatics appears isolated from the rest of electromagnetism, a field that studies annoying and sometimes spectacular effects, but of no much consequence to technological advancements or to the rest of Electricity and Magnetism for that matter. One may argue that it is easier to

describe an electrostatic precipitator than an FET transistor to novice learners. This may be, but there could be mention to the plethora of uses electrostatics finds in electronics for example, much as there is mention to sparks and crackles and discharge that rarely or never enjoy an explanation either. Anyway, one cannot help but reflect on the damage the unfortunate choice of a trivial descriptive word, such as 'static', might have caused to the understanding of generations of educators and authors. It is easy to perceive 'static charge' as the opposite of 'moving charge'. But could we perceive 'excess charge' as the opposite of 'moving charge'? Surely not asserts Beaty (1998). In this light, the removal of the term 'static electricity' from NCS and CAPS curricula should be seen as a step to the right direction. Yet most authors of NCS and CAPS textbooks have not taken notice.

5.2.2.5 Insulator electricity

Moreover, learners may be very well prompted to perceive Electrostatics as concerning primarily insulators, as opposed to Current Electricity which deals with conductors; one more source of contrast between the two fields. References in the texts that static charge originates in rubbing and friction (which by itself is a double misconception), accompanied by examples restricted to insulators, communicates exactly that, i.e. Static Electricity is 'insulator electricity'. Curricula too encourage this false perception. They downplay (CAPS) or ignore (NCS and NATED) mechanisms of charge transfer other than rubbing, and even polarisation is confined to insulators (NCS and CAPS). The reasons for this, almost deliberate domination of Elementary Electrostatics by insulators, needs further research.

5.2.2.6 Pseudo-science

The example of 'static electricity' given in the S&M textbooks in CT2, is quite absurd, but not at first glance: "Static electricity occurs naturally, especially in dry weather. For example,

when you put on a jersey made from synthetic wool, it crackles. If you put on the jersey in the dark, you can sometimes see sparks. This is because the jersey has become electrically charged, and electricity sparks and crackles when it discharges." (e.g. S&MC, 2011, p.190). Are we to understand that in dry weather objects become 'naturally' charged and when we touch them they spark and crackle? Does charge appear out of the blue in dry weather? Is an object charged by other means unnaturally charged? Is static electricity, whatever that is, naturally occurring as opposed to some other electricity that is not? And what is static electricity, is it an 'effect' that occurs or is it 'charge' that crackles? Neither an effect nor a charge could spark or crackle or discharge. And anybody who owns a jersey knows that sparks and crackles are observed upon taking the jersey off not upon putting it on. Both the body and the jersey are involved in the electrification of the jersey, which occurs upon separation of the two surfaces. As far as the effect of dry or humid 'weather' is concerned, several textbooks offer warnings on ability to charge without attempting an explanation, S&M being no exception.

Such careless narratives are not rare in textbooks (much could be said for the narrative in the last row of CT2 for example) and this particular excerpt is not handpicked as a unique example of author ineptitude. There is another reason for concern. An expert reader skimming through the text, be it a science educator, a physicist or a person in a textbook evaluation committee, will find all ingredients for a good example in it, jersey, sparks, static electricity… plus everyday experience and relevance. To the expert, these ingredients are already familiar and linked coherently in his/her mind, there is no need to delve into the text to understand the intended message. So irregularities may go easily unnoticed. A novice learner reading the text hastily may also pick up the message that sparks and crackles and jerseys have to do with static electricity and can get full marks with the sparkling jersey if the

teacher asks for an example of static electricity. But a novice learner who is a thinker, who seeks rational links and reasons in a text, who likes to probe, will end up utterly perplexed and disappointed. This learner might not recognise the text as unfortunate and incoherent, a textbook is an authoritative document after all. The learner is then left with the options that either science is hard or that s/he is incompetent, both of which are erroneous. Low self-esteem does not take us places. Is it possible that such learners have been driven out of science? Do mediocre science texts filter out learners who might otherwise have excelled? Are learners encouraged to study superficially in order to cope with unclear texts? A textbook should be written with such attention as to endure fine grain analysis. No research has been found on the effects of intellectual satisfaction on learners or lack thereof and such research would be worthwhile.

5.2.2.7 Textbook electrostatics

A most conspicuous absence from CT1 is the absence of the electric field. Since in NCS and CAPS the electric field is introduced in grade 11, we visited the opening pages to Electrostatics of the corresponding grade 11 textbooks to ascertain whether authors had revisited their 'definition' of electrostatics or whether they had added some extra comment to include the concept of the field. However, no such reference was found in any of the books. Below are examples of introductions from CAPS (same in NCS) grade 11 textbooks:

1) Forced introduction: "In grade 10, you learnt about the forces between charges. In this chapter you will learn exactly how to determine this force and about a basic law of electrostatics" (SIYA11C, undated, p318). PLAT11C (2012, p188) presents a similar introduction. A meaningful and purposeful introduction requires a lot of thought without necessarily being lengthy. These introductions do not fall in this category. Possibly authors were obligated to add a quick introduction, upon complains from some reviewer.

2) Attempt to bring in relevance: “ELECTROSTATICS: The forces of electric charges on each other explain how atoms and molecules are held in place. We need the ability to measure these forces and their effects before we can use them” (OXF11C, 2012, p203). Electrostatics is not about atoms and molecules, much as Mechanics is not about cars and bicycles. Nevertheless, the excerpt implies that electrostatics revolves around forces and their ‘measurement’. The last sentence is another example of an imprecise and thoughtless expression. Does Coulomb’s law or other relevant law give us ‘the ability to measure’ these forces and their effects? Is it a measuring device? Do we then take these forces and effects to use them? Are forces detachable and reusable once measured?

3) The NATED influence: “This module focuses on electric charge – both static, on a charged object, and moving, to form an electric current. It discusses how an electric current can affect its surroundings” (Introduction to Electricity and Magnetism, S&M11C, 2012, p.204). Although this excerpt does not address electrostatics in particular, it indicates the notion of the author that charge and to a lesser extent current are the primary concepts in electromagnetism. The last sentence is reminiscent of the magnetic effect of the electric current in NATED. However, the magnetic field is not just an ‘effect’ of the current. In classical electromagnetism it is considered a real entity that can exist without the need for a current - a changing electric field produces a changing magnetic field. Furthermore the expression delineates static and moving charges as producing dichotomous phenomena and it may also imply that the moving charge of the ‘electric current’ is excess charge much as the static charge in the expression is.

In the OXF11N (2009) and OXF11C (2012) textbooks, “Electrostatics and Coulomb’s law” and “Electric fields” appear as separate chapters signalling that electric fields are not part of electrostatics. The rest of the textbooks abide with the curricula by including the fields under

electrostatics, but their authors do not seem convinced. They all advocate the forces between charges and their calculation as the highpoint of electrostatics and by forces they mean implicitly or explicitly Coulomb forces.

It becomes evident that for textbook authors, electrostatics begins with a selection of effects caused by forces between static charges, and culminates with the determination of these forces via Coulomb's law. As far as the opening pages and introductions to electrostatics (or any other reference to electrostatics) are concerned, we are greeted with descriptions where not only are the main ideas of electrostatics missing, but its main ingredients, charge and electric field, are also abridged.

5.3 ASPECT OF ANALYSIS 2: Charge and its origins

5.3.1 Introduction: on macro-micro connections

In line with the introduction to this chapter, micro-macro connections should be expected to be a dominant feature of electricity in FET physical sciences textbooks. I aimed to determine if and how authors have attempted to explain observed electrostatics phenomena by establishing such connections. Hence, this aspect of analysis targets the analysis of the relevant textbooks in terms of how authors link previously acquired knowledge of the atom and associated theoretical models to explain aspects and processes in Elementary Electrostatics. In order to facilitate collection of data for this purpose, Table 5.2 was compiled to provide a rational plan for the development of a theoretically grounded system of categories and their 'definitions' (descriptors).

The right hand column in Table 5.2, labelled "MACRO", lists in summary descriptive terms and empirical inferences or 'macro-assumptions' that could have been collected by learners during their school carrier (in primary and junior high), and/or which may be re-introduced in grade 10. Such empirical inferences can be collected through a variety of simple practical experiences with electrostatics phenomena and careful reasoning. Such aspects of electrostatics are expected to feature in an average FET textbook at the start of Electricity and Magnetism. Items on the list include observed differences in behaviour of materials in terms of their electric properties, as well as the processes of charging and discharging, i.e. the transfer of charge to and fro objects. The column labelled "MICRO", lists theoretical considerations that could be employed to explain the corresponding macro-assumptions in the

table, thus linking macro to micro. Items on the list are based on theoretical models featuring as such implicitly or explicitly in the relevant curricula, predominantly under sections of Chemistry or Matter and Materials. Hence the left-hand column labelled "LINKS" lists headings in curricula or chapters/units in textbooks where items on the "MICRO" list may be located.

In NATED and CAPS, nearly all items listed under "LINKS" precede the section of Electrostatics. In NATED they are part of Std 9. In CAPS they are part of grade 10, but before Electricity and Magnetism. We would expect authors to have taken advantage of this more or less familiar background to learners in the writing of the chapter Electrostatics. In NCS (DoE, 2003 and DoE, 2006), the six areas of physical sciences were listed starting from the three physics topics, followed by Matter and Materials, an integrated area, and ending with two chemistry areas. The order of listing was not supposed to be a prescribed order for teaching, or in our case, the order of chapters in textbooks. It was just a list (one had to list the topics somehow) where Matter and Materials was to be perceived as a central area where physics and chemistry would link, as part of an integrated approach adopted by NCS. Educators were given the freedom to change the order of topics as they saw fit depending on their choice of context or thread. Unfortunately in the available textbooks, authors (or most possibly publishers), did not take advantage of this freedom or were unaware of it, though it was clearly stated in the curriculum. The chapters in all inspected NCS textbooks seem to follow the mock order appearing in NCS. We would expect this to have implications in the form of restrictions in the writing of the chapter Electrostatics for Grade 10 (i.e. Elementary Electrostatics).

Table 5.2 Macro-micro connections in Elementary Electrostatics – OVERVIEW

Source: Compiled by researcher, by consulting the NCS (DoE, 2006) and CAPS (DoBE, 2011) curricula

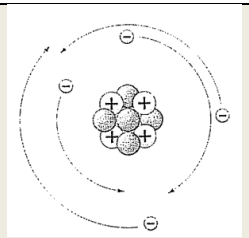
LINKS			MICRO (theoretical assumptions and inferences)	MACRO-MICRO CONNECTION (EXPLANATION)	MACRO (empirical assumptions and inferences)
Models of the Atom Atomic structure	Origins of electricity within the atom	Charge as property	Charge is an Inherent property of certain particles. Charge does not exist without matter.	1 →	Charge (has no meaning, is *something* that appears on rubbed objects)
		Charge quantisation	Elementary unit of charge, *e*. Protons have charge +*e*, electrons –*e*.	2 →	Two types of charge: positive and negative
			More protons than electrons More electrons than protons Equal number of protons and electrons	3 →	Positively charged object has been given +ve charge Negatively charged object has been given –ve charge Neutral object (has no charge or has equal quantities of +ve and –ve charge)
			(will be also associated to the electric field)	Empirical inference	Forces: Like repel, unlike attract
Conductors, semiconductors, insulators Periodic table, ionisation, ions, valence electrons, bonds, metallic bond model, sea of electrons	Materials with different electric properties	Conductors – insulators	Conductors contain mobile charge carriers: Free electrons, +ve, –ve ions, depending on type. Conductors can be ionic or metallic	4 →	Conductors allow charge to move Conductors can be solid liquid or gases,
			Insulators do not contain mobile charge carriers. Outer electrons relatively strongly bound	5 →	Insulators do not allow charge to move or charge stays in one place
Electronegativity, electron affinity Free electrons or ions	Transfer of charge and charge conservation	Charging	Good contact & separation → breaking of bonds (even poor) contact in conductors → conduction/flow of mobile charge carriers , charge distribution	6 →	Charging requires contact. Charging by rubbing (triboelectric charging) Conductors can be charged by touching other charged conductors (charging by conduction)
Metallic bond, sea of electrons in metals electron cloud in atom		Polarisation	Polarisation and polarisation force: In metals: Slight shift of sea of electrons In insulators: Slight shift of electron cloud, dipole, polar molecules	7 →	A charged object attracts uncharged objects
Ionisation, ions, electrolytes, de-excitation of atoms, electric field and potentials (insulator breakdown, dielectrics and capacitors in NCS)		Discharging	Sparks & Lightning: Ionisation of air / gases Human body & earth are ionic conductors & reservoirs of charge. Grounding. Charging by induction Humid days: Conductive liquid layer on objects (e.g. *dirty* water as ionic conductor) Discharging also requires contact	8 →	Objects discharge in humid conditions (or cannot be charged), grounding and sparks discharge objects

It must be noted that none of the three curricula NATED, NCS or CAPS, calls explicitly for macro-micro connections. Regarding the NATED curriculum, Elementary Electrostatics is not addressed at secondary school level. It only appears as a brief summary of aspects covered at junior high, placed prior to the introduction to Coulomb's law and electric field in standard 10, where it is labelled as "Static Electricity". Upon examining the NATED for lower standards, we found that under "Electrostatics" there was reference to the structure of the atom as consisting of a "positive nucleus surrounded by negative electrons" and that "substances become electrically charged by the addition or removal of electrons" (DoE&C, 1993, p.8). However this background, apart from misleading, is hardly enough to explain the charging or discharging of objects and the different electric properties of materials. Yet, this lower level NATED contains more references to microscopic considerations than the secondary level NCS and CAPS. CAPS grade 10 begins the topic by: "Know that all materials contain positive charges (protons) and negative charges (electrons)" (DoE, 2011, p.40). There are no other micro references. It is ironic that only NATED-Std 7 refers to the term "model" in the context of the atom as being an extension of the particle model of matter.

Categorisation Table 3 CATEGORY: Introduction to atomic model

Theoretically grounded 'definitions'	SPS		BJ		SS		PLATC		SIYAN	SIYAC		S&MN	S&MC		OXFN	OXFC	
Attempt to introduce atomic model or links to relevant chapters					✓	Vague ref. to previous knowledge. See (1)	✓	Late link to earlier chapter, see (7)			No intro and no links to atom, see (4)	✓	✓	Too brief, one line. No link to unit 3 "The atom", see (2)	✓	✓	No link to Module 1 unit 6 "Structure of atom". See (3)
Charge is an **inherent property** of electrons / protons (of matter)																✓	In margin with no prominence See (8)
The charge of protons and electrons is numerically **exactly equal** (careful experiments have found no difference)							✓	End of chapter. Protons and electrons are introduced late and not used to explain phenomena					✓	Implied (see 12) End of chapter	✓	✓	In intro to atom See (3)
The atomic-level unit of charge is the **fundamental or elementary unit of charge**, e = 1,6 x 10^{-19} C. Charge of electron = $-e$ Charge of proton = e	✓	Mentions **elementary charge** but only linked to electron.	✓	Wrong reasoning. **Elementary charge** only linked to electron. See (5)					✓	✓	In terms of electron charge. See (9)		✓	Elementary charge = charge of electron, but does refer to protons see (12)			
CHARGE QUANTIZATION: An object's charge is an integer multiple of e, the elementary unit of charge.							✓	In terms of electron charge. See (7)	✓	✓	Only linked to electron		✓	HOS: Millikan see (10)		✓	In terms of electron charge. See (6) HOS: Millikan, see (11)
Electrons are negative following Franklin's **convention**.									✓		NCS, 309: By convention, electrons carry – ve and protons +ve charge.						

	EXERPTS IN TEXTBOOKS	COMMENTS & NOTES
1)	SS (1989), p53 (Revision): NOTE: You will remember that all substances are made up of atoms. The charged particles in atoms are positive protons and negative electrons. The protons are in the nucleus of the atom and are not affected by rubbing the substances together. However, electrons form the outermost part of the atoms.	Misunderstanding of the process of charging and transfer of electrons. Suggests that protons are of no consequence to the charging of objects, unlike the outermost electrons.
2)	S&MC (2011), p190: Materials are made of atoms, and atoms contain negative electrons and positive protons. S&MN (2005), p91: Atoms contain electrons and protons.	No model of atom mentioned

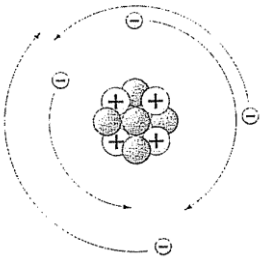
3)	OXFC (2011), p154 and nearly the same in OXFN (2008), p60: All materials consist of very small particles called atoms. At the centre of each atom is a nucleus that consists of neutrons that have no charge and protons that carry a positive charge. Outside the nucleus are much smaller particles called electrons. They carry a negative charge that is the same size as the positive charge of the protons. All materials contain charges. Any object consists of enormous numbers of atoms and has even more charge-carrying protons and electrons…. Caption of Figure: An atom has a nucleus made up of positive protons and uncharged neutrons. Moving round the nucleus are electrons carrying a negative charge… 	Inconsistency of science. No link to atomic model in M&M. Introduces a new model, but what model is this in the figure and why chosen? Bohr's? Yet, electrons seem to orbit in random orbits, some clockwise, some anticlockwise. This model was not included in Matter & Materials under "models of the atom", where the last model was about orbitals with no picture of the atom. The message sent is that physicists use different atomic models than chemists.
4)	SIYAC (undated), p254 and same in SIYAN (2010), p305: All objects surrounding us (including people!) contain large amounts of electric charge. There are two types of electric charge: **positive** charge and **negative** charge…..positive charge is carried by the protons in material and negative charge by electrons.	No intro to atom and no link to previous chapters. First part is MACRO, but refers to *contain*….Why do objects contain charge?
5)	BJ (1987), p68: Since the charge on a charged object originates from an excess or deficiency of electrons, it follows that the charge of smallest magnitude is the charge on only one electron….this is known as the elementary charge.	The argument should have been the other way round: Since matter consists of atoms that contain the basic charged particles of matter, protons and electrons, both with a charge numerically equal to the elementary charge, it follows that the charge of any charged object should be an integer multiple of the elementary charge.
6)	OXFC (2011), p160: **Principle of the quantisation of charge**: Every charge in the universe is an integer multiple of the electron charge. Stated as an equation: Charge $Q = nq_e$, where n is an integer and $q_e = 1{,}6x10^{-19}$ C. The charge carried by an electron is $– 1{,}6x10^{-19}$ C, and a proton is $+1{,}6x10^{-19}$ C.	No ref to elementary charge and confusing.
7)	PLATC (2011), p139: Quantisation of charge: You learned in Chapter 3 that there are two types of charged particles in an atom, positively charged protons and negatively charged electrons. The magnitude (size) of the charge is the same on a proton and an electron, only the sign is different…. Since charging always involves adding or removing electrons, the charge on an object is always a multiple of the electron charge, *e*.	a) No ref to elementary charge, but is the only book referring explicitly to the equality of proton-electron charge b) Charging does not <u>always</u> involve adding or removing electrons. Positive and negative ions can be mobile. The type of charge carrier depends on the type of conductor.
8)	OXFC (2011), p154: **Charge**: property of some particles that gives rise to electrical phenomena. **Net charge**: sum of the charges	Glossary-type definitions in the margin under 'New words". Unclear and vague and of no prominence. The first one is of no consequence to the chapter.
9)	SIYAC (undated), p262 & SIYAN (2010), p309: The basic unit of charge, called the elementary charge, *e*, is the amount of charge carried by one electron.	Both protons & electrons have charge equal to this unit. This underpins that protons and electrons have numerically equal charge, which is not mentioned anywhere.
10)	S&M (2011), p195: …Millikan managed to measure the charge on the oil droplets and found that they always had a charge of $1{,}6 \times 10^{-19}$ C or multiples of this number. He deduced that the smallest charge possible, the elementary charge, must be the charge of one electron…	HOS: Inaccurate , rhetoric of conclusions, straightforward, no reference to controversies. ….He "deduced"…?! (Niaz, 2000 b)
11)	OXFC (2011), p159: In 1911, Robert Millikan carried out an experiment in which he found that electric charges are always a multiple of $1{,}6 \times 10^{-19}$ C.	HOS: Inaccurate , rhetoric of conclusions, straightforward, , no reference to controversies
12)	S&MC (2011), p196: An object has an electric charge which is an integral multiple of the elementary charge. In symbols: $Q = nq_e$, where Q is the charge, n is an integer and q_e = charge on one electron The elementary charge is the charge on one electron = $1{,}6 \times 10^{-19}$ C. This is a positive number, so the charge on an electron is $-1{,}6 \times 10^{-19}$ C and the charge on a proton is $+1{,}6 \times 10^{-19}$ C.	An 'integral'? must be a typo. Passage makes no sense. How can the charge of an electron be both positive and negative?

5.3.2 Analysis and interpretation of data in CT3: Introduction to atomic model

5.3.2.1 General overview

A) Absence of links

As seen in CT3, six out of ten textbooks refer to the atom, most in a laconic manner, as containing protons and electrons. In the NCS and CAPS textbooks, the impression given is that authors were unaware that under Matter and Materials there was a chapter where models of the atom, atomic structure and other relevant items had been painstakingly introduced. Only PLATC (2011) makes a link to the relevant chapter, though quite late in the text. The SIYAC (undated) and SIYAN (2010) textbooks avoid any reference to the atom (excerpt 4 in CT3): "All objects surrounding us (including people!) contain large amounts of electric charge..."



OXFC (2011), p.154
OXFN (2008), p.60

The OXFC (2011) and OXFN (2008) textbooks present us with a figure of 'the atom', shown alongside, which is quite incompatible with anything learners meet in the topic Matter and Materials (under 'Models of the atom'). In the last more contemporary model of the atom learners are introduced to, they learn about atomic orbitals and hopefully realise that it is no longer easy or possible to represent an atom with a drawing. Why then in Electrostatics we are presented with this picture, which is reminiscent of Bohr's planetary model, but it is not even that? It may be that the author was unaware of the models that learners were introduced to under Matter and Materials, or perhaps the author thought that such knowledge was irrelevant to electrostatics. To the learners, in either case, the given picture represents

inconsistency in science and sends the erroneous message that chemists and physicists use different atomic models. This idea may also be encouraged implicitly and unwittingly by the curricula themselves, considering that the atom is introduced as 'chemistry'. Even in NCS and CAPS, where Matter and Materials was supposed to be an integrated area, the distinction between chemistry and physics was always present, more explicitly so in CAPS.

B) No distinction between macro and micro

Despite references to the atom, none of the textbooks refers to the atom as a *model*. Also none of the textbooks mention something along the lines: "we are going to use our knowledge of the atomic model to explain observed electrostatics phenomena". The impression given by all textbooks is that authors are not aware of the distinction between macro and micro and that they had no plan or goal in completing the chapter Electrostatics. PLATC (2011) starts the chapter in a promising way by introducing a series of practical activities where learners can observe and infer and produce macro assumptions. But then the chapter falls short on picking up from the macro to proceed to micro-explanations in a systematic and explicit way. Hence in all textbooks, the distinction between macro-descriptions or empirical observations and micro-explanations is far from clear if not non-existent. Furthermore, learners are given the idea that if they had some sort of a powerful microscope they would actually see electrons moving about.

C) Aspects of atomic model that need mention

CT3 lists aspects of the atomic model that are essential to understand the concept of charge and of the net charge on objects. One such aspect is that charge is an ***inherent property*** of certain subatomic particles, in our case of protons and electrons. Learners need to understand that charge is a fundamental property of matter, much like the mass, and that it cannot exist

apart from matter like some disembodied entity. An electron would *cease* to be an electron without its charge; it cannot happen. This understanding is particularly important considering that in science discourse we often refer to mobile charged particles as 'charge carriers'. The word 'carrier' may suggest to learners that charge is something that is carried like a burden which can be off-loaded and deposited at places. From the ten textbooks, only OXFC (2011) offers a glossary-type definition (excerpt 8 in CT3) "**charge**: property of some particles that gives rise to electrical phenomena", placed in the margin under 'New words' and given no prominence (presumably addressing English-second language learners). In all other textbooks, authors either did not see the need to account for charge as a fundamental property of matter and as a science concept in its own right, or perhaps thought that they had explained the concept by referring to lack or excess of electrons or perhaps they consider charge to be the actual electrons and protons. Unfortunately, these are also messages that they have transmitted to the learners.

The *quantisation* of charge, the *elementary charge, e,* and the fact that protons and electrons are found to have numerically exactly *equal* charge, equal to the elementary charge *e,* are also aspects in need of mention within the introduction of the atomic model. Regarding SA curricula, NATED 550 HG (DoE&C, undated, p.37) includes "Quantisation of charge" at the end of the "Electric fields", to be dealt with a discussion of Millikan's oil-drop experiment (only in HG). CAPS includes explicitly the quantisation of charge under "Electrostatics" for Grade 10, at a random placement, for which it also adds: "Every charge in the universe consists of integer multiples of the electron charge. $Q = nq_e$, where $q_e = 1.6x10^{-19}$ C and n is an integer" (DoE, 2011, p.41). Consequently, as shown in CT3, all CAPS textbooks address the quantisation of charge, but not all refer to the concept 'elementary charge' or to the equality of electron and proton charge or to the proton for that matter. All CAPS textbooks

introduce these aspects either towards the end or at the very end of the chapter where they serve no purpose. Yet the same textbooks (except PLATC, 2011) begin the chapter, abiding with CAPS, by stressing that objects with equal numbers of protons and electrons are neutral. The true reason why objects are neutral is not because they have equal numbers of protons and electrons, but because protons and electrons have (numerically) equal charge. It is irrational to introduce the elementary charge at the end. Three more textbooks from older curricula refer to the elementary charge by ignoring the proton.

Another interesting aspect that could worth a mention, but only found in SIYAN (2010), is that electrons are negative and protons are positive following Franklin's convention. Had it been the other way round, we would not have the distinction between conventional current and electron current in electric circuits, the electron 'flow' would be the flow of positive charge. Would this have been more convenient? The answer would be yes only if we are so short-sighted as to ignore other conductors like the human body, the earth, electrolytes, batteries, ionised gases (e.g. in sparks and lightning and fluorescent tubes and neon signs) and more (even semiconductors), where both positive and negative charged particles move in opposite directions. Current is just a flow rate of charge carried be charged particles passing a cross-section, no matter in which direction. Furthermore, electrons are not the only mobile charged particles despite insinuations and assertions in the curricula. The authors involve the human body regularly in examples, but no electrons move in the human body unlike mobile protons (hydrogen ions) which are plentiful.

5.3.3 Issues arising from localised points of articulation in CT3

5.3.3.1 Pseudo-science

In what follows, selected excerpts from CT3 are discussed in more detail, to reflect on messages they may transmit to learners. For convenience, they are repeated below under the numbering they are given in CT3. The corresponding statement from the CAPS document is also added for comparison.

CAPS document (DoBE, 2011, p41): Every charge in the universe consists of integer multiples of the electron charge. $Q = nq_e$, where $q_e = 1.6x10^{-19}$ C and n is an integer
Excerpt 6, OXFC (2011), p160: Every charge in the universe is an integer multiple of the electron charge. Stated as an equation: Charge $Q = nq_e$, where n is an integer and $q_e = 1,6x10^{-19}$ C. The charge carried by an electron is $– 1,6x10^{-19}$ C, and a proton is $+1,6x10^{-19}$ C.
Excerpt 12, S&MC (2011), p196: An object has an electric charge which is an integral multiple of the elementary charge. In symbols: $Q = nq_e$, where Q is the charge, n is an integer and q_e = charge on one electron The elementary charge is the charge on one electron = $1,6 \times 10^{-19}$ C. This is a positive number, so the charge on an electron is $–1,6 \times 10^{-19}$ C and the charge on a proton is $+1,6 \times 10^{-19}$ C.

Excerpts 6 and 12, are quite similar and reflect how authors mimic expressions in the curriculum, whether successful or unfortunate. This trend is typical in CAPS textbooks. Nevertheless, in these examples authors chose to extend ‘quantisation of charge’ to

incorporate the charge of a proton and very rightly so. S&MC (2011) even refers to the *elementary charge*. In science, the elementary charge is a fundamental physical constant and is given the symbol "*e*". Its value is 1,6 x 10^{-19} C. A proton would then have a charge *e* (= 1,6 x 10^{-19} C) and an electron a charge *–e* (= –1,6 x 10^{-19} C). Hence, the elementary charge equals the charge of a proton.

In examples 6 and 12, authors present the elementary charge as the charge of one electron, but with a positive value, q_e = 1,6x10^{-19} C, as stipulated in CAPS. In order to justify the positive charge of a proton and the negative charge of an electron, which are now in discord with the stated q_e = 1,6x10^{-19} C, authors seem to resort to a 'ploy'. They present the charge of an electron, this time without a symbol, as –1,6 x10^{-19} C and that of a proton as +1,6 x10^{-19} C. The inclusion of especially the "+" sign to the charge of the proton indicates very covertly that +1,6 x10^{-19} C is not the same as 1,6 x10^{-19} C. The latter is supposed to be understood as some 'nonspecific' value that is neither positive nor negative, which is nothing less than absurdity. The S&MC also states "This (q_e = 1,6x10^{-19} C) is a positive number, so the charge on an electron is –1,6 x 10^{-19} C…" which is most illogical.

All these could leave learners confused. They are a source of multiple interpretations. (Learners may be asking: Is the charge of the electron positive but the electron as a particle is negative? Are electrons positive when they are in excess and negative when they are missing or it is the other way round? Can a nucleus have charge since it has no electrons? If we do not use the "+" sign for a positive charge are we wrong? Are electrons more important than protons? And so on)

5.3.3.2 Unconvincing reasoning

Did authors strive to abide with the curriculum for the sake of textbook approval or is it a tradition amongst authors and curriculum developers to consider the electron as the elementary charge "*because* it is 'the only' particle that transfers between *objects*"? The latter would seem plausible based on the conviction demonstrated by excerpt 5, taken from a NATED 550 textbook and to a lesser extent by excerpt 7 from a CAPS textbook, where the same notion is implied.

Excerpt 5, BJ (1987), p.68: Since the charge on a charged object originates from an excess or deficiency of electrons, it follows that the charge of smallest magnitude is the charge on only one electron….this is known as the elementary charge.
Excerpt 7, PLATC (2011), p.139: Since charging always involves adding or removing electrons, the charge on an object is always a multiple of the electron charge, e.

The argument in excerpt 5 is in profound conflict with the nature of science regarding what is a theoretical model, how we use it to explain phenomena and the reasoning accompanying inferences made in the process. The example consists of two parts:

The first part tells us that the charge on a charged object is due to excess or deficiency of electrons. Despite reference to electrons this is a macro description as far as learners are concerned. The micro-macro connection had never been made to explain how and why it is electrons that transfer between objects. Learners are just *told* that it is electrons. The typical descriptive terms 'negative charge' and 'positive charge' have been replaced by 'excess of electrons' and 'deficiency of electrons' and tell us nothing insightful about the charging

process. Had the author made the micro-macro connection to explain the origin of electrons and how the object ended up charged, the argument in excerpt 5 would have been obsolete.

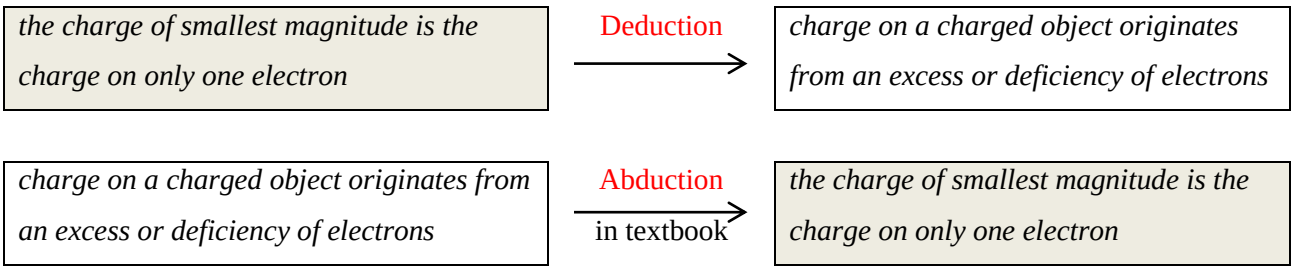
The second part is given as a consequence of the first part, "it follows that the charge of smallest magnitude is…" Using this argument from macro to micro, the author 'deduces' an assumption of the atomic model, i.e. that the electron charge is the atomic-level unit of charge. This conclusion cannot be inferred with the certainty that the author implies, the argument is not convincing (just because there are extra/missing electrons on an object does not necessarily imply that they have the smallest charge). At best, the second part should have been given as an inductive inference, that *perhaps* electrons are particles of smallest charge. But then, what would be the point of such argument? It leads to nothing certain. We cannot use macro-considerations to justify or reinvent assumptions of an already existing theoretical model because arguments involved would be riddled with uncertainty.

One may argue that Millikan himself did something similar with his oil-drop experiment, as described in Niaz, 2000b. What Millikan actually showed was that the transfer of charge on oil drops was occurring in integral multiples of *e*. He measured the value of this 'elementary charge' and presumed it to be the atomic level unit of charge and the charge of an electron. Millikan was convinced that this measurement was the elementary charge, a conviction that triggered the notorious Millikan-Ehrenhaft controversy that lasted for many years. But for the authors of the examples this is presented as obvious: "since electrons go on and off objects they must have the smallest charge".

A) Abductive reasoning

The argument of the authors in excerpts 5 and 7 can be also understood in terms of *abductive* reasoning. This is reasoning associated with everyday argumentation, where a seemingly 'deductive' inference is generated to explain an occurrence. However, abduction is rather the

reverse argument to a deduction. For example, "if there is load shedding the lights go off" is a deductive argument, but "lights go off, it's load shedding again" is an abductive argument. The explanation stemming from abductive reasoning is not beyond doubt, but is rather the most plausible explanation based on previous experience. Hence, abductive reasoning is not accompanied with the certainty of conclusion that deductive reasoning guarantees and should be avoided in science explanations. Shown below, are deductive and abductive arguments corresponding to excerpt 5.



The author of excerpt 5 (same can be said for excerpt 7) was already based on the assumption of "the electron as being the smallest charge" when s/he made the statement that "charge originates from an excess or deficiency of electrons". Yet in the textbook, the author presented the argument in the reverse order that rendered it untrustworthy. Such practices suggest lack of argumentation skills and lack of proper planning on the part of the authors, but also on the part of curriculum developers. Learners ought to have been given the background on elementary charge along with other background before they were *told* that the charge on objects is multiples of electrons.

B) Getting from macro to micro

A dominant idea among science educators of our times is that learners should be first encouraged to make macroscopic observations before they are introduced to theoretical

constructs or as it is commonly expressed "moving from macro to micro". This makes a lot of sense, particularly so in electricity as explained at the start of the chapter. However, moving from macro to micro does not mean 'use macro to invent micro'. It means, once learners had sufficient exposure to basic phenomena, introduce them to a theoretical model and use it to start *explaining* these phenomena. Unless of course the purpose of instruction is for learners to develop their own model, i.e. to *construct* scientific knowledge. The uncertainty of conclusion in this case (due to inductive reasoning) is the reason why such constructs need to be tested and retested and revised, until they become powerful enough to be taken seriously, to be taken 'as real'. The norm unfortunately is that the time for this process is not available at school.

C) Physics textbook authors need guidance

In linking macro to micro, the norm in normal science is to use theoretical constructs/models to explain phenomena, a process which involves deductive reasoning and leads to explanations that leave no doubt (Ogborn, 2008), at least this is the aim. This does not mean that inductive reasoning has no place in scientific argument. Anyway under 'chemistry', SA curricula and textbooks refer explicitly to theoretical models and use them to explain bulk properties of matter. In grade 10 the particle theory is deployed to explain states of matter and phase changes, in grade 11 the kinetic theory of gases is used to explain the empirical gas laws, atomic models are also introduced under chemistry and are used to explain the placement of elements in the periodic table and consequent trends and properties. But under electrostatics we find no call for particular theoretical constructs to explain charge and the charging process. Curricula leave authors on their own to figure out how to negotiate the requested references to electrons and protons in the charging process and to select appropriate theoretical constructs from 'chemistry'. But without guidance authors do not seem capable or

knowledgeable enough to identify suitable theoretical constructs and concepts from other topics to accomplish the task of linking macro to micro. When it comes to physics in general, curricular references to models and theories are rare. A learner leaving school must be under the impression that chemistry is about models and theories used to explain and that physics is about laws and principles used to calculate.

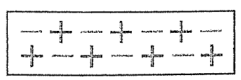
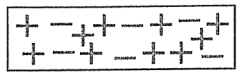
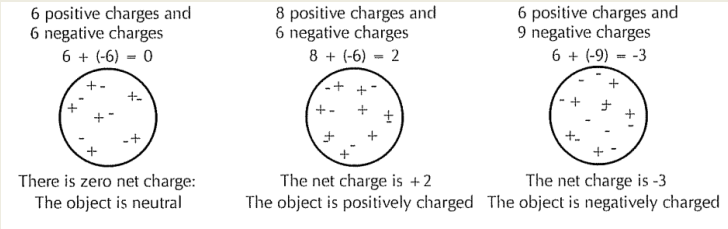
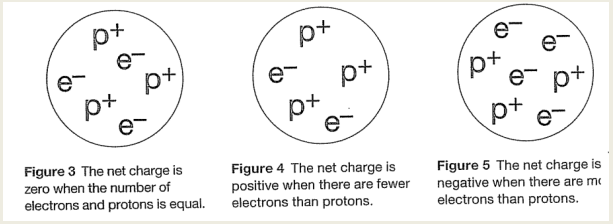
5.4 ASPECT OF ANALYSIS 3: Charged and uncharged objects

This is a continuation of the introduction to the atomic model with the aim to examine whether and how authors apply basic knowledge on elementary charge and the structure of the atom to make the macro-micro connection with objects that have been described as electrically charged or neutral. As has been already discussed, textbook accounts of the atomic model under electrostatics were in general neither unproblematic nor systematic nor were there links to other topics where the structure of the atom was expounded more methodically.

Categorisation Table 4 CATEGORY: Charged and uncharged objects

Theoretically grounded 'definitions'	SPS		BJ		SS		PLATC		SIYAN	SIYAC		S&MN	S&MC		OXFN	OXFC	
A **neutral** or **uncharged** object has equal numbers of protons and electrons (and so it has zero net charge)	✓	MICRO See (1a)		No revision given	✓	MICRO	✓	MACRO & MICRO at end See (3)		✓	NCS: MACRO CAPS: MACRO & MICRO See (4)	✓	✓	MICRO	✓	✓	MICRO
A **charged** object has unequal numbers of protons and electrons (and so it has a net charge)	✓	MICRO In terms of electrons See (1a)			✓	MICRO	✓	MACRO & MICRO at end See (3)		✓	NCS: MACRO CAPS: MACRO & MICRO See (4)	✓	✓	MICRO	✓	✓	MICRO
Charge imbalance brings about **change in behaviour** of objects														Promising but falls short See (2)			
Reference to **net charge** and attempt to explain its meaning. Elucidate that when we refer to the *charge* of an object (symbol q or Q) we actually mean the *net charge* of the object	✓	Refers to the *charge* of a charged object See (1b)							✓	✓	MACRO Erroneous info on net charge in a figure. See (4)					✓	Glossary in margin: **Net charge**: sum of the charges Also in a figure, see (5)
Neutral does not mean no charged particles, but **no net charge**. (Make explicit)																✓	In text only macro and unjustified. See (6)
(Reference or link) Protons are tightly bound in nucleus, electrons relatively **loosely**.						See (9)					In bits and pieces see conductors/ insulators				✓		See (7)
(Reference or link) Process of removing an electron from atom = *ionization*. Atom with missing electron = **positive ion** Atom with extra electron = **negative ion**																✠	Irrelevant inclusion on ions See (8)

	EXERPTS IN TEXTBOOKS	COMMENTS & NOTES
1)	SPS (1987), p.68: a) Positive charges develop on objects when **electrons** are *removed*. Negative charges develop…when **electrons** are *added*. An *uncharged* or *neutral* object has an equal number of protons and electrons. There is thus no **excess** charge on the object. b) A *charged electroscope* with a known charge can be used to determine the **type of charge** (in excess) of an object.	Charges develop? Are charges and electrons different entities? What are charges and how is their development related to electrons? The only text that refers to "excess charge" as the charge of a charged object.
2)	S&MC (2011), p.190, S&MN (2005), p.91: …..The electrons and protons in each material are no longer balanced. One material has extra electrons and the other missing electrons. The materials have become charged.	But does not extend the argument to the net charge of the objects or to the new behaviours of the objects.

3)	PLATC (2011), p.135: (MACRO) When an object is charged it does not mean that it has only one kind of charge. Every object has both positive and negative charges. An uncharged or **neutral** object has the same number of positive and negative charges, as shown in Fig 15.1 (a). A positively charged object has fewer negative charges than positive charges. This is shown in Fig 15.1 (b). A negatively charged object has more negative charges than positive charges. *(4 pages later)* PLATC (2011), p.139: (MICRO) Up until now we have talked about positively and negatively charged objects. Charged objects are charged because the number of protons and electrons in them is not the same. Negatively charged objects have more electrons than protons; positively charged objects have more protons than electrons. Neutral objects have the same number of protons and electrons. When we charge an object it is the electrons that move onto or off the object. When we make an object negatively charged, we add electrons. When we make it positively charged we remove electrons. Since charging always involves adding or removing electrons, the charge on an object is always a multiple of the electron charge, e.  Figure 15.1 (a) A neutral object  Figure 15.1 (b) A positively charged object	Thoughts of a reasonable learner on the received messages: So an object is charged with different types of charge? At the same time? What is the difference between charge and charges? Charges are distinct *somethings* with symbols "–" and "+"that exist inside materials. When the object is neutral the *somethings* are arranged orderly in the material. When the object is charged the *somethings* fall into disarray, especially the positive ones, perhaps because the object in fig (b) is positively charged. Or is it more positively than negatively charged? (since objects can be charged with different types of charge) Another reason why objects are charged is when the numbers of electrons and protons are not the same. This case is similar to the case of positive and negative *somethings*. But we are not told how electrons and protons are arranged in the material. And we are told that it is only the electrons that can increase or decrease, unlike the *somethings* shown in the figures. Charge is a multiple of the electron charge. But this cannot be the case with the +ve and -ve *somethings* because the number of "+" has increased instead of staying the same in fig (b). Atoms have their own electrons. Where do electrons of charging come from? Are they found lose in-between atoms? And if the number of protons and electrons in a neutral object is the same, there must be lose protons between atoms too. In this case, why can't these protons move in and out?
4)	SIYAC (undated), p. 254-255 SIYAN (2010), p.305: All objects…contain large amounts of electric charge. There are two types of electric charge: **positive** charge and **negative** charge. If the same amounts of negative and positive charge are found in an object, there is *no net charge* and the object is electrically **neutral**. If there is more than one type of charge than the other on the object then the object is said to be **electrically charged**. The picture below shows what the distribution of charge might look like for a neutral, positively charged and negatively charged object (MACRO).  *(Only in CAPS book)* Positive charge is carried by the protons in the material and negative charge by electrons. The overall charge of an object is usually due to changes in the number of electrons. To make an object: **Positively charged**: electrons are removed making the object electron **deficient**. **Negatively charged**: electrons are added giving the object an **excess** of electrons. So in practice what happens is that the number of positive charges (protons) remains the same and the number of electrons changes (MICRO): *(The exact same figure as above is repeated)*	NOS: "*what the distribution of charge might look like*" and also "*in practice*…". Is this reality? Thoughts of a reasonable learner on the received messages: The text refers to 'charge' in an object, as if it is one thing, but the figure refers to 'charges' in an object and shows many "–" and "+" signs, presumably the charges. Is charge made of many charges? What is the difference between the two? By subtracting the numbers of charges we get a number with no unit called the 'net charge'. What is this number? Why not 'net charges"? Why is the number of negative charges taken as negative? It should have been positive, it means how many –ve charges. What do we get if we add the numbers of the charges? Shouldn't this be the 'total charges'? The figure also shows that +ve and –ve charges inside the object form pairs in random locations. Is each pair two charges or one charge or no charge? (In CAPS only) Now we are told that the –ve and +ve charge is carried by electrons and protons. Are the "–" and "+" in the figure electrons and protons or just their charge that has been offloaded there? Why do +ve and –ve charges form pairs? Do protons and electrons form pairs too? Where do they come from?
5)	OXFC (2011), p.154: ....All materials contain charges. Any object consists of enormous numbers of atoms and has even more charge-carrying protons and electrons. An object that has an equal number of electrons and protons is neutral. Although the object has a large number of charges the **net charge** of the object is zero. …. (*in margin*): **NEW WORDS - net charge**: sum of the charges  **Figure 3** The net charge is zero when the number of electrons and protons is equal. **Figure 4** The net charge is positive when there are fewer electrons than protons. **Figure 5** The net charge is negative when there are m electrons than protons.	Does not make clear were these protons and electrons come from. The text could be easily understood as "an object contains atoms plus charge-carrying protons and electrons (as extras)" and that the charges in materials are these extra protons and electrons. This idea is also reinforced by the figure. Protons and electrons are shown in random positions. And what is the net charge in the figures which can be positive or negative? The unit of charge (as coulomb) is introduced at the end of the chapter.

6)	OXFC (2011), p.154: An object that has an equal number of electrons and protons is neutral (MICRO). Although the object has a large number of charges the **net charge** of the object is zero (MACRO).	"Net charge" only associated with neutral objects. Fragmented presentation mixing macro and micro descriptions. The concepts 'neutral' and 'zero net charge' are not linked explicitly. What are 'charge' and 'charges'? They do not have the same meaning in the text.
7)	OXFN (2008), p.60: We can explain the results in terms of our knowledge of matter. When two substances rub together, it is the electrons on the outsides of the atoms that are closest and can move from one substance to the other if the conditions are right. The protons are tightly bound to the nucleus and are not free to move.	If learners figure out by themselves that the text refers to atoms located at the surface of the rubbed materials, the excerpt projects the idea that the rubbing action causes electrons to be 'scraped off'. But this should be true for the electrons of both surfaces that come into contact, which conflicts with what learners learn under triboelectric charging where one surface loses electrons and the other one gains. This is a problem with the word 'rubbing' if it is not justified as an action for improving the condition for contact and separation of the two surfaces. Considering that there is no link to electronegativity in the chapter, the excerpt also projects the idea that nuclei play no role in the charging process.
8)	OXFC (2011), p.154: **Charges on ions**: An advantage of calling the two kinds of charge positive and negative is that can we add them together to obtain the net charge. This is also useful in chemistry. For example, Cl^- means that the chloride ion has one more electron than protons. Mg^{+2} is an ion that has two electrons fewer than protons.	What is *charge* and *net charge*? What if we add a positive charge and a negative charge? Or five positive charges and three negative charges? What would be the net charge then? The answer to both these questions depends on the quantities of charge! Charge as a physical quantity is overlooked. This inclusion relates to the choice of labels *positive* and *negative* rather than to the introduction of ions as possible charge carriers in electricity. Perhaps it is presented as a link to chemistry, but it projects that ions are irrelevant to electrostatics. Overall it is an irrelevant inclusion.
9)	SS (1989), p. 53: NOTE: You will remember that all substances are made up of atoms. The charged particles in atoms are positive protons and negative electrons. The protons are in the nucleus of the atom and are not affected by rubbing the substances together. However, electrons form the outermost part of atoms….. Why is it that protons are not transferred when substances are charged by friction?	Reference to the atomic model, but it implies that protons being in the interior of the atom are not affected by the rubbing, instead of being tightly bound to the atom. Electrons on the other hand can be 'rubbed off'? It may also imply that protons do not affect the charging process.

5.4.1 Analysis and interpretation of data in CT4: Charged and uncharged objects

5.4.1.1 General overview

The first two rows in CT4 indicate that eight out of ten textbooks have touched on the aspects on neutral and charged objects in terms of numbers of electrons and protons. MICRO in CT4 denotes that the author expounds by referring to protons and electrons (or just to electrons in SPS, 1987). MACRO denotes cases where authors expound in terms of 'positive' and 'negative charges'. The labels MICRO and MACRO in CT4 are used tentatively and have been assigned based on assumed intentions of the authors. The case of MACRO and the reason why it is included in this section of micro-considerations will be explained in what follows. Two CAPS textbooks, PLATC and SIYAC, offer both MACRO and MICRO presentations in a distinct manner.

The remaining five rows in CT4 are hardly populated with inclusions in textbooks. The aspect "Charge imbalance brings about **change in behaviour** of objects" in the third row, was meant to examine whether authors have emphasised that observed electrostatics phenomena are the result of charge imbalance, or separation, or of non-zero net charge or similar, or whether they have pointed out that charged objects behave differently than when uncharged. This could justify why we are making the effort to study charge and the charging process. We do not study charge just because it is part of matter, but because it has consequences. If it was not for its consequences, the concept of charge might have not existed. In the textbooks we looked for passages along the lines: "Neutral objects have equal positive and negative charge, their charges are balanced or cancelled. But when this balance

is disturbed, objects exhibit certain behaviours…do things they did not do before... ” But nothing remotely similar was found in any of the books. The authors do not extrapolate charge imbalance to object behaviour. The end of the imbalance argument is that ‘the object is charged’, as typified by excerpt 2 in CT4: “The electrons and protons in each material are no longer balanced. One material has extra electrons and the other missing electrons. The materials have become charged.” As has been discussed under Perceptions of Electrostatics and Static Electricity, authors tend to attribute electrostatics phenomena to the staticness of charge rather than to charge imbalance.

The concept “net charge”, representing charge imbalance in an object, was not addressed in most textbooks either. Yet it is in elementary electrostatics where learners need guidance to distinguish between *charge* as a property, *charged particle* and *net charge* and where preciseness and consistency of expression should be given particular attention. None of the authors has attempted such a distinction. When authors refer to ‘charges’ they usually mean charged particles and by charged particles they mean protons and electrons, e.g. “so in practice what happens is that the number of positive charges (protons) remains the same….” (SIYAC, undated p.255). Charge is never presented as a meaningful / physical quantity, consequently, the only references to net charge found in the books, represented by excerpts 4 and 5 in CT4, send the message (explicitly so in excerpt 4) that net charge is *a number*, signifying whether an object is positively or negatively charged. Authors also refer to the singular term ‘charge’, often mingled with ‘charges’ in the same phrase, though charge as a property was never introduced. Hence, authors unwittingly encourage multiple interpretations and endorse confusion. Further insight on these problems is given in the next section.

It follows, and this should be stressed as a primary concern, that although both curricula and authors aim at explaining what a neutral and a charged object is, they do not target the

"charge of an object" as a concept. With the exception of SPS, authors fall short of concluding that a charged object has a *net charge*, which is what we typically call the *charge* of/on the object as a matter of routine. When learners meet the term *charge* (and its symbol q or Q) in subsequent parts of electrostatics, whether it is the charge of a point particle or the charge on a conductor, it will actually mean *net charge*. Expressions such as charge distribution, charge density, the field of a charge or charge in a field and so on, all refer to the net charge of objects. Oddly enough, several authors point out that there is 'no excess charge' on neutral objects, or that a neutral object has 'zero net charge', but they never extend the argument to the net charge of charged objects. For example:

Excerpt 4 (SIYAN, 2010, p.305 & SIYAC, undated, p.254): …. If the same amounts of negative and positive charge are found in an object, there is *no net charge* and the object is electrically **neutral**. If there is more than one type of charge than the other on the object then the object is said to be **electrically charged**.

Excerpt 6 (OXFC, 2011, p.154): An object that has an equal number of electrons and protons is neutral. Although the object has a large number of charges the **net charge** of the object is zero…..a positevely charged object …is electron defficient….

PLATC (2011), p.135 in margin box: "KEY WORDS: **neutral** – with no excess electric charge, that is, the same number of positive and negative charges" (There is no other key word in this section.)

Both NCS and CAPS curricula remark under guidelines for teachers: "It is reasonable to call the two types of charge "positive" and "negative" because when they are added the net charge is zero" (DoE, 2006, p.28 and DoBE, 2011, p.40). This comment was included because NCS had called for "justify the use of the names positive and negative*"*. CAPS simply stipulates: "Know that an object that has an equal number of electrons and protons is

neutral (no net charge)". One may argue that authors have avoided addressing the "net charge" on charged objects in their effort to abide with the curricula, which associate net charge with only neutral objects. However, this cannot be the case because all authors, except PLATC (2011), have also neglected to justify the use of the names "positive" and "negative" suggested by the same curricula.

The use of the expression 'charge *on* the object' rather than 'charge *of* the object', is a matter of trend rather than consensus among science educationists. Presumably this is because the norm in solids is for excess charge to reside on the surface of the object. Textbook authors have extended the use of this expression to subatomic particles. So for example, they often refer to the charge *on* an electron, which, apart from nonsensical, may be reinforcing the idea that charge is something detachable from particles, much as the expression 'charge carrier' discussed earlier. However, we have not come across research addressing how learners or teachers perceive *charge* as a concept.

Returning to CT4, the inclusion of the aspect: "Protons are tightly bound in the nucleus and electrons relatively loosely" was meant to examine whether authors have attempted to justify the claim that "the charge on objects is due to excess or lack of electrons" in terms of ease of transfer of electrons. Only OXFC (2011) has attempted a reminiscent approach, though not successfully (see excerpt 7 in CT4). The excerpts in CT4 also show that the majority of authors did not even link charge of objects (net charge) to the atom, despite references to protons and electrons. Consequences of this practice are discussed in what follows. The same aspect is also a precursor to the introduction to ions and the ionisation process, since ions are mobile charged particles often involved in the transfer of charge between objects (in the

human body for example). But none of the authors[1] made reference to ions as possible mobile charge carriers. In fact some authors seem to be unaware that there are conductors where the charge carriers are only ions and where no mobile electrons can exist, as evidenced by the examples below:

SIYAC (undated), p. 261: "Some materials allow electrons to move relatively freely through them (e.g. most metals, human body)…called **conductors**."

S&MN (2005), p.94: "…the girl is touching the dome so that electrons flow into her…"

OXFN (2008), p.64: "…the bottom of the cloud also repels the like-charged electrons on the Earth's surface, leaving positive charges behind."

The numerous blank cells in CT4 suggest that textbooks cover little in terms of addressing the origin of charge on charged objects and its meaning. Concerning the examples accompanying CT4, effort has been put to include enough text and diagrams as not to lose the context each author had intended. Each excerpt is accompanied by a comment, sometimes in the form of questions, often questions a learner might have asked. This is particularly the case with the longer excerpts 3 and 4, where a 'hypothetical' learner reads text and figures in the examples very carefully. The comments of the learner are perhaps exaggerated, but the point is that all such meanings and the unanswered questions they generate emanate from the text. In these examples there is a lot of room for multiple interpretations, whereas in science we should aim for one through precise and consistent argument.

[1] The SPS (1987) distinguishes the charge carriers in metallic conductors from those in electrolytes and ionised gases, but does so in the introduction of the Electric Current, p 92.

5.4.2 Issues arising from localised points of articulation in CT4

5.4.2.1 Introduction – on inscriptions

In the common tradition of social sciences, according to Han & Roth (2006), visual representations are called "inscriptions" to differentiate from 'mental representations'. Inscriptions can be graphs, data tables, equations, diagrams and so on, but no words. They play a central role in the making and understanding of science, as evidenced by their predominance in scientific texts and in science textbooks. "Inscriptions are both the means to bring to life phenomena and support their existence" (Bowen & Roth, 2002, p.303). However, inscriptions need to be interpreted, much as a written text, if they are to contribute to knowledge and understanding. For scientists, having been enculturated into the scientific community, this happens unproblematically, often spontaneously, depending on the inscription and its context. Learners on the other hand need guidance to 'read' inscriptions, and research points to the fact that this is not an easy task (e.g. Bowen & Roth, 2002; Han & Roth, 2006; Roth & Tobin, 1997).

For Lemke (1998), meaning-making is a social semiotic practice and as such, it cannot be adequately understood in terms of just one semiotic modality. In scientific communication, meaning-making appears to result from the joint codeployment of two or more semiotic modalities, considered in fact incommensurable, and this codeployment is necessary for canonical interpretation. Language and inscriptions are such semiotic modalities and much like language, inscriptions are "*inherently social objects*" (Han & Roth, 2006, p.176). It follows that interpretation of inscriptions is influenced by social and contextual factors,

which in turn implies that different individuals may come up with a variety of interpretations for the same inscription. In science education where the aim is an *intended meaning*, multiple interpretations are not a desired outcome. To this effect, Bowen and Roth (2002) refer to the need for inscriptions to be embedded in texts in such a way as to limit learners' interpretations. Captions and text and presumably any other written information accompanying the inscription ought to direct learners "into developing a particular understanding of the argument as the written claim(s) and representation(s) mutually stabilise each other" (Bowen & Roth, 2002, p.304).

5.4.2.2 Macro presentations and inscriptions in textbooks

All above scholars converge to the notion that 'reading' an inscription involves interpretation of both the inscription and the text that accompanies it, in conjunction to one another. Text and inscription is the whole material to be understood. Apart from the central role of inscriptions in physics, we believe that the way inscriptions are deployed in science textbooks affects learners' experiences on learning science. Hence, in the following we discuss the examples from CT4 that include pictorial representations relating to charged and uncharged objects. Three of these examples are excerpts from CAPS grade 10 textbooks, which makes their analysis all the more pertinent.

Excerpt 3 in CT4 (MACRO) (from PLATC, 2011, p.135)

The excerpt is preceded by two practical activities in which "charge", "positive charge" and "negative charge" are introduced as descriptive terms in the macro tradition. For example, "when you rubbed the ruler you gave it a **charge**" or "…we call the two types of charge **positive** and **negative**". We first discuss the MACRO part of the example, which is shown below:

PLATC (2011), p.135:

When an object is charged it does not mean that it has only one kind of charge. Every object has both positive and negative charges. An uncharged or **neutral** object has the same number of positive and negative charges, as shown in Fig 15.1 (a). A positively charged object has fewer negative charges than positive charges. This is shown in Fig 15.1 (b). A negatively charged object has more negative charges than positive charges.

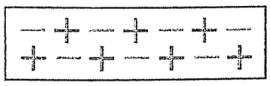


Figure 15.1 (a) A neutral object

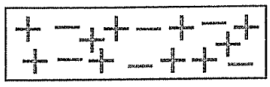
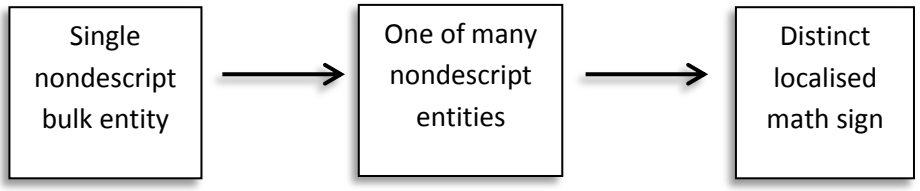


Figure 15.1 (b) A positively charged object

Reading through the text, we notice that there are references to "charge" and "charges". The term "charge" appears only in the opening sentence: "When an object is charged it does not mean that it has only one kind of charge". In this sentence, charge is tacitly presented as a single nondescript entity, something like a bulk characteristic attributed to an object, which does not conflict with the preceding descriptive section where learners met charge as something 'given' to objects upon rubbing. The same sentence, the expression of which is quite unfortunate, also claims that a charged object has more than one type of charge, so we understand that it has both a positive charge and a negative charge, or positive and negative "charges". Here, "charges" could mean two such bulk attributes, one positive, one negative. Indeed the next sentence confirms that "Every object has both positive and negative "charges". Possibly the author's intention was to convey that every charged object has both positive and negative charged particles. Yet the message sent could easily be that a charged object is charged with both positive and negative charge. In addition, there is no reference to *net charge* anywhere in the chapter and learners have no means to infer such a concept.

Upon reading the remaining sentences "An uncharged or neutral object has the same number of positive and negative charges, as shown in Fig..." the meaning of "charges" that we have so far constructed becomes obsolete. Now we are told that objects have a number of positive

and negative charges. “Charges” now mean many nondescript entities of the same kind, so “charge” cannot be a bulk attribute anymore. The “charge” which at the start of the example was a single nondescript bulk entity has now become one of many nondescript entities.



Source: Compiled by researcher

Figure 5.1 Notions of “charge” in excerpt 3 in CT4

The text directs us to the figure[2] twice, in the form: “…as shown…” implying that the role of the inscription is ‘to illustrate’. Firstly we are directed to Fig 15.1 (a), which shows a rectangular shape with “+” and “–” signs in its interior, and no other information. Its caption proclaims that this is “a neutral object”. It is left to the learners to infer what the figure ‘illustrates’ and how it is linked to the text. One may argue that this is an easy case for learners to make the *translation* from text to inscription. Since the text refers to neutral objects as having same number of negative and positive charges and since the figure shows same numbers of “+” and “–” signs, learners can infer that the signs must be the “charges”. In addition, due to association with algebra, learners can also infer that “+” signs must be the positive charges and “–” signs the negative. “Charge”, from nondescript entity has now become a distinct and localised mathematical sign. These inferences can be extrapolated to Fig 15.1 (b) which ‘illustrates’, according to the caption, “a positively charged object”. The different notions for “charge” learners could construct so far are represented in Figure 5.1.

[2] In the textbook, the inscription of example 3 appears in the next page following the text, so learners have to turn the page to find it. This is not ideal as learners need to interpret text and inscription at the same time, linking the two, as is generally the case with science inscriptions.

However, the lower figure in the excerpt (labelled Figure 15.1) also depicts extra information not articulated in the text. The charges in the 'neutral object' are arranged in an orderly manner, forming regular arrays of alternating negative and positive charges, as if following some unknown rule. The arrangement suggests that the charges are stationary. In the 'positively charged object' there are excess positive charges and this time the distribution of charges is irregular, suggesting the possibility of movement of both positive and negative charges. This contradicts what learners are about to learn on the charging of solid objects (textbooks, as discussed earlier, do not consider ionic conductors). We also notice that positive charges somehow 'congregate' together, which contradicts what learners learned earlier, that like charges repel. The author does not specify whether the two figures show the same 'object' under different circumstances or not. If the objects are different, one may infer that some objects have stationary charges but others have charges that move. If the two 'objects' are the same, one may infer that excess charge wreaks havoc in the object by displacing all other charges. In the latter case and upon comparing Figures 15.1 (a) and (b) we also notice that both the numbers of positive and negative charges have changed; the number of positive charges has increased and the number of negative charges has decreased. This too contradicts claims in subsequent sections.

Finally, are all these charges inside the objects or on the surface of the objects? The author refers repeatedly to an object as ***having*** charges, which does not shed any light, and the figures show "+" and "–" signs contained in 2D shapes. Learners are more likely to form mental images favouring charges inside the object, similar to their experiences with particle models in chemistry. It is also instinctive to translate signs within a 2D rectangle as signs within a 3D box rather than on top of the box. Once again this notion is in conflict with the charging of solids when learners learn that excess charge resides on the surface of objects.

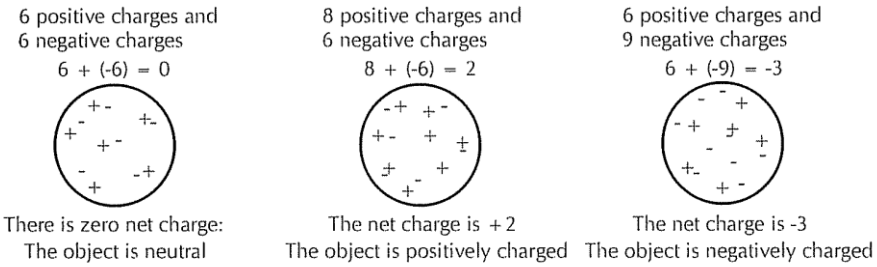
The distinction between model and reality has not been articulated and the captions reinforce confusion between the two. Learners are prompted to infer that this is how charges look like inside objects. Learners are left on their own to negotiate what is reality and what they could perceive as reality, much as they are left on their own to negotiate meanings for "charge".

Excerpt 4 in CT4 (MACRO) (from SIYAC, undated, p.254 & SIYAN, 2010, p.305)

The SIYA books begin straight away with excerpt 4 under the heading: "Two kinds of charge". Below is the MACRO part of the example:

SIYAC, undated, p.254 & SIYAN, 2010, p. 305

(MACRO) All objects surrounding us (including people) contain large amounts of electric charge. There are two types of electric charge: **positive** charge and **negative** charge. If the same amounts of negative and positive charge are found in an object, there is *no net charge* and the object is electrically **neutral**. If there is more than one type of charge than the other on the object then the object is said to be **electrically charged**. The picture below shows what the distribution of charge might look like for a neutral, positively charged and negatively charged object.



Similar arguments and concerns can be raised in excerpt 4. The term "charge" has different meanings in the text and in the figure, left to the learners to figure out. The positive and negative charges, or "+" and "–" signs, also appear to follow some unknown rule, because this time positive and negative charges come in 'pairs'. In the two cases 'illustrating' charged objects, some pairs seem to be missing a partner. In this example, instead of captions we are

presented with extra textual information that has to do with the numbers of charges rather than with their distribution as the text proclaims.

Nevertheless, upon looking at the information accompanying the picture we see items that do not make sense either logically or mathematically. If we add 6 oranges and 6 apples we do not get zero, we get 6 oranges and 6 apples. If we see them as fruits, we get 12 fruits. If we see them as mass we get 1,5 kg (say), and so on. If we add 6 electrons and 6 protons we do not get zero, we get 6 electrons and 6 protons. If we see them as particles, we get 12 particles. If we see them as charge we should say so and we should specify a unit for it, as in the case of 'fruit' and 'kilogram'. What exactly does the author add in this example with such conviction? What is "–6" and what is "0"? Learners have not been introduced to the charge as a physical quantity, and they have not been introduced to the unit "coulomb" or to the elementary charge "*e*", which is done eight pages later in the chapter. In the last figure for example, what are learners supposed to understand by the expression "*the net charge is –3*"? Learners will notice that the given numbers of 'charges' have been subtracted for a strange reason, and mechanically they will figure out that –3 relates to the 3 extra negative charges in the figure. But "–3" is not a measure of anything and certainly it is not net charge. Learners instead of being driven to build conceptual understanding are given absurdities. It leaves much to speculate on the author's understanding of the meaning of *quantity* in science and of the meaning of *unit*.

And what exactly is the role of this figure? The text claims that it is to 'illustrate' the distribution of charge "The picture below shows what the distribution of charge might look like…", also denoting that the inscription depicts reality. Furthermore, distribution of charge, whatever that may be, was never expounded in the text. On the other hand, the figure itself

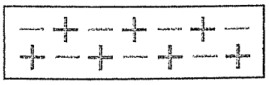
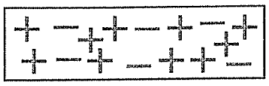
focuses on the concept “net charge”, which it associates to both charged and neutral objects, unlike the text which only associates it with neutral objects. There is an obvious lack of correlation between text and figure, in terms of the use of the terms “charge” and “net charge” and also in terms of focus. Considering that the figure supplies additional information not communicated in the text, and considering that it attempts an explanation of the concept “net charge”, its function can be perceived as explanatory and complementary to the text rather than illustrative. But this must be an additional source of uncertainty for learners. How are they expected to react with the figure? Is the extra information something to pay attention to and learn from or something to ignore and concentrate on the distribution of charge as directed? And what are they expected to infer from the shown distribution which only raises concerns?

5.4.2.3 Micro-considerations for charged & uncharged

CT4 shows that eight out of ten examined textbooks have discussed charged and uncharged objects in terms of numbers of protons and electrons, marked as MICRO in CT4. This was done in more or less the same way, with most authors taking care to note that it was a matter of addition or removal of electrons and generalising this notion to all objects. Hence, as discussed previously, authors left no space for other types of charge carrier and the possible transfer of charge via ions. Here however we examine how authors link such micro-considerations to MACRO references of positive and negative ‘charge’ or ‘charges’. We do this by continuing our analysis of the examples from CT4 that offered pictorial representations.

Excerpt 3 in CT4 (MICRO) (from PLATC, 2011, p.135)

The MACRO part of excerpt 3 from PLATC (2011) is followed by sections referring to the charging process of conductors and insulators, discussed in terms of 'charges', and there is even reference to 'mobile charges' in conductors. This is followed by polarisation, which although it is discussed in terms of positive and negative 'charges', it also includes an out of the blue reference to a conductor as having "*many mobile electrons*" (PLATC, 2011, p.137). Eventually four pages later, we arrive at the section on quantisation of charge where we find the first reference to the atom along with the corresponding MICRO excerpt for charged and uncharged objects. Below, both MACRO and MICRO excerpts from PLATC (2011) are shown next to each other for comparison:

MACRO excerpt (PLATC, 2011, p.135)	MICRO excerpt (PLATC, 2011, p.139)
…. Every object has both positive and negative charges. An uncharged or **neutral** object has the same number of positive and negative charges. A positively charged object has fewer negative charges than positive charges. A negatively charged object has more negative charges than positive charges.  Figure 15.1 (a) A neutral object  Figure 15.1 (b) A positively charged object	….Up until now we have talked about positively and negatively charged objects. Charged objects are charged because the number of protons and electrons in them is not the same. Negatively charged objects have more electrons than protons; positively charged objects have more protons than electrons. Neutral objects have the same number of protons and electrons. When we charge an object it is the electrons that move onto or off the object. When we make an object negatively charged, we add electrons. When we make it positively charged we remove electrons…

If we compare the first paragraphs of the MACRO and MICRO excerpts we notice no difference except that the terms *positive charges* and *negative charges* of the MACRO have

been replaced in the MICRO by the terms *protons* and *electrons*. Although the author does not link the MICRO to the MACRO version, and one can interpret the MICRO as a different reason for objects being charged or uncharged, a learner will most probably assume that each positive charge or "+" sign is a proton and each negative charge or "–" sign is an electron. However, the second paragraph of the MICRO excerpt conflicts with the inscription accompanying the MACRO excerpt. The inscription suggests that protons have been added to the object, but now learners are told that "it is the electrons that move onto or off the object". What are learners supposed to understand now?

The collection of meanings for "charge" from the MACRO excerpt of example 3 can be now supplemented with protons and electrons inside the object, as shown in Figure 5.2, which elsewhere in the textbook will be replaced again by "+" and "–" signs, but this time the signs will be located on the surface of objects.

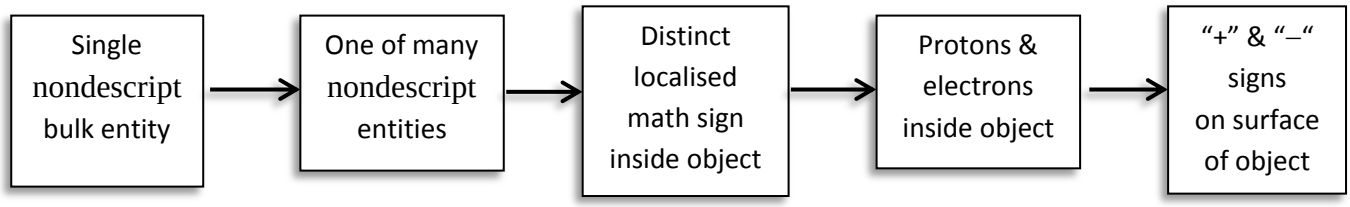


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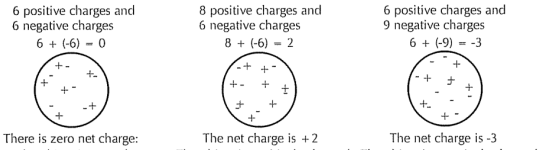
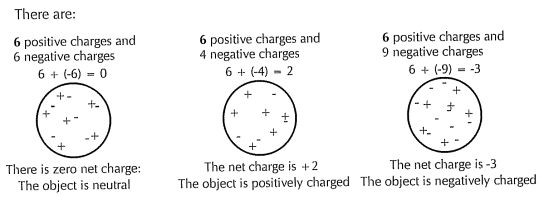
Figure 5.2 Meanings of charge continue…

Excerpt 4 in CT4 (MICRO) (from SIYAC, undated, p.254-255)

The MICRO excerpt of excerpt 4 from SIYAC follows immediately after the MACRO and it is only found in the CAPS version of the series.

MACRO excerpt (SIYAC, undated, p.254)	MICRO excerpt (SIYAC, undated, p.255)
… There are two types of electric charge: **positive** charge and **negative** charge. If the same amounts of negative and positive charge are found in an object, there is *no net charge* and the object is electrically **neutral**. If there is more than one type of charge than the other on the object then the object is said to be **electrically charged**. The picture below shows what the distribution of charge might look like …  	Positive charge is carried by the protons in the material and negative charge by electrons. The overall charge of an object is usually due to changes in the number of electrons. To make an object: **Positively charged**: electrons are removed making the object electron **deficient**. **Negatively charged**: electrons are added giving the object an **excess** of electron**s**. So in practice what happens is that the number of positive charges (protons) remains the same and the number of electrons changes: 

Unlike in PLATC, the SIYAC author states clearly that positive charge is carried by protons etc. Hence we understand that the "+" and "–" signs in the figures are either the *charges carried* by protons and electrons or the actual protons and electrons. In the former case, we are left with the question: What exactly is the 'charge' carried by these particles? The answer to which will never come up in the book. Unfortunately we have no reasons to 'see' whether electrons have entered or left the 'object', as claimed, because the three diagrams in the figure show different numbers of everything and we cannot compare. The repetition of the same figure as in the MACRO excerpt affirms that "+" and "–" signs have to do with protons and electrons, which in neutral materials come in pairs. All these conflict with what learners

have learned about the "structure of the atom", but then again, the author has never claimed connection to the atom. According to the author, this is what happens *in practice*. We are once again prompted to perceive this unfortunate model as reality and live with its complexities and the myriads of unwanted interpretations it generates.

Excerpt 5 in CT4 (MICRO)(from OXFC, 2011, p.154)

The OXFN and OXFC texts, begin the chapter with a brief introduction to the "atom", though the word "model" is never introduced along with it. Excerpt 5 in CT4 is part of this introduction and is repeated below. The inscription included in the example appears only in the CAPS version of the series (OXFC, 2011).

OXFC (2011), p.154 MICRO excerpt

All materials consist of very small particles called atoms… All materials contain charges. Any object consists of enormous numbers of atoms and has even more charge-carrying protons and electrons.

An object that has an equal number of electrons and protons is neutral. Although the object has a large number of charges the **net charge** of the object is zero.

A positively charged object has fewer electrons than protons. It is electron deficient. If it is negatively charged, an object has more electrons than protons. It has an excess of electrons.

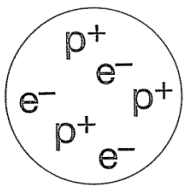


Figure 3 The net charge is zero when the number of electrons and protons is equal.

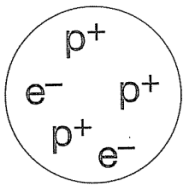


Figure 4 The net charge is positive when there are fewer electrons than protons.

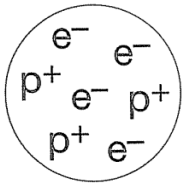


Figure 5 The net charge is negative when there are m electrons than protons.

The author articulates in terms of protons and electrons, but there are also references to 'charges'. Charges, as in the case of SIYAC, can be understood as either something carried by protons and electrons or as the actual protons and electrons. The inscription has been added as an afterthought (it does not feature in the NCS book, OXFN, 2008) with no changes in the text to accommodate it or direct learners to it, despite the fact that as in the previous

examples it depicts extra information and introduces new symbols which will never be used again in the chapter. But perhaps the biggest reason for concern is the possible message sent by the expression "Any object consists of enormous numbers of atoms and has even more charge-carrying protons and electrons". Learners may interpret this as objects consisting of atoms and in addition they contain extra protons and electrons which determine whether the object is charged or not. The inscription may be reinforcing this idea by showing protons and electrons in haphazard positions. In fact this erroneous notion may be associated with the previous examples as well which show 'charges' arranged in ways that would not agree with the particle model of matter or the structure of the atom. None of the textbooks (except for OXFN, see excerpt 7 in CT4) refers to electrons and protons in their context within the atom, even when there are statements that it is only electron numbers that change. The message sent is that the origin of charge lies in the protons and electrons rather than in the atom, as if charges in electrostatics are spares and autonomous. A similar notion was detected among prospective teachers in Sarikaya (2007):

> PTs imagined that the smallest units of matter were the protons and the electrons rather than the atoms or the molecules, as if these particles had been independent of each other in matter…the positive and negative charges in the matter were shown in the same way in their textbooks. (Sarikaya, 2007, p.56)

References to electrons and protons alone do not guarantee that learners will associate them with the atom. Yet distinction of materials in terms of their electric properties and processes such as charging and polarisation cannot be understood without acknowledging the freedoms and behaviours charged particles are afforded within the atom.

5.4.3 When macro is not macro and micro is not micro

The insights gained by the analysis of the diagrams and accompanying texts in CT4, and which represent 75% of grade 10 CAPS textbooks, raise two pivotal questions: a) Are inclusions of such diagrams representing positive and negative charges inside neutral and charged objects really helpful? and b) What is the rationale behind this double presentation of MACRO and MICRO? Some insights on these questions are given in what follows.

5.4.3.1 On diagrams for counting charges

What is the intended purpose of the diagrams in CT4? According to the accompanying texts the primary role of the diagrams is for us, readers, to see the two types of charges and count them. We are expected to count charges to 'see' that a neutral object has equal numbers of positive and negative charges, while a charged object has unequal numbers, and this would presumably enhance our understanding. But it is doubtful whether counting charges would offer extra understanding that we would not pick up from the text alone. What does generate new understandings however, is the extra information depicted by the diagrams and which is not accounted for in the text. It has been argued in the previous section that the messages sent by these diagrams are a reason for concern. Insights generated are misleading rather than helping. This is because the featured diagrams are models, representations of some unknown microcosm of 'charges', the behaviours of which are unlike anything learners have learned so far or are about to learn in what follows. Learners are left to decipher these models and invent assumptions that will conflict with future learning. The true accomplishment of these

diagrams is utter confusion, because they are neither representations of a consensus scientific model nor do they reflect a strategic approach to representing charges.

In science education, visual representations are valued pedagogic tools for understanding and explaining, when needed, provided they are well thought and appropriately introduced. But authors of the examples under consideration do not appear to have had a clear vision of what they wanted to achieve by including the figures, other than comparing numbers. In PLATC (2011), the figure appears to be included for the sake of including a figure, though five pages later there is a similar figure showing charges in conducting spheres, see Figure 5.3. In SIYAC (undated), the diagram appears as if taken ready-made from some source (internet perhaps) that offered the seeming advantage of incorporating 'net charge', seen perhaps as a 'bonus'. In OXFC (2011) the diagram is an afterthought that does not feature in the NCS version (OXFN, 2008), but also offers the 'bonus' of 'net charge'. Such superficial deployment of diagrams/representations in science textbooks ought to have negative consequences for learners. Furthermore, comparing numbers of positive and negative charges does not really command the deployment of a visual aid, especially so for Grade 10 learners. No research was found on the effect of such diagrams.

To address the second question posed above however, on the rationale behind the double presentation of MACRO and MICRO in the texts, is not as straightforward. This is the main concern of the remaining parts of this section. Up to this point (as has been stated earlier, p.140), an excerpt is provisionally described as MACRO if the author articulates in terms of positive and negative charge/s and MICRO if there is reference to electrons and protons.

5.4.3.2 Authors avoid the term 'electron'

A trend that has been identified in general through the analysis of the sections of Electrostatics is that authors favour elaborating on electrostatics phenomena in terms of positive and negative charge/s, unless they are compelled by the curriculum to refer to electrons. And even then 'electrons' may be evaded, as we find in expressions such as: "This means that they (objects) gain or lose negative charge" (SIYAC, undated, p.255) or "although charges in an insulator cannot move from atom to atom they can spend more of their time on one side of the atom…" (OXFC, 2011, p.156 and OXFN, 2008, p.63). Although the intention of these authors was possibly to make the text easier, ironically, both of these expressions are now wrong because the term *electron* has been replaced by the term 'charge'. According to the SIYAC (undated) author, only negative charge transfers between objects implying that positive charge does not. In the SIYAC example, the author uses *negative charge* to mean *electrons*. In physics, *charge* is a physical quantity and has a particular meaning (property), different from that of *electron* (particle). In physics, positive charge may transfer between solid objects (this is discussed under CT7 and CT8). In the second (OXFC, 2011) example, the author presents us with the notion that 'charge' is something that moves between or inside atoms. The OXFC (2011) author also refers to *charge* in the sense of *electrons*, and in addition blatantly disregards the existence of the charge of the nucleus and the charge of other electrons that do not move from atom to atom. The author unwittingly has detached the concept of 'charge' from the atom as if two independent entities: the 'charge' and the 'atom'. Nevertheless, the examples suggest that in both cases authors had clearly *electrons* in mind, but they chose to use the term *charge* instead.

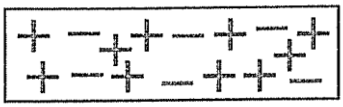
5.4.3.3 Alternative micro-cosmos

It appears that most authors espouse the idea that notions of electrons and protons make the text seem harder and thus intimidating to learners. Concerning elementary electrostatics, no research was found on aspects relating to how learners respond to texts articulating in terms of positive/negative charges or protons/electrons. It is possible that this idea originates in the notion that learners should be exposed to macro observations and empirical assumptions first before introduced to micro considerations, the latter being perceived as the 'hard part' of science. If this is the case, we ought to accept that the concept *charge* as should be used in macroscopic experiences, i.e. as a descriptive and unsubstantiated bulk attribute, has been misunderstood and/or eroded through generations of textbooks and teaching. In textbooks we find that the terms *charge* and *charges* are being used interchangeably, after 'charges' having being introduced abruptly and with no justification for the transition from 'charge' to 'charges'. We are lead implicitly to understand that 'charges' are distinct entities existing inside materials. In this sense, 'charges' have nothing to do with the empirical term 'charge' that we assume from macroscopic observations. 'Charges' are part of a mind construct, much like atoms, protons and electrons are. Hence authors in their effort to avoid theoretically based micro-considerations, which they consider 'hard', tacitly and possibly unknowingly introduce us to an inferior mind construct of a micro-cosmos of positive/negative charges with no assumptions or internal consistency and no explanatory power. Such inferior constructs, instead of explaining and unifying electrostatics phenomena, can only 'illustrate' one particular aspect, in the case of CT4, the numbers of positive/negative 'charges' in charged and uncharged objects. Furió *et al*. (2004) make a similar remark on the reasoning of high school and undergraduate university students "these forms of reasoning… look not for a unified explanation of the different electrostatic phenomena but for a unique response to a

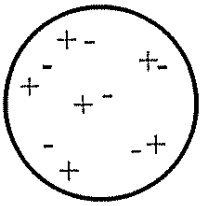
specific situation" (Furió *et al*., 2004, p.306), which they attribute to methodological deficiencies resulting from 'fixation to previously badly learned ideas'.

5.4.3.4 Quasi-macro or the "Quasi-modo" model

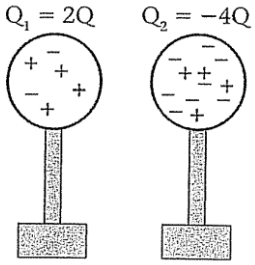
What the logic may be behind replacing powerful theoretical constructs learners are already familiar with (such as the particulate model of matter and the atomic model) with seriously compromised constructs, such as the ones represented by the figures in CT4, since in both cases learners would have to deal with models of a micro-cosmos? The analysis so far suggests that authors were not interested in distinguishing between *macro* and *micro* and linking the two. Instead it appears that authors aimed at *easy* before introducing *hard* presentations. For authors, MACRO corresponds to an *easy* way of elaborating on an electrostatics process / phenomenon through an effortless (or cunning?) transition from "charge of an object" to "charges in an object", afforded by the similarity of the vocabulary, for example, "When an object is charged it does not mean that it has only one type of charge. Every object has both positive and negative charges" (PLATC, 2011, p.135). In the CAPS textbooks such expressions are usually accompanied by visual representations as shown in Figure 5.3.



PLATC (2011), p. 135



SIYAC (undated), p. 255



PLATC (2011), p. 140

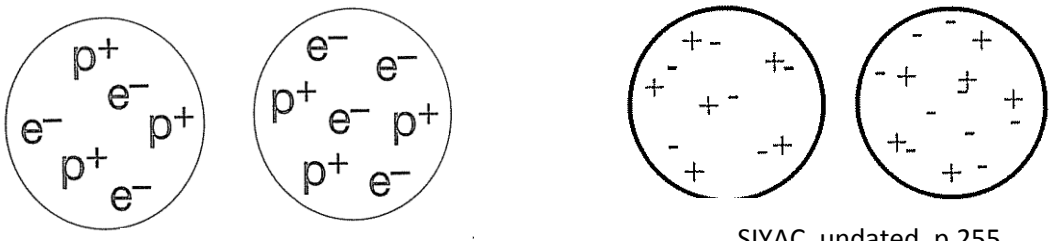
Figure 5.3 Representations of the "quasi-modo" model of matter, representing 'charges' inside objects.

Since ‘charge’ is neither introduced as a descriptive term nor as a physical quantity nor as anything else, and since ‘charges’ are introduced abruptly with no justification for the plural, the novice learner of electricity is prompted to understand that ‘charges’ are used as a continuation of (macro) descriptions that are now shifted to the interior of objects. This notion is enhanced by expressions such as: “the picture below shows what the distribution of charge might look like…” (SIYAC, 2011, p.254), which imply ‘we are looking at reality at a micro-level’. According to the scientific mode of thought however, the inaccessible world of micro cannot be described on macro-terms (Ogborn, 2008). Properties and behaviours of micro-entities assigned or assumed by the scientific mind have nothing in common with the behaviours and the nature of entities of real world systems.

Hence, the mind construct of ‘charges’ employed by the authors for an easy transition to the micro-level, is regarded in this study as a quasi-macro model (named “quasi-modo”), with the prefix *quasi* standing for pseudo or false. It cannot be macro since it concerns happenings in an inaccessible micro-cosmos that feigns reality though no micro-assumptions in the scientific tradition have been mediated for it. Ironically, scientists often discuss electrical phenomena in terms of ‘charge’ and ‘charges’ in short-cut descriptions which are however microscopic. By ‘charges’, other scientists understand exactly what is meant from the context. Scientists are aware of what charge and charged particles are, where they come from and how they behave, they may not need a detailed microscopic description in terms of atoms and electrons to understand a process. But textbook authors cannot afford to take this short-cut of ‘charges’ when addressing novice learners because for them ‘charges’ is meaningless. Without introducing charge and charged particles in the context of the atom, and articulating consistently in precise terms, learners will have nothing to hold on and will invent own understandings.

5.4.3.5 Quasi-micro or the "electron-proton" model

According to the data in CT4, eight out of the ten books also distinguish between charged and uncharged objects in terms of numbers of protons and electrons, taking care to note that it is only the number of electrons that varies. In all but one cases, the distinction is presented as a statement with no justification, which means that there are no attempts to link the particles (protons/electrons) and their said behaviour to the atomic model or other relevant theoretical construct. Only OXFN (2008) (see excerpt 7 in CT4) attempts a link to "our knowledge of matter" that has been removed from the CAPS version (OXFC, 2011). In this sense, references to protons and electrons shed no further understanding than references to the non-descript positive and negative charges do. This is characteristically illustrated by the PLATC (2011) and SIYAC (undated) texts, already discussed, which firstly present the distinction in terms of positive and negative charges followed by a second distinct presentation in terms of protons and electrons, and yet, the only difference between the two is the replacement of the terms "positive/negative charges" with the terms "protons/electrons" and the unjustified statement that it is only electrons that transfer. Hence, although the introduction to the terms protons/electrons is presented as a revelation, nothing new is revealed. The message sent is that matter consists of protons and electrons randomly arranged and their numbers determine whether an object is charged or not.



OXFC, 2011, p.154

SIYAC, undated, p.255

Figure 5.4 Representations of the "electron-proton" model of matter, representing protons and electrons inside objects

Figure 5.4 shows the types of representations of this model, the "proton-electron" author model of matter, with the extra assumption that only electrons can move in or out. Comparing this to the model in Figure 5.3 (p.162) we see essentially nothing different.

5.4.3.6 Author notions of 'science models'

> It is important to realise that what we will go on to describe is only a theory. It cannot be proved beyond doubt, but the fact that it helps us to explain our observations of changes in phase, and other properties of matter, suggests that it probably is more than just a theory.
> (SIYAN, 2010, p.38, on the Kinetic Theory of Matter)

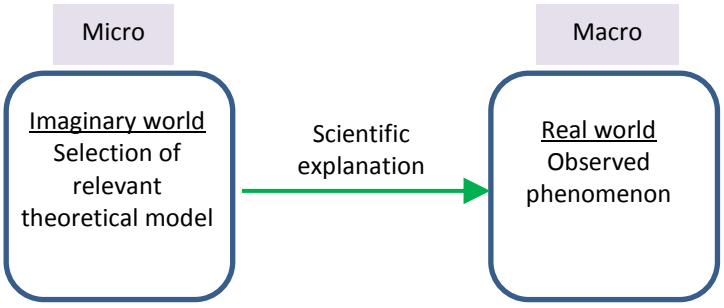
The distinction between macro and micro appears to be unclear in the minds of the authors, as indicated by the inclusion of models such as the "quasi-modo" and the "electron-proton" models of matter, which neither qualify as macro nor as micro nor have they any explanatory power. In an effort to gain more insight on the understanding of South African science textbook authors on the nature and use of scientific models in science education, sections of the textbooks under Mater and Materials were visited to look for excerpts on "models". The table in Appendix C lists excerpts found in the grade 10 CAPS textbooks. Apart from the SIYAN (2010), no corresponding sections were found in the remaining NATED and NCS textbooks of any grade, despite the occasional 'historic' references to the development of the atomic model. The SIYAN (2010) offers some insights on what a 'theory' is in the introduction to the "Kinetic theory of matter", which is shown above. The excerpt suggests that for the SIYAN (2010) author a science theory is no more than 'tall stories' that should be taken with caution, as in the everyday meaning of the word 'theory'. This is in stark contrast with the consensus view among science educators, scientists and philosophers of science for whom a scientific theory is a well-established, highly substantiated, internally consistent system of explanations (e.g. Lederman, 2007). The explicit inclusion on models in the CAPS textbooks can be seen as a positive step towards integrating nature of science (NOS) in

science instruction. However, the excerpts in Appendix C leave a bitter taste. In none of the textbooks is the distinction between a scientific model and other instructional models extant or clear. Characteristically, OXFC (2011) includes an excerpt on "How to recognise a scientific model" by following vocabulary clues: "The words "model"-atomic model- and "theory"-kinetic molecular theory- are clues that you are using a scientific model. Another clue is that the situation has been simplified" (OXFC, 2011, p.9). Three books, SIYAC (undated), S&MC (2011) and OXFC (2011), clearly state that science models are simplifications of reality, while in the fourth book this is implied "you cannot see atoms…but you can imagine what…look like by referring to the diagrams…" (PLATC, 2011, p.15). In fact, in all four books, a science model is portrayed as a visual representation or picture: "these (models) show and explain scientific ideas or theories" (PLATC, 2011, p. 17) or "scientists came up with lots of different models or pictures to describe what atoms look like" (SIYAC, undated, p.62) or "but we must remember that they (models) are only a picture" (S&MC, 2011, p.20). Although the authors of the excerpts in Appendix C may not be the authors of Electrostatics, the table nevertheless gives an idea of understandings of science authors on the construct NOS and particularly so on the notions and use of scientific models. There is a striking similarity of these erroneous notions in all textbooks, which indicates that authors might have only looked at other textbooks for ideas rather than researching scholarly articles. Another possibility is that authors during their training as teachers were not introduced adequately or sufficiently to the construct NOS. Smit and Finegold (1995), in a population study of 16 South African universities, found that more than half of prospective physical sciences teachers, already in possession of at least a three-year BSc degree and enrolled for a post-graduate teacher's diploma, demonstrated similar understandings on the nature and use of scientific models, as the textbook authors in this study do. In the same paper it is also pointed out that the perception of a model as a replica, simplification, etc. of a

real thing, was more prominent among students with a background in the biological sciences (but not restricted to them). These 'biology' students were also the majority among the group of post-graduate students, though they were all being prepared to teach physics and chemistry as an integrated subject at secondary school level. Smit and Finegold (1995) suggest that the notion of a science model as a copy of reality, held prominently among the group of 'biology' students, may be due to their exposure during their previous studies to replicas of the human skeleton, lungs and other organs, cells, insects, and so on, which are referred to as models. The notion of 'model' in biological disciplines interferes with the notion of (science) model as is expected to be understood in the physical sciences. Erroneous notions of a science model, held by students, might be at the source of students' misconceptions identified in the literature, assert Smit and Finegold (1995), referring to misconceptions in the topic of optics, a number of which are revealed by the study accounted for in the paper.

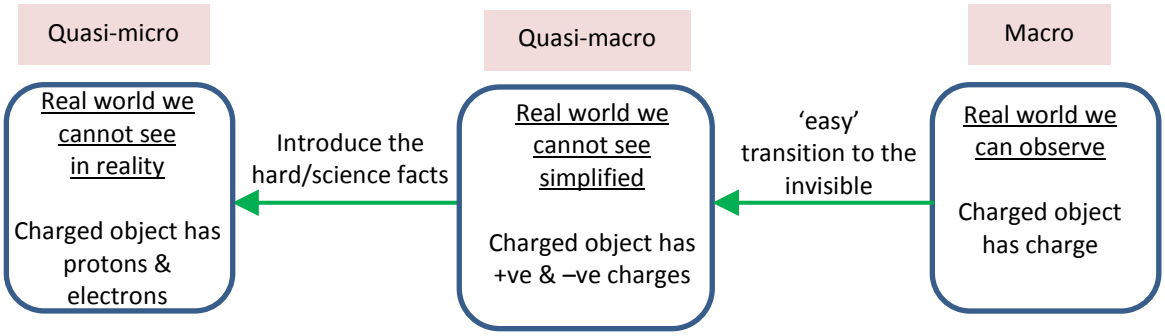
5.4.3.7 Authors' notion of 'science explanation'

Hence, it appears that for textbook authors, there is no distinction between a scientific model and a model that aids teaching; a scientific model is a diagram or picture depicting a simplification of a real world system. In this case, a link between macro and micro makes no sense because the concern shifts to the issue of simplification and complexity. This ought to have consequences on the goal of a *textbook explanation* as compared to the goal of a *scientific explanation*. Although simplicity is valued in science, simplification is not the final goal of a scientific explanation. For the scientist, a *scientific explanation* is using a theoretical construct to tell the story of how its *imaginary* players have acted to produce a real world phenomenon (Ogborn, 2008). This is represented schematically by Figure 5.5 (this author's diagram). A scientific explanation is based on deductive arguments and so it is expected to leave no doubt, which means to lead to one interpretation.



Source: By researcher

Figure 5.5 A "scientific explanation"



Source: By researcher

Figure 5.6 Textbook 'explanation' of charged / uncharged objects

On the other hand, the endeavours of the textbook authors as revealed by the preceding analysis on charged and uncharged objects, indicates that they somehow take the reverse path from the one depicted in Figure 5.5. The author's path is shown in Figure 5.6 (this author's diagram). The authors from the macro-level proceed to the quasi-macro through a supposedly 'easy' transition from *charge* to *charges* and then reveal that positive and negative charges are in fact protons and electrons and this culminates the presentation of charged and uncharged objects. Hence it appears that the authors' goal is not to explain the macro-observation, but to use it as a vehicle to 'introduce' the micro-cosmos in a simplified manner

because we cannot see it. This for the authors is considered an ‘explanation’. It is reasonable to expect that such an ‘explanation’ would allow for different interpretations of the micro-cosmos depending on the type and extend of the simplification. Regarding explanations, it seems that the maxim for textbook authors is “simplification of the micro-cosmos”, the maxim for the scientist is “beyond doubt explanation of the macro-cosmos”.

5.5 ASPECT OF ANALYSIS 4: Materials with different electric properties

5.5.1 Conductors and insulators in the curricula

As far as curricula are concerned, in NATED there is no reference to conductors and insulators, neither in the standard 10 nor in the standard 7 documents where Electrostatics appears. In CAPS, the section on "*conductors and insulators*" which was featuring in NCS, has been removed from Electrostatics. Perhaps curriculum developers of CAPS felt that the distinction between conductors and insulators is dealt with adequately and sufficiently under "Mater and Materials". Yet, upon examination of the chapter "Mater and Materials" in the grade 10 textbooks, we find that this distinction is done briefly and only in macroscopic terms as expected (e.g. in terms of allowing current or 'electricity' or similar), as shown in Table 5.3. In addition, two remarks ought to be made concerning the underlined expressions in Table 5.3, as these could present a potential source of confusion for learners: Firstly, in all four textbooks the distinction between conductors and insulators is unclear because it is not done on common grounds. For example, a conductor *allows current* / an insulator *does not carry charge*, or, *allows current* / *does not conduct electricity*. Furthermore, since learners are being introduced to conductors, why are they expected to already know what it means "*to conduct*"? With such imprecise expressions learners might fail to grasp what is that distinguishes the two classes of materials. Secondly, three of the four CAPS textbooks make use of the word 'electricity'. What are learners supposed to understand by 'electricity'? It could mean *charge* or *current* or *energy* or something else that learners must figure out. The

'meaning' of the word *electricity* or lack thereof has been discussed in section 5.1.3. It is possible that some authors believe that 'electricity', being such a familiar term, makes the text less intimidating. It is also possible that some authors use it because 'everybody else does', a practice that could allude as to why at schools today we are still trapped in two-century old science ideas. Concerns on the similarity of textbooks are occasionally raised in the literature, as in de Posada (1999) "...the primary innovations in science textbooks since the beginning of the century have been in format, not content" (p.438). No research was found on the understanding of the word 'electricity' among learners or teachers.

Table 5.3 Distinction between conductors and insulators as presented in the Topic "Matter & Materials" in CAPS grade 10 textbooks

Textbook	An electrical conductor /insulator is…
PLATC (2011)	p.9: Materials that can transmit an electric current p.10: Materials that do not conduct electricity They do not allow current to pass through...
SIYAC (undated)	p.43: A substance that allows an electric current to pass through it A non-conducting material that does not carry any charge
S&MC (2011)	p.44: some materials let electricity pass through them very easily…conductors materials that do not allow a current to pass through…insulators
OXFC (2011)	p.28: substance that allows electric current to pass through An insulator does not conduct electricity

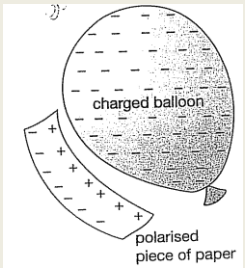
The NCS, under "Mater and Materials", remarked that the distinction between conductors and insulators was to be done descriptively at first, with the possible aim to expand this to a microscopic explanation under Electrostatics: "There is some overlap between this section and Electricity and Magnetism…this is more descriptive. It may be useful to raise the idea that metals have outer electrons, which are free to move, through the crystal lattice,

anticipating the atomic theory…" (DoE, 2006, p.38). But it seems that this point was overlooked by CAPS developers. Furthermore, in the CAPS topic "Mater and Materials", the section *Classification of Materials* is conveyed as a *revision* from Grade 9. If this is the case, then we may ask what new did curriculum developers envisioned for the learners of grade 10? Should they not attempt to extend this grade 9 knowledge from the descriptive level to something more substantial, more insightful?

Categorisation Table 5 CATEGORY: Distinction between conductors and insulators

MACRO	SPS		BJ		SS		PLATC		SIYAN	SIYAC		S&MN	S&MC		OXFN	OXFC	
Materials can be classified in terms of their different electric properties.																	OXFN (2008): "Classify" by memory See (8c)
Conductors are materials that allow charge to move through or along them easily.				Implied & refers to charge See (2)					✓	✓	In terms of distribution & allow movement See (4b & 4c)				✓		Test with electroscope See (8b)
Insulators do not allow movement of charge (hence, when charged, the charge remains at the place where it was rubbed).			✓	In terms of 'charges' See (2)				Unacceptable distinction See (3a)	✓	✓	In terms of distribution & allow movement See (4b & 4c)	✓		Don't allow electricity See (6)	✓	✓	OXFN (2008): See (8b) OXFC (2011): "key words" see (7)
MICRO																	
Insulators: There are no mobile charged particles (charge carriers) in the material. Electrons are tightly bound to nuclei.	✓	In terms of charge carriers See (1)					✓	See (3b)	✓	✓	See (4a) in terms of "move through" SIYAN (2010) only, see (5)						Only implied under polarisation See (9)
Conductors: Existence of mobile charged particles (charge carriers) that can move with relative ease throughout the material.		Implied See (1)					✓	See (3c)	✓	✓	Allow electrons to move through Empty-pipe See (4a)	✓		Allow electrons to move through See (6)			
Metallic conductors: Mobile charge carriers are electrons. Link: Sea of electrons / free / delocalised electrons that infuse the arrays of positively charged ion cores. In electricity focus on metallic conductors.							✓	But assigns mobile electrons to all conductors See (3e)	✓		SIYAN (2010) only, but assigns mobile electrons to all conductors See (5)						
Conductors (**ionic**): The mobile charge carriers are positive and negative ions, e.g. the human body or the ground/earth. There are no free electrons in the human body.											SIYAC (undated), p.261 Electrons move freely in human body			S&MN (2005) p.94 Electrons flow in human body p99 & 101: water and moist air conduct			OXFN (2008), p 60 moving electrons in human body p.64 moving electrons in Earth's surface

	EXERPTS IN TEXTBOOKS	COMMENTS & NOTES
1)	SPS (1987), p.69: Heading: "Distribution of charge on conductors" When a conductor is charged so that it carries an excess charge, the like charge carriers repel one another so that the charge is spread over the surface of the conductor…. Non-conductors can also be charged, but the charge is not spread evenly across the surface. It remains concentrated where it was placed because the charge carriers cannot move freely through such a substance.	The distinction (implied) between conductors and insulators is done in terms of charge spreading on the surface There is no previous introduction or mention to conductors and non-conductors or to 'charge carriers'. The section "Distribution of charge on conductors" starts abruptly.
2)	BJ (1987), p.64: If we charge an insulated *conductor* by touching it with a charged conductor, the charge distributes itself over the whole outer surface… A non-conductor may also be charged, but the charges do not distribute themselves over the surface of the conductor. They remain at the point at which they have been put.	The distinction (implied) between conductors and insulators is done in terms of charge distribution on the surface.
3)	PLATC (2011), p.137: a) Objects that can be charged by rubbing are **insulators**. Charges are either rubbed onto or off them. b) In an insulator the charges are not free to move, that is, they are not mobile. Some insulators can be charged by rubbing, but some cannot, for example, wood. c) A **conductor** is a material in which there are many mobile charges. Any charges placed on a conductor will immediately spread out evenly on the conductor. If you are holding the conductor, the excess charges will move through your hand and into the ground, so you will not be able to charge the conductor. You can only charge a conductor if you do not touch it with your hand and it is resting on an insulator so it does not come into contact with the Earth. d) Box: "**Conductor** – materials that conduct electric current. **Insulators** – materials which do not conduct electric current" e) Bottom of page under polarisation: "In a conductor there are many mobile electrons that can move within the object…"	Distinction (implied) between conductors and insulators in terms of: a) charging by rubbing b) & c) existence of mobile charges d) conducting or not conducting electric current Characteristics of conductors with no counterparts for insulators: c) spreading of charge over entire surface e) existence of mobile electrons Errors: c) charge does not spread evenly on surface, unless conductor is spherical e) mobile electrons exist in metallic conductors. Cannot be generalised to all conductors Unrelated definitions. Info in box does not relate to text. Conduction as a concept has not been explained.
4)	SIYAC (undated), p.261 & SIYAN (2010), p.309: a) Some materials allow electrons to move relatively freely through them (e.g. most metals, human body)…called **conductors** Other materials do not allow the charge carriers, the electrons, to move through…the electrons are bound to the atoms… called **non-conductors** or **insulators**. b) If an excess charge is placed on an insulator, it will stay where it is put and there will be a concentration of charge in that area of the object. However, if an excess of charge is placed on a conductor, the like charges will repel each other and spread out over the outside surface of the object…. (SIYAC, undated, p.272 & SIYAN, 2010, p.312): Summary: c) Conductors allow charge to move through them easily Insulators do not allow charge to move through them easily	There is no link between micro and macro descriptions or claims, for example parts (a) and (b). In the summary there is only a macro distinction between conductors & insulators rather than embracing the new knowledge that learners acquired in grade 10. Misconceptions: Human body is an ionic conductor, no mobile electrons. The type of charge carriers depends on the type of conductor, which are not necessarily electrons as implied. EMPTY PIPE: …move 'through them' rather than already in them… No advantage taken of the micro connection. Essentially a macro description with electrons.
5)	SIYAN (2010), p.309: "Extension: Charge and electrons" …In a conducting material (e.g. copper), when the atoms bond to form the material, some of the outermost, loosely bound electrons become detached from the individual atoms and so become free to move around. The charge carried by these electrons can move around in the material. In insulators, there are very few, if any, free electrons and so the charge cannot move around the material.	This applies to solid metallic conductors, not to conductors in general This part has been removed from the CAPS textbook, yet this should be the starting point for a micro-distinction between conductors/insulators. No link to the metallic bond model from Mater and Materials and no link to 4a and 4b above.

6)	S&MN (2005), p.99: some materials are good at allowing electrons, and therefore electrical charges, to flow through them. These are **conductors**, and can be used to conduct electricity. Metals are generally good conductors and so is carbon in the form of graphite. Other materials don't allow electricity to flow through them at all. These are **insulators**, and can be used to prevent electricity from flowing. Non-metals are generally used as insulators. ….the wire inside the cable is a conductor, and allows electricity to flow <u>from the plug to the television</u>….as you can see, both conductors and insulators are very important for the safe use of electricity….	Located at end of chapter and is presented more as enrichment rather than anything of consequence to the chapter. It appears more relevant to electric circuits. Use of macroscopic descriptions using the words electron and electricity. 'Electricity' is used with multiple meanings, which will differ depending on the reader. Underlined: Misconception detected in primary school learners. Also reflects the sequential and local reasoning adopted throughout Electricity and Magnetism in this series of textbooks.
7)	OXFC (2011): **NOTHING on *conductors*,** but p.158 refers to conducting spheres (called for in CAPS) p.155: The substance that loses electrons becomes positive and the other one becomes negative. When this happens to an **insulator** such as wool or glass the substance remains charged. Key words: insulator: material that does not allow charges to travel through it.	No reference to conductors. Learners are to infer that insulators are materials that retain their charge. A common macro description of insulators is given in the margin not linked to the text.
8)	OXFN (2008), p.61-62: "The electroscope" a) The disc, rod and gold leaf are all conductors of electricity. This means that electrons can move freely from atom to atom…. Electrons are <u>repelled</u> from the disc and move down the rod… b) Further down: **Conductors** of electricity allow charges to move through them – **insulators** do not. You can use an electroscope to test whether substances are conductors of electricity or insulators (*instructions are given of what to look for, but no explanations*) c) p.63 "Activity 3: "Electrostatics", question 2: Classify the following substances as conductors or insulators: metals, plastic, wood, human skin, cotton cloth, salt solution, dry salt, sugar and air. (*In a previous activity learners have hopefully tested some of these items with an electroscope*)	Electrons moving "from atom to atom" is not in agreement with the metallic bond model and the notion of 'sea of electrons' or free electrons. The electroscope and its behaviour is presented before introducing conductors and before polarisation. Author relies upon knowledge of forces between charges for learners to invent polarisation. Learners are expected to memorise which items are conductors or insulators based on a test with the electroscope (supposedly done in a practical activity earlier. What happens if learners have not done the activity?) Why are learners asked to classify materials they have never encountered before in the chapter, such as gases, liquids, metallic and ionic conductors? Why are such materials conductors or insulators? The author cannot explain this distinction, yet learners are expected to do so unguided.
9)	OXFN (2008), p.63 & OXFC (2011), p.156: "Polarisation" Although charges in an insulator cannot move from atom to atom, they can spend more of their time on one side of an atom or molecule than on the other. (*Presumably it means in the presence of external charge, not mentioned, in which case the atom polarises*) Fig shows how the negative charge on the balloon repels the electrons into the paper. Caption in OXF-CAPS fig: "Polarisation in a solid. Electrons move to one side of the atoms and molecules"  **Figure 13** Polarisation in a solid. Electrons move to one side of the atoms and molecules.	We have never been told how or why charges move or not move in conductors and insulators. What is "spend their time"? What are the circumstances that cause charges to spend more time in some places than in others? What are the charges in the atom? Then we are told that electrons are repelled into the paper. There is no coherence or consistency. "*<u>Charges</u> can spend more time on one side of the <u>atom</u>*", implies that the only charges in the atom are the electrons. The author overlooks the charge of the nucleus as if it is of no consequence. What we see in the figure is not in agreement with the claim in the caption.

5.5.2 Analysis and interpretation of data in CT5: Distinction between conductors and insulators

5.5.2.1 General overview

A) Classification into conductors and insulators

In electricity, one would expect the distinction between conductors and insulators to be of utmost importance, with conductors being a major focus. Yet this is not the case in the examined texts under electrostatics. None of the authors articulates explicitly that materials can be classified into groups based on their electric properties (first row in CT5). Learners are left on their own to infer this classification, which in some texts is impossible due to lack of reference to particular or comparative behaviours. Also none of the CAPS and NCS textbooks makes the link to the topic "Mater and Materials" where various classifications of materials are expanded descriptively, including the classification into conductors, semiconductors and insulators. As has been noted earlier, it appears that authors, when they embarked in the writing of the chapter "Electrostatics", did so without first becoming familiar with the entirety of the grade 10 syllabus, let alone with the whole of the FET curriculum. It also appears that there was no communication between authors of different sections of the same textbook.

B) Overall presentation of conductors and insulators in the textbooks

The aspects of analysis listed in the left hand column of CT5 concern the primary cause of distinction between conductors and insulators. They have been separated into ***macro***

descriptions of observable differences in behaviour and ***micro*** descriptions which consider aspects of the atomic and metallic bond models that would enable explanations of macro behaviours. This was to cater for the possibility that textbooks offered both macro and micro presentations. In the case of macro, the primary distinction would be the observation of whether materials allow or do not allow charge to move through or along them. In the case of micro, this would be the existence or non-existence of mobile charged particles in the materials.

Data in CT5 were collected by placing 'ticks' where textbooks mentioned something reminiscent of the corresponding aspect of analysis in the left-hand column. These direct to corresponding examples in CT5, where passages are displayed in the order in which they appear in each book, and which at times involved collecting bits and pieces from different sections of the chapter. Allocating ticks to macro and micro aspects in CT5 however, was not a straightforward task, hence the shown allocation is not cast in stone. This is because authors, more often than not, mingle micro-considerations with macro descriptions. For example, "some materials are good at allowing electrons, and therefore electrical charges, to flow through them" (excerpt 6 in CT5). Allowing charge to flow/move through them is a description of a macroscopic behaviour of materials. We can infer this behaviour through experiments. The expression of excerpt 6, which is also found in SIYAC (undated) and SIYAN (2010) books of excerpt 4, is a macro description disguised as micro by replacing 'charge' with 'electrons'. This replacement sheds no new light on why materials exhibit this macro behaviour of 'allowing'. Eventually, using discretion as to the intentions of the author, the expression was placed under *micro*. As the analysis of CT4 has revealed, authors use the word 'electron' in the belief that they link macro to micro and in most textbooks this is as far as a 'micro-macro connection' goes.

The data in CT5 reveal that apart from PLATC (2011), SIYAC (undated) and SIYAN (2010) textbooks, there are very few ticks allocated. This signifies that most authors have overlooked the primary cause of distinction between conductors and insulators. Five out of ten textbooks are given either one or none ticks. This represents 100% of the NATED and 50% of the CAPS approved books.

The OXFC (2011) refers to insulators, but does not mention conductors. The S&MC (2011) does not even mention the words *conductor* and *insulator* and just refers to *objects*. Similarly, the SS (1989) only refers to *substances*, and that 'some' substances can be charged by friction. This is the only hint that materials may have different electric properties. Elsewhere in the SS (1989) book there is a diagram of 'conducting' spheres given as an example of charge conservation, while the text states "…two charged spheres are brought into contact. The two spheres are of equal size and so the charge spreads over them equally" (SS, 1989, p.53). The fact that these spheres behave in the said way because they are conductors and that other non-conducting spheres would behave differently, was of no importance to the author. In fact, the SS (1989) and the S&MC (2011) are remarkably similar in this respect. However, the goal in SS (1989) is to argue that charge can be transferred from object to object, no matter what these objects are, and that charge is conserved. But the S&MC (2011) shows no evidence of discernible goal while there is evidence that the author is not conversant with the difference in behaviour between conductors and insulators, as explained under "charging" later on. The remaining seven textbooks refer to both conductors and insulators. They distinguish between the two in different ways, but implicitly and unsystematically.

CT5 reveals that none of the textbooks refer to metallic conductors as a special case of conductors in which the mobile charge carriers are electrons. References to (mobile) electrons are associated with all conductors in general. NCS books and half of the CAPS

books (PLATC, 2011 & SIYAC, undated) fall in this category (50% of the books). The remaining books either do not refer to electrons or they do not refer to conductors. The data suggest that authors are not aware of the distinction between ionic and metallic conductors. As a result, the last row in CT5 concerning ionic conductors has no ticks allocated. Instead, we have included instances from the texts where authors refer to the human body, the air or the ground without being aware that these are ionic conductors, because in most such instances they articulate in terms of electrons rather than positive and negative ions. The S&MN (2005) refers to 'moist air' as conducting "It's actually quite easy to explain thunderstorms when you know about electrostatics….when the thunderstorm is about to start, the air becomes moist. This means it can conduct electricity more effectively" (S&MN, 2005, p.101). The excerpt reflects utter misunderstanding of both the conductivity of water and air, let alone lightning and thunderstorms. Nevertheless, the author must have realised that during a thunderstorm the air somehow becomes conductive, and decided to attribute it to moisture. Yet the same author has claimed earlier in the chapter that "Static electricity occurs naturally, especially in dry weather", discussed in CT2. It becomes apparent that the author is unaware of the concept *ionised air*, has inadequate understanding of the topic Electrostatics and has not done research on it. The case is reminiscent of Gunstone *et al*. (2009) findings, where teachers and authors in Australia, whose understanding on DC circuits was a cause of concern, were of the opinion that DC electricity was essentially straightforward, as has been discussed in the Introduction. The combination of *not knowing* and *not being aware of it* (lack of metacognition) when it comes to physics authors may result in texts which may sound brief and simple, but which in actuality may be too simplistic to contribute to meaning making.

5.5.2.2 Contingent instead of efficient causes of distinction

Upon examining the examples in CT5 we find that although most authors overlook the primary cause of distinction between conductors and insulators they do mention other features or characteristic behaviours. These have been collected in Table 5.4, where they are listed per book and in the order in which they appear in each book. There are certain general remarks that can be made on this list:

A) Partial correlation of features

In most cases the number of features assigned to conductors differs from the number of features assigned to insulators. This is reflected sketchily in the column labelled "Feat.", where the left and right numbers denote the number of features assigned to conductors and insulators respectively. We also note that not all features assigned to conductors find counterparts in insulators and vice versa. The last column labelled "Correl." denotes how many features of conductors are correlated to those of insulators, in the sense that in the texts they appear at a reasonable distance from each other for learners to grasp the contrasting behaviour of the two classes of materials. Table 5.4 reveals that apart from the SIYAC (undated) and SIYAN (2010) books, which exhibit 3 and 4 correlations, all other textbooks manage 2 or less.

Table 5.4 Features of conductors / insulators per textbook

Textb	Conductor features	Insulator features	Feat.	Correl.
SPS	Charge carriers repel and spread ---	Charge does not spread Charge carriers cannot move freely	1 – 2	1
BJ	Charge distributes over outer surface	Charge does not distribute all over	1 – 1	1
SS	Nothing	Nothing	0 – 0	
PLATC	--- Many mobile charges Charges spread out evenly Can be charged if not touched Conducts current (in margin box) Many mobile electrons (under polarisation)	Can be charged by rubbing (but not all) Charges are not mobile --- --- Do not conduct current (in margin box) ---	5 – 3	2
SIYAN	Allow electrons to move through --- Excess charge spreads, like charges repel Loosely bound electrons become free Allow charge to move through (in summary)	Do not allow charge carriers/electrons to move Electrons are bound to atoms Excess charge stays put, concentrated charge Few free electrons if any Do not allow charge to move (in summary)	4 – 5	4
SIYAC	Allow electrons to move through --- Excess charge spreads, like charges repel ~~Loosely bound electrons become free~~ removed Allow charge to move through (in summary)	Do not allow charge carriers/electrons to move Electrons are bound to atoms Excess charge stays put, concentrated charge ~~Few free electrons if any~~ removed Do not allow charge to move (in summary)	3 – 4	3
S&MN	Allow electrons/charges to flow through Uses: to conduct electricity Allows electricity to flow	Don't allow electricity to flow through Uses: prevent electricity from flowing	3 – 2	2
S&MC	Nothing	Nothing	0 – 0	
OXFN	Electrons move freely from atom to atom Allow charges to move through them ---	--- Do not allow charges to move through Charges cannot move from atom to atom	2 – 2	1
OXFC	Nothing	Remains charged Does not allow charges to travel through (in box) Charges cannot move from atom to atom (polar.)	0 – 3	0

Categorisation Table 6 Dominant features of conductors / insulators in the textbooks

GR	Conductors	Textbooks		Insulators	Textbooks	
(I)	Spreading (repelling) charge over surface, distribution over surface	SPS BJ PLATC SIYAN SIYAC	5	Charge does not spread/ distribute, stays put	SPS BJ SIYAN SIYAC	4
(II)	Allow charge/electrons/electricity to move/flow through	SIYAN SIYAC S&MN OXFN	4	Do not allow movement of charge/ charge carriers /electrons/ electricity through	SIYAN SIYAC S&MN OXFN OXFC	5
(III)	Can be charged if not touched	PLATC	1	Charged by rubbing Remains charged	PLATC OXFC	2
(IV)	Conduct current	PLATC	1	Do not conduct current	PLATC	1
(V)	Has mobile charges / electrons	PLATC	1	Has no mobile charges charge carriers do not move freely	SPS PLATC	2
(VI)	Loosely bound electrons become free Electrons move from atom to atom	SIYAN OXFN	2	Electrons bound to atoms No free electrons Charges don't move from atom to atom	SIYAN SIYAC OXFN	3

B) ***Lack of micro – macro distinction and "simple causal" reasoning***

In textbooks that offer two features or more per class of materials, these are listed in no particular order or logic. For instance, micro features may be followed by macro and then by micro and so on, as typified by the example from SIYAN (2010) (features of insulators) below:

Do not allow charge carriers/electrons to move through	Macro-micro mix (quasi)
Electrons are bound to atoms	Micro
Excess charge stays put, concentrated charge	Macro (in the context of the text)
Few free electrons if any	Micro
Do not allow charge to move	Macro (in summary of chapter)

Just by looking at the random listing of features per book in Table 5.4 one could guess that behaviours attributed to conductors and insulators are likely to be given as unjustified statements and unrelated claims for learners to memorise. The mingling of the macro and micro domains may signal lack of clear distinction between the two in the mind of some authors, in which case a scientific explanation or macro-micro connection would be inconceivable. Indeed if we go back to the examples of CT5, we find that overall words/expressions such as *because*, *therefore*, *that is why*, etc. are conspicuously missing in favour of resolute statements. Nevertheless, three instances were found that qualify as attempts to an explanation, and these are shown below:

1) *SPS (1987),p.69*: When a conductor is charged so that it carries an excess charge, the like charge carriers repel one another so that the charge is spread over the surface of the conductor…. Non-conductors can also be charged, but the charge is not spread evenly across the surface. It remains concentrated where it was placed because the charge carriers cannot move freely through such a substance.
3) *PLATC (2011), p.137*: … the excess charges will move through your hand and into the ground, so you will not be able to charge the conductor.
5) *SIYAN (2010), p.309*: … loosely bound electrons become detached from the individual atoms and so become free to move around … there are very few, if any, free electrons and so the charge cannot move around the material.

The SPS (1987) author attempts to explain the macroscopic inferences of spreading or concentration of excess charge in terms of behaviour of charge carriers, the microscopic players. This macro-micro connection however is incomplete and so it leaves many doubts and room for guesswork. Learners may be asking, why do charge carriers repel in conductors, but not in insulators? Why do charge carriers cannot move in insulators? Do conductors have empty spaces for charge to move through? Etc. The author did not disclose the conditions under which mobile charge carriers may or may not exist in a material, which would justify the primary cause of distinction between conductors and insulators, and how the existence of mobile charge carriers 'allows movement' of excess charge. Whether charge spreads or not is a consequence of this primary cause; spreading is a contingent cause of distinction. The next attempt from PLATC (2011) is also ineffectual, since learners have never been told why the human body and the ground behave in the said way or why the charge on conductors spreads, and according to the author 'evenly'. In fact, in none of the texts is there any mention of our body being a conductor, let alone a reservoir of charge. Learners may be also asking why is it that the human body does not behave in the same way when touching a charged insulator. The process of charge transfer by conduction does not feature in FET curricula and authors do not distinguish it from other processes of charging (this aspect is analysed later on).

The above examples from SPS (1987) and PLATC (2011) can be also understood as reflecting a reduced causal reasoning or "*simple causal*" reasoning (Viennot & Rainson, 1999), in which the complexity of a phenomenon is disregarded by using a simple claim of the type 'one cause for one effect'. For example, "charge spreads because like charges repel" (SPS, 1987), or "you can't charge a conductor because charge moves through your hand" (PLATC, 2011). This type of simplistic (everyday) reasoning does not favour a systemic approach to understanding science concepts and processes. In the literature, whenever it has

been detected among science learners it has been identified as a problem, as in Furió *et al*. (2004), one of the few papers concerned with learner difficulties on elementary electrostatics. Simple causal reasoning used in textbooks is more likely to leave learners with more questions than answers, leads to unwanted interpretations and sends the message that science is difficult.

The last example from SIYAN (2010) (an excerpt that has been removed from SIYAC (undated) is the only example amid the texts in which we find something reminiscence of the metallic bond model. The example explains why charge may move in metallic conductors but not in insulators, referring to neutral objects. However this insight is presented as extra information and it is not used to explain contingent behaviours of conductors/insulators previously listed in the chapter. Furthermore, there are two theoretical constructs involved here, the metallic bond model and the atomic model, but these are not presented as such or distinguished.

On a positive note, unlike in "Matter and Materials", the word *electricity* does not feature in the expressions of the authors of Electrostatics, with the exception of S&MN (2005) and to a lesser extent OXFN (2008) (excerpts 6 and 8 in CT5).

C) Dominant features of conductors and insulators in the textbooks

Due to scarcity of primary causes of distinction, CT5 revealed no strong correlation between texts and the theoretically grounded aspects of analysis in the left hand column. Hence, an inductive category table, CT6, was developed based on the texts. CT6 maps the frequency of features in the texts assigned to conductors and insulators and reveals that these fall into 6 groups, marked with the Latin numerals (I) to (VI) in the left hand column. A 7th degenerate group could be added, where authors did not distinguish between the two classes of materials,

which is the case of SS (1989) (referring to substances) and S&MC (2011) (referring to objects). The first two groups of distinction are notably the most favoured by authors.

Group (I) *Distinction in terms of spreading or distribution of excess charge over surface*

This distinction requires the presence of excess charge or else it cannot be inferred. This is a hint that 'spreading' of excess charge cannot be the primary cause of distinction between conductors and insulators. From the expanded examples in CT5 it can be seen that five out of ten books mention that the charge on conductors spreads over its surface, three of which (BJ,1987, SIYAC, undated, and SIYAN, 2010) refer explicitly to the outer surface. Of the same five books, only three (SPS, 1987, SIYAC, undated, and SIYAN, 2010) attempt an explanation by referring to '*like charges repel*' as the cause of spreading over the surface. None of the texts refer to a conductor at *electrostatic equilibrium*, where charges are at rest and no net force acts on any charge. In science, excess charge is assumed to reside on the outer surface of a conductor as a consequence of the conductor being at electrostatic equilibrium. This is usually justified via the concept of the *electric field* and not by repulsive forces. Learners in the three South African curricula are not supposed to be familiar with electric fields at this stage. However, they are familiar with the metallic bond model and so the concept of electrostatic equilibrium could be introduced in terms of redistribution of the sea of electrons in metallic conductors, were both attractive and repulsive forces are involved, and where excess charge is presented as part of the structure of the conductor. The prospect of an explanation involving the electric field prompted examination of further texts, beyond Elementary Electrostatics, to find out whether authors revisit conductors, particularly articulating on the field inside a conductor, under the section of "Electric fields". Electric fields are found in the grade 11 NCS and CAPS textbooks, while in NATED they are a continuation of the Standard 10 texts examined so far. Among the new texts, only two were

found referring to charge distribution on conductors and the field inside a conductor. Since there are only two, they are discussed here along with the other references to conductors.

The first one is from BJ (1987) an excerpt of which is shown in Figure 5.7. The excerpt is preceded by a series of photographs of seed patterns formed around charged conductors of varying shapes and configurations. The accompanying text links the electric field outside the conductor to the charge distribution shown in the diagram, but does not link the charge distribution to the field inside the conductor. The author states that *no field exists* inside the conductor, rather than that the field inside the conductor *is zero*. The former implies that a notion of field inside a conductor is irrelevant, while the latter would have allowed the possibility that the field inside the conductor might have been non-zero under different circumstances. This would have provoked learners to question what happens in the interior of the conductor. Hence, the text unwittingly prompts the erroneous understanding that the interior of the conductor is of no consequence to the distribution of charge on its surface.

No field exists inside an irregularly shaped hollow conductor. However, the charge residing on the outer surface is *not uniformly distributed*. The greater concentration of seeds around the sharp point indicates that the *charge is more concentrated where the curvature is greatest*. See Fig. 7.6.

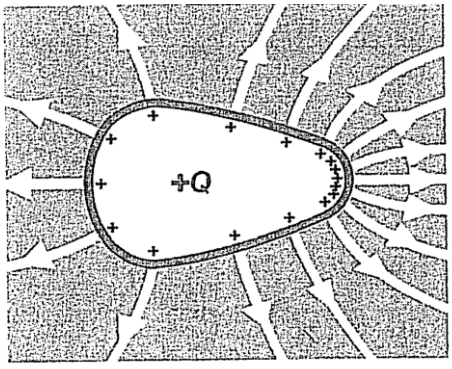


Fig. 7.6 The charge distribution and electric field lines for an irregularly shaped object. Notice the high density of charge and lines where the curvature is greatest.

BJ (1987), p.76

Imagine a hollow sphere made of metal. Suppose you tried to rub charges onto the inner surface of the sphere. Since like charges repel, the charges will move as far apart as possible. The greatest distance they can move is to the outside surface of the sphere (see Figure 9.5).

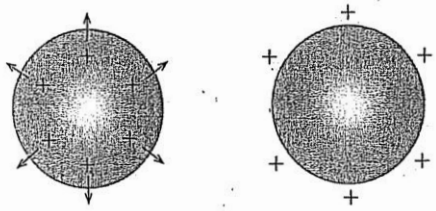


Figure 9.5 Charges placed on the inside surface of a metal sphere (a) will move to the outside surface (b).

Because charges can move easily in a metal, they will never stay on the inside surface of any hollow metal object. Therefore the electric field inside is always zero. Even if an external electric field is applied to the object, the charges on the outside surface will rearrange themselves so that the field inside remains zero.

PLAT11C (2012), p.195

Figure 5.7 References to electric field inside conductors in textbooks

Furthermore, each field line in the diagram is shown to start at each "+" sign, as if each charge has its own field line associated with it. This may be understood by learners (and perhaps this was the intention of the author) that the field at a certain location is due to the local charge. However, at each point near the surface of a conductor, the electric field is not only due to the local charge but to the total charge all over the conductor. The shown representation may raise all sorts of unwanted understandings on the nature and purpose of field lines, but also misunderstandings relating to the strength of fields, since field is presented as relating only to the number of local charges. For instance, it may prohibit learners from grasping why the field just outside a small sphere of small charge might be a lot stronger than the field just outside a large sphere with a much larger charge.

The PLAT11C (2012) excerpt in Figure 5.7 explains distribution of charge on the outer surface of conductors in terms of repulsive forces between like charges, much as grade 10 texts do. It also appears that the diagram provided is not the intended one, because the text refers to inner and outer surfaces while the diagram shows a conductor that is not hollow. The argument provided is that "because charges repel they move on the outer surface of the conductor and as a consequence the field inside the conductor is zero". The argument however should have been the other way round, that "because the field inside a conductor at electrostatic equilibrium is zero, any excess charge must be located on its outer surface". In science, a common justification for this argument is that if excess charge was to be found in the interior of a conductor, its electric field would cause mobile charged particles in the conductor to move (charged particles in an electric field experience a force). This movement would result in mobile charged particles redistributing themselves (free electrons in this example) until they came to positions where no charged particle would experience any net

force, which happens when the field inside the conductor becomes zero. Hence, a conductor is at electrostatic equilibrium only if the electric field in its interior is zero. This state is achieved if there is no excess charge in the interior, and so we assume that any excess charge must be located on its outer surface. *Equilibrium* is a key word in the discussion of distribution of charge on conductors, and it means that no net force acts on any charge, hence the staticness of the excess charge. According to the PLAT11C (2012) excerpt "since like charges repel, the charges will move as far as possible. The greatest distance they can move is to the outside surface…" (p.195) The excerpt conveys the notion that charges continuously repel, even when they arrive on the surface where they are kept in place by some unknown reason. A similar scenario from the grade 10 SIYAC books is included in Figure 5.12. Further instances of repulsive forces between excess charges are discussed further down. This common 'explanation' in textbooks is counterintuitive. We cannot claim that like charges repel and then show them next to one another on the surface of a conductor as being stationary. The notion defeats the laws of dynamics and logic. "Why don't charges jump out of the material?" or "Why can't we find a charge at the centre of the conductor (which should be possible if repulsion was all there was)?" or "How does the surface trap charges?" learners may be asking and very justifiably so. These are reasonable questions that the model of 'repelling forces' cannot answer. If we assume that charge resides on the surface and is stationary, it must be at equilibrium. This means there must be attractive forces acting on it as much as there are repulsive, all of which result in zero net force. Excess charge is part of the material and interacts with all charges in the material (a case of superposition of forces).

Group (II) *Distinction in terms of 'allowing' something to flow or move through*

This is a distinction between conductors and insulators, which according to CT6 is favoured by most texts, much as the spreading of charge to which it relates. The expression 'allow

electricity to *flow* through' is most probably a remnant of pre-nineteenth century times when 'electricity' was considered an imponderable fluid. It is a macro distinction since we can infer it from observations that some objects allow charge to move through while others do not. At secondary school level however, and considering that learners are familiar with contemporary ideas of the structure of the atom and other models not known in the 19th century, one would expect this expression to be given some insightful explanation accounting for the 'ability' of an object to allow or not allow movement of charge. But as discussed earlier, texts furnish learners with a list of statements without distinguishing between macro and micro. We saw that the few attempts to an 'explanation' lacked the theoretical grounding, thus inciting doubts rather than clarity. As the general analysis has revealed so far, authors do not link established theoretical models to electrostatics. Without understanding of the role of the material, the word 'allow', whether authors refer to 'allowing' charge or electricity or electrons to move through the material, may prompt the notion that conductors are like porous or empty pipes of some sort where charge can enter from one end and exit out the other, while insulators block this in-and-out movement. This is a dangerous understanding because learners will fail to see charge as part of the material. In addition it may play a role in instigating local and sequential reasoning in DC circuits, which has been identified in the literature as problematic (e.g. Duit & Rhoneck, 1997/98; Viennot, 1998; 2008).

Group (III) *Distinction in terms of the ability to become charged or to retain charge*

Two CAPS texts, PLATC (2011) and OXFC (2011), impart this distinction. It is claimed in PLATC (2011) that "objects that can be charged by rubbing are **insulators**" (p.137), implying that conductors cannot be charged in this way. This is the seeming distinction between the two. But soon after there is a contradicting claim that conductors can be charged if not touched, though we are not told if the charging has occurred my means of rubbing (one

can rub a conductor without touching it). Hence the distinction between conductors and insulators is essentially based on the ease by which they discharge if touched. A similar distinction is found in the OXFC (2011), which however does not refer to conductors at all. In the main text we find that "when this happens to an **insulator**…the substance remains charged" (p.155), implying that conductors cannot stay charged. Although these are only two books, they represent 20% of the examined texts and 50% of the CAPS books. PLATC (2011) offers another four distinctions, of which one is in the margin, the other is under polarisation, and so the distinction in terms of the ability to be charged (by rubbing) is by far the most prominent. This can be seen in excerpt 3 in CT5. In OXFC (2011), this is the only distinction. A second one is given in the margin, but is of no consequence to the text. A third CAPS book, S&MC (2011), does not refer to conductors or insulators, and the only hint of differing behaviour is "plastics, particularly plastic and polystyrene, are very good at picking up electrical charge…" (S&MC, 2011, p.192). An implicit message that may be send by most examined texts, especially the CAPS texts where conductors are noticeably downplayed, is that charging occurs (only) by rubbing, and to a lesser extent that conductors cannot be charged, or at least they are not of much use in electrostatics since their charge spreads or disappears.

Features reflected in the remaining three groups have been already discussed, and one can note that only the last two groups concern micro-perspectives. These are usually found under the section of polarisation.

5.5.3 Issues arising from localised points of articulation: Charge distribution on conductors

5.5.3.1 The "pushing charges" model

> A van de Graaff generator can build up a charge on a metal dome. If the charge is caused by extra electrons, the dome has a negative charge. These electrons all repel one another, but they stay where they are because there is nowhere for them to go…..
> (S&MN, 2005, p. 102)

A) Electrostatic equilibrium and superposition of forces are overlooked

As pointed out in the preceding section, texts that attempted a justification for the spreading of charge on conductors did so by referring to 'repulsive' forces between 'charges', typified by the example: "if an excess charge is placed on a conductor, the like charges will repel each other and spread out over the outside surface of the object" (SIYAC, undated p.261). It appears that authors were either unaware of the concept *electrostatic equilibrium* or underestimated its significance in the context of conductors. Had they been cognisant that excess charge should experience zero net force perhaps they would have thought twice before reasoning in terms of 'like charges repelling and moving as far as they can go', implying that they continuously repel.

The spreading of charge in texts appears implicitly or explicitly in two scenarios. One scenario is when excess charge is placed in the interior of a conductor, in which case 'charges' repel and move to the outer surface. We imagine 'charges' moving apart explosion-like from the interior of the conductor radially outwards. The second scenario is when excess charge is placed at some location on the surface of a conductor, in which case the 'charges'

push each other and spread along the entire surface. The two scenarios are represented respectively for spherical conductors by the 2-D diagrams (a) and (b) in Figure 5.8.

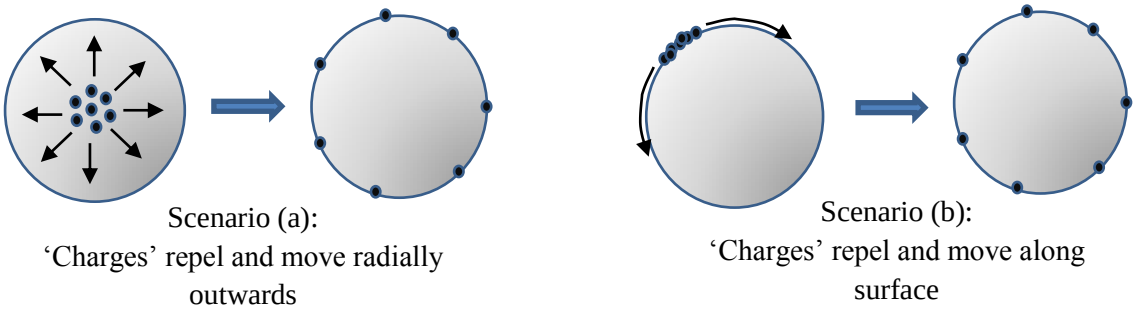


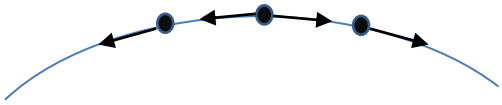
Figure 5.8 Two scenarios of repelling excess 'charges' in textbooks

Source: By researcher

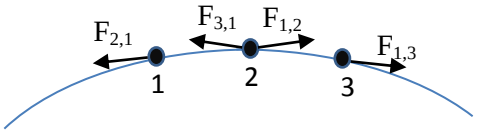
The difference in the motion of 'charges' in the two diagrams of Figure 5.8 should already hint that repulsive forces between the 'charges' themselves cannot be the only forces acting on the 'charges'. Why for instance the 'charges' in scenario (b) do not move radially outwards from their centre of charge as the 'charges' in scenario (a) do? And why do the 'charges' in scenario (a) do not continue their outward straight-line motion to escape the material? The model of repulsive forces or the "pushing charges" model has no consistency as readers have to invent different assumptions for each scenario. Yet one thing is common in both scenarios: the surface seems to play a vital role in holding 'charges'. The model contradicts itself.

But it also appears that authors in their accounts for the spreading of charge have also disregarded the principle of superposition of forces. This is more evident by scenario (b) in Figure 5.8, which is more common in the grade 10 texts. Authors may be sending the message that 'charges' are like billiard balls that can spread all over the table by pushing their adjacent neighbours further away. Figure 5.9 (a), represents such a mental image that learners

are likely to form for the spreading of charge on a spherical conductor. The arrows in the diagram represent forces that 'charges' are supposedly exerting on their neighbours and are shown to act along the surface of the conductor. This is the way that learners are likely to visualise the forces since charge is expected to remain on the surface and spread all over. And possibly this is how it was intended by the authors. But these forces do not exist, they are not even Coulomb forces which should be acting along the line joining two 'charges' as shown in Figure 5.9 (b). In either case, such forces could not possibly cause charge to stay on the surface, let alone spread.



(a) Notion of pushing neighbours on conductors



(b) Coulomb forces would not act along the surface

Figure 5.9 Charges are assumed to interact only with neighbouring charges

Source: By researcher

The interaction of 'charges' cannot be understood along the lines of billiard balls pushing one another in sequence and spreading. Billiard balls interact upon contact (the *push*) and so they can only interact with adjacent neighbours and only during contact. But the electric force is neither a push nor a pull, it is an action-at-a-distance (at least prior to the introduction to the electric field). Each 'charge' should be understood as experiencing a force from all other 'charges' as shown in Figure 5.10, whether neighbours or not and each 'charge' should be understood as exerting a force on all other 'charges' simultaneously and continuously. But then, each 'charge' would

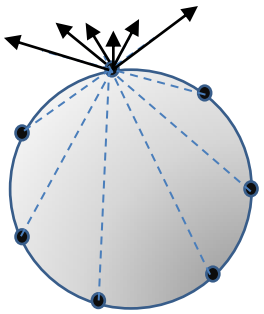


Figure 5.10 Each 'charge' should be repelled by all other 'charges'

Source: By researcher

experience a net force that would send it flying away from the conductor. From whichever angle we look at the model of "pushing charges", it cannot justify why the excess charge stays on the surface and why does it spread.

5.5.3.2 The "distinct particle" model

> When we place a charge on a spherical conductor the repulsive forces between the individual like charges cause them to spread uniformly over the surface.
>
> (SIYAC, undated, p. 261)

A) The conductor is overlooked

Texts espouse the notion that excess 'charges' are distinct and isolated add-ons to a conductor. The 'stuff' that makes up the conductor is neither affected nor affects the actions of the foreign charges. In this "*distinct particle*" construct, represented by Figure 5.11, excess 'charges' are distinguishable from the 'stuff' of the material, behave independently of the material and are governed only by the *repulsive forces* they exert on one another. And even these forces as discussed above, might not be necessarily the typical Coulomb forces of electrostatics. The notion that excess 'charges' interact only between themselves is conveyed even when there are references to 'mobile charges' in the material: "A conductor is a material in which there are many mobile charges. Any charges placed on a conductor will immediately spread out evenly on the conductor" (PLATC, 2011, p.137). The two sentences are not linked. We may appreciate that the existence of mobile charges is one of the features of conductors, but we will not understand it as playing a role in the spreading of excess charge. The excerpt gives the impression that excess 'charges' on conductors spread because this is what they do.

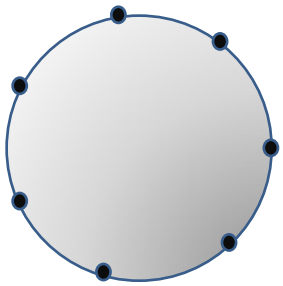


Figure 5.11 "Distinct particle" model

Source: By researcher

B) Positive charge is avoided

The tradition in curricula is to assert that only electrons are added or removed from objects. The *distinct particle* model favours the excess of electrons but not the deficiency of electrons from objects. Repulsion and spreading of positive charge would be awkward to justify with the *distinct particle* model in mind, in fact impossible. Could this be the reason why authors avoid discussing distribution and transfer of positive charge on positively charged conductors, as suggested by Figure 5.12 (p.197). The figure shows clearly that negatively charged conductors dominate the scene (no other relevant figures of conductors were found in the grade 10 textbooks). The figure shows only one example with a positively charged conductor from SPS (1987), but there is no comment accompanying it. Negatively charged conductors imply excess of electrons that we can easily picture as little balls moving and assuming their positions over the conductor. Had the authors chosen positively charged conductors, which would imply missing electrons from the material, we would be prompted to think in terms of the material rather than ignoring it. And this time the *distinct particle* model would be obsolete, whereas the metallic bond model could explain both cases. Learners could then think in terms of rearrangement of the sea of electrons, which contemplates both repulsive and attractive forces in the whole material, a fundamentally different view-point due a fundamentally different model. In South African curricula the metallic bond model is introduced prior to Electrostatics. This would be a chance to put it into good use, with the double advantage of linking physics and chemistry and demonstrating that science models are there for us to use and explain. This is a primary reason why we learn about them. De Posada (1999) raise similar concerns on Spanish textbooks, half of which "virtually define" the metallic bond model and consequently experimental facts cannot be understood by students. Furthermore they elaborate on the high pedagogic value activities promoting the application of models to new situations have.

C) Sharp points of conductors: Need for contact and the air are disregarded

Five textbooks (50% of the Grade 10 books, mostly NATED and NCS) refer to the concentration of charge at sharp points of conductors. Of these, four include figures, of which SPS (1987), SIYAC (undated) and SIYAN (2010) are shown in Figure 5.12. BJ (1987) has already been discussed with Figure 5.7 (p.186). The action of sharp points is considered essential in understanding lightning strikes and the discharging action of lightning rods among other applications. In SPS, SIYAN and SIYAC, which attempt an explanation for the discharging action of the point (the corresponding text from the SIYA books is omitted from Figure 5.12), the negative charge of the pointed conductor very conveniently accommodates the claim of 'leaking' charge from the sharp edge. Learners are expected to understand that negative charges/electrons repel one another towards the tip being the furthest away and they accumulate there, resulting in some charges to be pushed out from the tip and into nothingness. But how would excess charge 'leak' if it was missing electrons? This is left to learners to work out, despite the fact that positively charged conductors are more relevant when it comes to lightning rods and thunderstorms. The *distinct particle* model cannot justify the 'leaking' of positive charge.

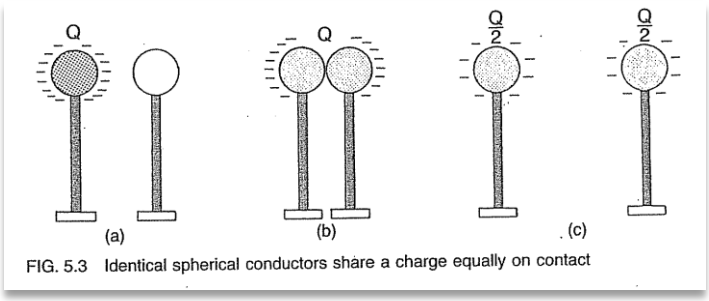
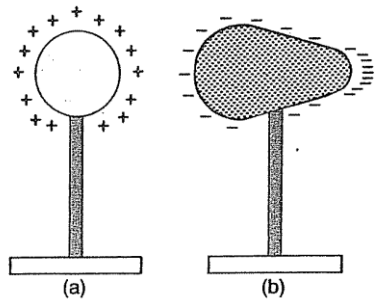


FIG. 5.3 Identical spherical conductors share a charge equally on contact

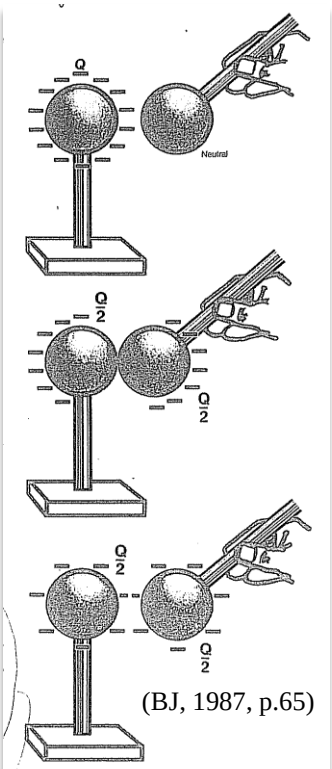
(SPS, 1987, p.71)



(SPS, 1987, p.69)

FIG. 5.1 The distribution of charge on a conductor depends on its shape

In a pointed conductor (b) the charge becomes concentrated around the point or points. The charge tends to "leak" away rapidly since the density of the charge around the points is high. The sharp spikes at the top of a lightning conductor assist in removing electric charges from a building so that a build-up of high charges is prevented. Modern buildings which have been reinforced by means of metal rods in the concrete do not need special lightning conductors.

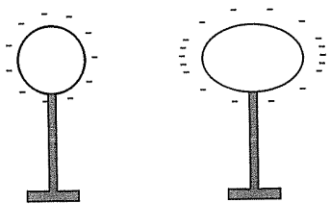


(BJ, 1987, p.65)

Fig. 6.2 When a charged conducting sphere is brought into contact with an identical uncharged sphere, the charge is shared equally.

The electrostatic force determines the arrangement of charge on the surface of conductors. This is possible because charges can move inside a conductive material. When we place a charge on a spherical conductor the repulsive forces between the individual like charges cause them to spread uniformly over the surface of the sphere. However, for conductors with irregular shapes, there is a concentration of charge near the point or points of the object.

Notice in Figure 16.1 that we show a concentration of charge with more – or + signs, while we represent uniformly spread charges with uniformly spaced – or + signs.



(SIYAC, undated, p.261
same in SIYAN, 2010)

Figure 16.1: Charge on conductors

Figure 5.12 Figures from textbooks on charge distribution. Authors favour negative excess charge.

The explanation for the accumulation of charge at sharp points and its 'leaking' is not as straightforward as implied in the texts along the lines 'charges repel and are pushed to the tips where due to strong repulsion some may be pushed out'. This notion is self-contradicting and any reasonable learner would ask "but why don't charges at the tips push back?" Some authors may be either unaware of or do not grasp the notion of a conductor at equilibrium. Even at the tips where the surface charge density is larger, no charge should experience any net force. The fact that charge concentration is greater at sharper edges is known from empirical evidence. But what exactly governs the accumulation of charge at sharper points and how the shape of a conductor may affect this concentration is not well understood and there is even some conflict in the science literature (e.g. Enze, 1986; Fan, 1988; Zhang, 1988). One would expect authors to anticipate learner reactions to counterintuitive claims and address these in a rational convincing way. This is not always easy and it may require some research, as is the case with the sharp points of conductors. Yet this case reflects one more incident of authors not researching their claims disregarding learner concerns. How does an author justify accumulation of charge at sharp points since it is not well understood? But an author could have said just that, that scientists are still trying to understand this phenomenon, which would have made science to appear as an ongoing human endeavour of real people who also have to think and struggle.

Furthermore, beyond the sharp edge of the conductor there is no nothingness, there is air which plays a vital role in the whole process. An important requirement for charge to transfer is the *need for contact* between objects. Charge does not leap into nothingness or even between objects, the objects must be in contact. The two objects in this case are the pointed conductor and the air. No reference was found in any of the texts to the need for contact for charge to transfer. In contrast, there are references (discussed under charging) to leaping

charges and charges being rubbed onto and off objects and in this case leaking. The OXFN (2008) is the only text that refers to the air around the conductor and offers some reasonable justification "This is because electric charges concentrate around a sharp point. When this happens, the surrounding air also becomes charged and provides a conducting path that leads to a slower discharge than a lightning strike" (OXFN, 2008, p.64).

The discharging action of sharp points is better understood when learners are familiar with *electric fields*, though nothing relevant was found in the grade 11 NCS and CAPS textbooks under electric fields. The electric field around the sharp point is very strong and thus it can ionise the air around the point. Ionised air is a conductor. Its mobile charge carriers are positive ions and electrons. We have a case where ionised air is in contact with a charged conductor and so there is a transfer of charge from the charged conductor to the air (the leaking). This could be explained by movement of electrons either from the air into the conductor, if the conductor is positively charged ('leak' of positive charge), or by electrons from the conductor into the air if the conductor is negatively charged ('leak' of negative charge). However, 'leaking' is not a scientific term even though it is used by engineers and other experts. Authors should think twice before using such 'slang' words for the unwanted understandings they may incite. The discharge of the conductor through the conductive air is a type of electrical discharge (a corona discharge in this case). Electrical discharge is often mentioned in textbooks when referring to sparks and lightning, but it is never linked to the conductive/ionised air. Electrical discharge is also responsible for the charging of a conductor by touching it with a charged insulator, a common case in textbooks especially when charging electroscopes. However authors appear unaware of it and present it implicitly and sometimes explicitly as charging by contact or conduction.

D) Consequences for learners

Authors of electrostatics seem convinced that repulsive forces between isolated charges explain adequately well the spreading of charge on conductors. Could this erroneous understanding be the reason why they overlook the use of theoretical models in their texts? If authors do not see a reason to involve the material, any attempt to introduce a theoretical construct for its structure would seem unnecessary, even pointless. This practice ought to have consequences for learners. Guruswamy *et al.* (1997) found that a considerable number of students at different levels were unable to predict correctly the transfer of charge between conductors and that they used '*student devised* rules' for explanations. The most prominent 'rule' was that charges do not transfer between conductors with like charge because '*like charges repel*'. Other 'rules' included charges that cannot transfer from a charged to an uncharged conductor '*because there is no attraction*', i.e. the most prominent 'rules' were linked to "like charges repel, unlike attract", which means that students perceived 'charges' on conductors as isolated. This is exactly the message sent in the analysed textbooks. Hence for South African learners, any possible 'student devised rules' of the type found by Guruswamy *et al.* (1997) may originate in the '*author devised models*' found in South African textbooks. No relevant research was found on the ideas of South African learners, teachers or university students. Nevertheless, once again (as in the analysis of CT4) we meet a practice where authors use inferior models to 'explain' one particular aspect, in this case 'the spreading of charge on conductors', disregarding the fact that this model cannot justify the transfer of charge between objects and hence all subsequent sections on charging and discharging.

5.6 ASPECT OF ANALYSIS 5: Transfer of charge and charge conservation

5.6.1 Charging and charge conservation in the curricula

In all three curricula, the charging process is associated with only insulators, as shown in Table 5.5. This is presented as charging *by friction* or *contact* in NATED or *by contact* or *rubbing* in NCS and CAPS, with the latter also introducing the expression "*triboelectric charging*". CAPS is the only curriculum where charging by conduction is hinted. The only references relating to the transfer of charge or to the charging processes are depicted in Table 5.5. The table in addition includes the relevant excerpt from the standard 7 NATED, because the standard 10 document stipulates that 'Static Electricity' is to be done as a revision of this standard 7 knowledge.

In Table 5.5 it can be noted that the term '*friction*' that appears in NATED has been replaced by the term 'rubbing' in NCS and CAPS. This can be seen as a positive development for the learning of electrostatics. Friction, due to its association with energy, instigates the erroneous understanding that electrons may pick up energy to jump out of the material and hence that friction is causing the charging process. Research on misconceptions indicates that a number of students and teachers mistakenly perceive friction to be the cause of charging (e.g. in Baser & Geban, 2007; Beaty, 1998).

Table 5.5 Charging and charge conservation in the curricula

NATED std 7 (DoE&C, 1993, p.7-8)	Charge by friction – Investigate the phenomena where the objects are electrostatically charged by friction…(practicals with insulators) The electroscope: charging by contact. ….Charge an electroscope by contact.
NATED std 10 (DoE&C, undated, p.36)	Static electricity: A brief revision of the following… Charging an object by means of contact… Principle of conservation of charge.
NCS gr 10 (DoE, 2006, p.28-29)	Describe how objects (insulators) can be charged by contact (or rubbing). Apply the law of conservation of charge to explain that materials charged by contact carry opposite charges of equal magnitude.
CAPS gr 10 (DoBE, 2011, p.40-41)	TWO KINDS OF CHARGE: … Know that +vely charge objects are electron deficient, -vely charged objects have excess of electrons. Describe how objects (insulators) can be charged by contact (or rubbing) – triboelectric charging. CHARGE CONSERVATION: Know that the SI unit for electric charge is the coulomb. State the principle of conservation of charge as: *The net charge of an isolated system remains constant during any physical process*, e.g. two charges making contact and then separating. Apply the principle of conservation of charge. Know that when two identical conducting objects having charges Q_1 and Q_2 on insulating stands touch, that each has the same final charge on separation…

The expression '*by contact*' appears in all curricula, but in all curricula its meaning is elusive. Does it simply mean the 'touching' of two objects or does it denote a particular process of charging called "charging by contact"?

In NATED Std 7, charging by contact appears to apply specifically to the charging of an electroscope (a conductor) and is distinguishable from the charging by friction. However in NATED Std 10, charging by contact appears to refer to charging by friction, as a revision of charging from Std 7. It also implies that contact is not always necessary "…*by means of contact*".

In NCS, charging by contact appears interchangeable with the charging by rubbing, as implied by the expression "materials charged by contact carry opposite charges of equal magnitude". We find the same statement in CAPS with the addition of a third name for the same process, 'triboelectric charging'. The latter can be also seen as a step forward as it designates a unique name to an important charging process that appears to have no standard/consensus name. Nevertheless concerning the term 'contact', further down in CAPS we also find the unfortunate expression "…two charges making contact and then separating". As it stands the expression is senseless, but one can infer from the context that the 'two charges' possibly stand for 'two charged conductors' that are brought into contact and then separated (i.e. transfer of charge by conduction). If this is the case, the process of charge transfer occurs via a very different mechanism from that of triboelectric charging. It remains to be seen how authors of CAPS textbooks have translated this poor expression.

5.6.2 Triboelectric charging: scientific understanding

According to the scientific understanding of the process, two conditions are required for charging to occur. The first condition is the need for *contact* between two objects followed by *separation*. This contact, unlike in the case of conduction, must be thorough and often over a relatively large surface area, followed by separation of the surfaces. It is upon the separation of the two surfaces that charging may occur. While two surfaces are in contact they bond, because their particles interact (intermolecular forces). In daily life, the bonding of smooth surfaces can be observed in the most mundane tasks, as for example in the difficulty we experience when trying to separate the edges of a refuse plastic bag, or when we page through a new magazine and its pages seem to stick to one another, or in the cling wrap that seems to stick to everything including metallic surfaces, to the use of sticky tapes, and so on.

In fact all adhesives rely on this type of bonding. Learners surely experience such occurrences more often than they experience rubbing and sparks and yet in the textbooks such experiences have gone unnoticed. Rubbing enables repeated contact and separation of surfaces, where simple contact would not be effective in bringing the two close enough to actually touch, if they are fibrous or rough or covered by a thin layer of oil and/or impurities.

The second condition is that the materials of the two objects must be *different* for charging to occur. This is because different materials are likely to have molecules/particles of different electronegativities. The further apart materials are shown in a given "triboelectric series" the more likely to become noticeably or 'more' charged.

For insulators, we may assume that molecules of the opposite surfaces bond together through shared pairs of electrons. Separation of the surfaces tears these bonds apart. The surface with the more electronegative molecules 'snatches' more pairs of electrons than the other, because it attracts them more strongly, and ends up with excess electrons. (In some materials with long molecules, like plastics, molecules may be torn apart during separation.) The requirement for *different* materials in this type of charging is precisely for enabling one surface to attract shared pairs of electrons more strongly than the other. In such a case, upon separation, the more 'electronegative' surface ends up with patches of negative ions, the other with patches of positive ions and the two appear charged with equal (net) charge of opposite sign.

Hence, the cause of charging is that one surface attracts shared pairs of electrons more strongly than the other. The formation of 'definitions' in CT7 which follows are thus based on this understanding.

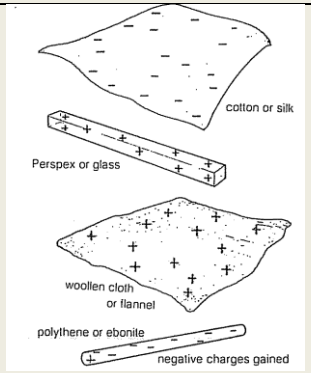
In CAPS, learners gain background on chemical bonds, ions, electronegativity and electron affinity in "Matter and Materials" prior to Electrostatics. They revisit these concepts again in

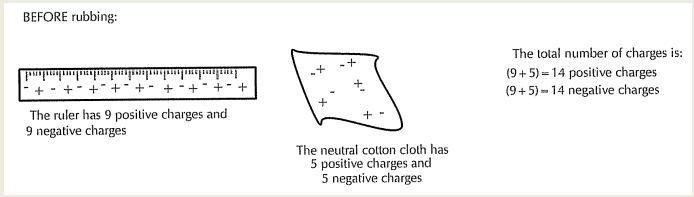
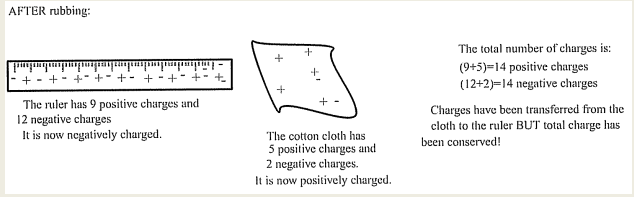
Grade 11 with the addition of intermolecular forces. In NCS, all such concepts are included under the grade 10 “Matter and Materials”, but with no prescribed order for the placement of the knowledge area “Matter and Materials” relative to Electrostatics or to other knowledge areas. In NATED 550, the relevant concepts are dealt with in standard 9. An explanation of triboelectric charging would link the knowledge areas “Matter and Materials” and “Electricity and Magnetism” or physics and chemistry, and would enhance conceptual understanding by putting such inferred concepts into good use. It would also broaden the range of everyday experiences of learners related to electrostatics phenomena, such as discussed above, that could be mentioned but go unnoticed in all textbooks.

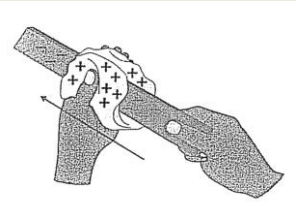
Categorisation Table 7 CATEGORY: Triboelectric charging

Theoretically grounded 'definitions'	SPS		BJ		SS		PLATC		SIYAN	SIYAC		S&MN	S&MC		OXFN	OXFC	
GENERAL CONDITION: Charge transfer (charging/discharging) **requires contact** – explicit emphasis																	
CONDITION 1: In triboelectric charging, **good contact** (surfaces bond) and **separation** (breaking of bonds) is necessary. Rubbing increases contact/separation										✓	"By contact" Simple mention see (6b)					✓	"By contact" Simple mention see (9)
CONDITION 2: The two materials/surfaces must be **dissimilar**					✓	Casual mention See (3a)										✓	Casually See (9)
Triboelectric series is given for predicting type of charge. Link series to electronegativity										✓	see (6b,c)	✓	✓	see (7c)		✓	See (9)
PROCESS: Upon **separation**, bonds break. One surface keeps more electrons than the other, leaving them equally but oppositely charged. (Link to electronegativity / affinity)														The energy used in rubbing … see (7f)		✓	"some materials attract e^- more than others" see (9 & 10)
Norm in solids: Objects acquire charge by losing or gaining electrons…	✓	see (1)	✓	see (2a)	✓	see (3c)	✓	Late See (4b)	✓	✓	see (5b)	✓	✓	See (7a, b, c)	✓	✓	not explicitly see (9 & 10)
In insulators: Separation leaves areas /patches of ions on the surfaces that are **immobile**														charge spreads / flows see (7e)			
CONSERVATION: Charge has been separated via transfer of electrons, but the net charge of the two surfaces is still zero.			✓	See (2a)					✓	✓	net charge is disregarded see (5b)			Friction & VDG produce charge see (8c,d)	✓		See (10)
Link above to charge **conservation**			✓	Good variety see (2)	✓	See (3d)	✓	see (4c)	✓	✓	See (5b and 6d)		✓	See (7f)	✓		See (10)

	EXERPTS IN TEXTBOOKS	COMMENTS & NOTES
1)	SPS (1987), p.68: Certain substances can be electrically **charged by friction**. This is called electrification. Two types of charges are obtained, viz. **positive** (+) and **negative** (-) charges. *Positively charged objects*: glass rubbed with silk; Perspex rubbed with silk; Cellulose acetate rubbed with wool. *Negatively charged objects*: polystyrene with wool; polythene with wool; ebonite with wool. *Positive* charges develop on objects when **electrons** are *removed*. *Negative* charges develop on objects when **electrons** are *added*. An *electroscope* can be charged by contact by accepting part of the charge of the object with which it is making contact.	Text is in the form of revision/reminders from standard 7. The concept of charge is overlooked. "Charges develop" implies creation of charge. Transfer of electrons is associated with all materials. It appears that the type of charge is to be memorised rather than justified somehow. No link to conservation of charge, in fact it contradicts it. "Charging by contact" seems to be a transfer of charge from a charged "object" to a conductor.

2)	BJ (1987), p. 64: a) In your standard 7 course, you learned in considerable detail about how objects may be charged by friction and about the attractive and repulsive forces which exist between charged objects… What charge is produced on a polythene strip (or ebonite rod) when it is rubbed with a flannel cloth? How may a positively charged rod be produced? … In terms of transfer of electrons, explain why a cellulose acetate strip becomes charged when rubbed with a flannel cloth (or a glass rod with a silk cloth) b) p.65-66: under CONSERVATION OF CHARGE When an object becomes charged, charge is acquired by the transfer of charges from one object to the other. The charge is not created, but is merely *transferred* from one object to another. Before a neutral glass rod is rubbed with a neutral silk cloth, the sum of the positive and negative charges on each is zero. During rubbing, electrons are transferred from the glass onto the silk. The glass acquires a positive charge and the silk an *equal* negative charge. The sum of the positive and negative charges on the glass and silk remains zero. Charge has therefore been conserved. *More examples are given from various processes…*	Text is in the form of revision/reminders from standard 7, but refers to "considerable detail". However, this cannot be the case because: The cause of charging appears to be friction and it also appears that the type of charge of objects is to be memorised (i.e. which object gains or loses electrons). Good link to conservation of charge. However, it is not clear what is meant by "*transfer of charges from one object to the other*" and "*charge is not created, but is merely transferred from one object to another*". What is the meaning of *charge* in each sentence? The first sentence may imply that both +ve and –ve charge transfers (charge = property), but the second one implies one type (charge = particles). In the second half of the paragraph, charge has the meaning of property. Learners will be asking: Do both types of charge transfer between the objects or only negative charge from one to the other?
3)	SS (1989), p. 53: a) In Standard 7 you found that when different substances are rubbed together they often become oppositely charged. This is called charging by friction. **Example**: Perspex and glass become positively charged when they are rubbed with silk. Polyvinylchloride (PVC) becomes negatively charged when rubbed with cotton and so does ebonite when rubbed with wool. b) Before the substances are rubbed together they are **electrically neutral**. The number of protons and of electrons in each substance is the same. c) NOTE: You will remember that all substances are made up of atoms. The charged particles in atoms are positive protons and negative electrons. The protons are in the nucleus of the atom and are not affected by rubbing the substances together. However, electrons form the outermost part of atoms. When substances are rubbed together, electrons can be transferred from the one substance to the other (see fig). The one substance then becomes positively charged because it has more protons than electrons. The other one becomes negatively charged because it now has more electrons than protons. Caption in figure: When different substances are rubbed together they become charged because electrons move from the one to the other. d) During the charging process, the total number of positive and negative charges remains constant. All that happens is that a transfer of charge occurs, i.e. a movement of charge from one substance to the other. This is an example of the Principle of Conservation of Charge…		Text is revision from standard 7. It does not present friction as the cause of charging. However it remains unclear how objects are charged by rubbing (why/how electrons transfer from one substance to the other?) Gives the impression that electrons are mobile. Nucleus is presented as having no effect on the charging process. "they often become oppositely charged", does it mean that at other times they become charged with the same type of charge, or not charged at all? It appears that the type of charge on objects is expected to be memorised. Do diagrams represent net charge? We are not told. The charge seems to spread evenly all over the objects. Charge conservation is not observed in the diagrams.
4)	PLATC (2011), p. 134-135 **through experiments introducing terms descriptevely** a) Experiment 1: Testing for charge: …. In experiment 1, you saw that after you rubbed the plastic rruler on your clothes or your hair, the ruler picked up little bits of paper. The paper was attracted to the ruler. When you rubbed the ruler, you gave it a **charge**. we know that it was the ruler that was charged and not the paper because when you rub a sheet of paper it does not attract small bits of paper. In this chapter we will use the following test for charge: *An object is charged if it attracts small bits of paper*. Experiment 2: Charging single and two pieces of tape: …. In part A you charged two tapes and saw that they repelled, or moved away from, each other. Since the two tapes were charged using the same method, they must have had the same kind of charge. from this experiment we can conclude that: *Like charges repel each other.* In part B you stuck two lengths of tape together. Initially the combined lengths were uncharged. When you pulled them apart, each tape was charged. When you put them together again, the combintation was uncharged. How is this possible? The charges on the two tapes must cancel each other out. For this reason, we call the two types of charge positive and negative. When the tapes were brought close together, they attracted, or moved toward, each other. From this experiment we can coclude that: *Opposite charges atract each other.*	There are so many inferences one could make through these experiments, but went unnoticed. The author could seize the opportunity to discuss good contact and separation, dissimilar materials, charge conservation, even the remark that the tapes were charged without rubbing. But all these have been overlooked and the author only concentrated on forces. Why did the author use tapes then? Is it because they were featuring in some other book? The idea of the tape experiments originate from Bill Beaty's site (Beaty, 1996b) to demonstrate that friction or rubbing are not the cause of charging. This inclusion is not based on research. "*The charges on the two tapes must cancel each other out. For this reason, we call the two types of charge positive and negative*": What a waisted opportunity to introduce charge conservation….It seems that the names positive/negative were more important.

b) p.139: under QUANTISATION OF CHARGE: When we charge an object <u>it is electrons that move onto or off</u> the object. When we make an object negatively charged we add electrons… c) p. 139: under CHARGE CONSERVATION: Charge cannot be created or destroyed. We say that charge is conserved. That means that if an object becomes, for example, negatively charged by rubbing it with a cloth then the cloth must become positively charged. The number of electrons gained by the object equals the number of electrons lost by the cloth.	"*Because when you rub a sheet of paper it does not attract small bits of paper*" is a claim that paper cannot be charged, why not? Charge cpnservation appears towards the end , as per CAPS curriculum, and it is not linked to anything. It refers to gained and lost electrons, but in the previous pages under charging of objects only macro descriptions were given. Therefore, no tick has been alocated.
5) SIYAC (undated), p. 255-256: TRIBOELECTRIC CHARGING SIYAN (2010), p.305-306: CONSERVATION OF CHARGE a) Objects can become charged in many ways <u>including by contact</u> with or being rubbed by other objects. This means that they can <u>gain or lose negative charge.</u> For example, charging happens when you rub your feet against the carpet. When you then touch something metallic or another person, you feel a shock as the excess charge that you have collected is discharged. When you rub your feet against the carpet, <u>negative charge is transferred to you from the carpet</u>. The carpet will then become positively charged by the same amount. b) Another example is to take two neutral objects such as a plastic ruler and a cotton cloth. To begin, the two objects are neutral (i.e. have the same amounts of positive and negative charge). Note: we <u>present the positive charge with a + and the negative charge with a -.</u> This is just to **illustrate the balance and charges that occur, not the actual location** of the positive and negative charges. The <u>charges are spread throughout the material</u> and the <u>real change</u> happens by increasing or decreasing electrons on the surface of the materials.   Now, if the cloth is used to rub the ruler, negative charge is transferred from the cloth to the ruler. The ruler is now negatively charged (i.e. it has an excess of electrons) and the cloth is positively charged (i.e. is electron deficient). If you count up all the positive and negative charges at the beginning and the end, there are still the same amount, i.e. total charge has been conserved!	Does not explain why the number of +ve charges stays the same and why -ve change. No link to atom. **NOS**: actual location, real change… in real world… 'Including by contact' is presented as a method of charging and does not refer to the need for contact. 'Negative charge transfers' implies that positive charge does not. In this sense, -ve charge means electrons. Electrons transfer between solids. There are no mobile electrons in the human body. Most chances are that the carpet will become negatively charged. The author 'forces' a negative charge on the human body to justify the transfer of charge, because 'only negative charge transfers' and hence to justify the discharging of it. It implies that positively charged objects do not discharge. In insulators 'charges' should not 'spread throughout the material' as claimed. This can be understood as "–" and "+" signs in the diagrams representing electrons / missing electrons. At least the text attempts to explain the representation of charges in the diagrams. The concept of '<u>net charge</u>' is missing. Learners have to count total number of 'charges' in objects, though text refers to 'calculate'. The SIYA- NCS presents example 5 as CONSERVATION OF CHARGE
6) SIYAC (undated) only, p. 256-258 **A solved example is given prior ….** a) Note that in this example the numbers are made up to be easy to calculate. In the <u>real world</u> only a tiny fraction of the charges would move from one object to the other, but the total charge would still be conserved. b) The process of materials becoming charged when they come into contact with other materials is known as triboelectric charging. Materials can be arranged in a tribo-electric series according to the likelihood of them gaining or losing electrons. If a material has equal numbers of positive and negative charges we describe it as being neutral (not favouring positive or negative overall charge). If a neutral material loses electrons it becomes electron deficient…. c) <u>For this reason</u> we describe the ordering of materials in the triboelectric series as <u>more positive</u> or <u>more negative</u> depending on whether they are more likely to lose or gain electrons. This tribo-electric series can allow us to determine <u>whether one material is likely to become charged from another material</u>. Materials from the more positive end of the series are more likely to lose electrons than those from the more negative end. so when two materials are chosen and rubbed together the one that is more positive in the series will lose electrons and the one that is more negative in the series will gain electrons. For example, amber is more negative than wool and so if a piece of wool is rubbed against a piece of amber then the amber will become negatively charged.	a) It implies that only triboelectric charging involves contact of materials. Model and reality are again confused. b) "not favouring" charge? Does it mean the material favours staying neutral? Anthropomorphic statement? c) More positive / more negative refers to electronegativity, the primary source of this distinction. No link to electronegativity.

d) P. 260: In all of the examples we've looked at charge was not created or destroyed <u>but it moved from one material to another</u>.	
7) S&MC (2011), p.190-191; S&MN (2005), p.91-92 (**similar with some reshuffling**): a) If you rub two materials together, it is possible that electrons might be <u>rubbed off</u> from one material onto the other. The electrons and protons in each material are no longer balanced. One material has extra electrons and the other missing electrons. The materials have become charged. b) If a polythene rod is rubbed with a cloth, electrons are transferred from the cloth to the rod. This gives the rod extra electrons. Electrons have a negative charge, so the rod has an <u>overall</u> negative charge. The cloth now has <u>too few electrons and too many protons</u>. Protons have a positive charge, so the cloth has an <u>overall</u> positive charge.  Rubbing a polythene rod with a cloth c) If you rub a Perspex rod with wool, it loses electrons to the wool. The Perspex rod becomes positively charged and the wool becomes negatively charged. (Triboelectric series is given) A list of materials ranked according to how strongly they attract electrons <u>when rubbed</u>. This allows us to say, for example, that polythene will become negatively charged when rubbed with wool; wool will become positively charged. d) S&MC (2011), p.192 & S&MN (2005), p. 97: Plastics, particularly plastic and polystyrene, are very <u>good at picking up electric charge</u>. We can illustrate this by rubbing a balloon against clean, dry hair. The charged balloon will pick up small pieces of paper and attract a stream of smooth-flowing water. e) S&MC (2011), p.193 & S&MN (2005), p.97: When the (polystyrene) balls touch the (Perspex) rod, <u>electrons flow</u> from the balls to the rod and the balls become positively charged. The charges are now the same and they repel each other and the rod. f) S&MC (2011), p 194 & S&MN (2005), p91: A PVC pipe becomes negatively charged when it is rubbed with a cloth. The cloth gains a positive charge. The charges on the pipe and cloth were separated, but the sum of the positive and negative charges is still equal. The charge was not produced by rubbing the pipe. The <u>energy used in rubbing has only separated</u> the positive and negative charges already in the atoms.	a) Electrons are 'rubbed off': Do electrons leap through the air? Does the rubbed material always end up positive since its electrons are rubbed off? Conservation of charge is not observed in the diagram. b) *Overall* negative charge, instead of *net* charge (indicating how the concept 'net charge' is disregarded, the concept does not exist). The cloth has *too few* electrons and *too many* protons. Learners might think that nearly all electrons have gone from the cloth. But why does the cloth has now *too many* protons? Where did they come from? c) No link to electronegativity. d) "Picking up" charge conveys the wrong message. Nevertheless, why does a balloon rubbed on hair illustrate the behaviour of plastics? Also, *polystyrene* and *rubber* (the balloon) do not feature in the given triboelectric series, nor is there an indication of which materials are the *plastics*. No attention whatsoever. e) "Electrons flow" between two insulators? Wrong, the process is confused with conduction between conductors. f) Rubbing is the cause of charging (used with the connotations of friction)
8) S&MN (2005) only, a) P.92: ACTIVITY 4: In humid and wet weather the water droplets in the air "leak" away the charge. b) p.93: ELECTROSCOPE: If you touch the metal ball with a positively charged Perspex rod, they <u>pick up the positive charge</u> and swing away… c) p. 94: VAN DE GRAAF GENERATOR: Using a cloth to rub a plastic rod is not a very satisfactory way to <u>produce an electric charge</u>. A good way of <u>producing a lot of charge</u> is to use a Van de Graaff generator…. <u>The friction</u> between the rollers and the belt charges the belt…..any object touching the dome also becomes negatively charged…<u>electrons flow into her</u> (girl) d) p.95-96: PHOTOCOPIER:…which is <u>charged with static electricity</u> p. 96: the charge <u>leaks away</u> where light falls on to the drum, the copier drum is <u>charged with electricity</u>, black toner <u>attaches</u> to the charged parts of the drum e) p. 101: THUNDERSTORMS: When lightning strikes, negative charge from the bottom of the cloud <u>leaps down</u> through the air to the ground…..you should stay away from hilltops and trees or you will <u>pick up</u> a stronger positive charge….and the lightning will be attracted to you. f) p. 102 ELECTRIC CIRCUITS: In Unit 2 you saw that a van de Graaff generator can <u>build up a charge</u> on a metal dome…	All underlined expressions are problematic. No attention to detail has been paid and ideas communicated to learners range from the building up of charge (i.e. charge is created/produced), to charge leaking or leaping into the air, to friction being the cause of charging.

9)	OXFC (2011), p. 154: CHARGING BY CONTACT Some materials have a greater attraction for electrons than others. So when two different materials are brought into contact some electrons will transfer from the one to the other. The transfer is increased by rubbing the materials together. This is sometimes called triboelectric charging. Table 1 enables you to predict the sign of the charge two substances will obtain if they are rubbed together. The one that is higher on the table is the one that becomes positive. A piece of paper rubbed on glass becomes negatively charged but if it is rubbed on a rubber balloon, the paper becomes positively charged. **Did you know?** Charging by contact can be dangerous. When petrol is pumped into a petrol tank the hose is kept neutral and is placed against the pipe of the tank to avoid a build up of charge.	The only comment that is reminiscent of electronegativity. It appears that the author was unaware that the concept had been already introduced under Matter and Materials and avoided its introduction. Message: Transfer happens during contact and if materials are different. Learners must associate the difference in materials with the difference in attraction for electrons. They are prompted to picture electrons moving from one material into the other as if they were mobile, though the examples that follow refer to insulators. A build-up of charge implies charge creation.
10)	OXFN (2008), p.60: TRANSFER OF CHARGE We can explain the results in terms of our knowledge of matter. When two substances rub together, it is the electrons on the outsides of the atoms that are closest and can move from the one substance to the other if the conditions are right. The protons are tightly bound in the nucleus and are not free to move. Some atoms or groups of atoms called **molecules**, attract electrons more than others. In this case, rubbing moves electrons from your hand to the plastic. This is called **charging by friction**. The plastic now has more protons than electrons and is negatively charged. Your hand becomes positively charged because it has fewer electrons than before. They are charged because there has been a transfer of charge. So, the sum of the negative charge on the plastic and the positive charge on the hand is zero and there has not been a change in the total amount of charge in the system. This is an example of **conservation of electrical charge** – *the total charge of a system remains constant, charge is neither created nor is it destroyed*.	"Rubbing moves electrons" implies that rubbing (and presumably friction) is the cause of charging. This contradicts the previous statement that some molecules attract electrons more than others (reminiscent of electronegativity). And before that we are told that electrons are removed because they are on the outsides of atoms, hence they can be removed by rubbing. Protons are presented as having no effect on the charging process. "There has been a transfer of charge" is in the sense that there has been a transfer of electrons. Hence according to the author, charge transfers only to the object that appears negatively charged. The human body is presented as having mobile electrons. The excerpt links to the conservation of charge.

5.6.3 Analysis and interpretation of data in CT7: Triboelectric charging

5.6.3.1 General overview of the data in ct7

A) Need for contact

The first 'definition' in CT7, "*charge transfer (charging/discharging) requires contact*", is not restricted to triboelectric charging, but refers to any type of charge transfer. It is placed at the start of CT7 as this is the start of the analysis of charge transfer in the textbooks. An important requirement for charge to transfer is that two objects must be brought into contact. Charge does not leap into space or from one object onto another, the objects must be in contact. Throughout the chapters of electrostatics, no textbook was found to mention this important requirement for charge to transfer, hence no ticks have been allocated in this first row of CT7. Because this omission may have serious implications in the teaching and learning of the topic, issues related to it are discussed in more detail in section 5.6.4.

B) Presentations of triboelectric charging in the textbooks

The conditions

None of the textbooks refers to the need for contact and separation (condition 1). Two CAPS books, SIYAC (undated) and OXFC (2011), mention the term 'contact' in the context of "when two materials are brought into contact…", but without implying any special characteristic for this contact and without referring to subsequent separation. The OXFC (2011) (excerpt 9 in CT7) states that electrons are transferred during contact, in which case separation would play no role in the charging process. The PLATC (2011) (excerpt 4 in CT7) includes an experiment (exp.2) with sticky tapes and yet fails to point out that the two tapes

become charged without rubbing. Even though the text refers to the tapes being neutral when stuck together and charged when separated, it fails to highlight the condition of contact and separation, among other important macro-inferences one could make from it. The author does not seem to grasp the significance of this experiment and take advantage of it – it appears that it has been included due to the simplicity of the equipment/tapes. The "sticky tape" experiment had been suggested by Beaty (1996b) primarily as evidence that friction is not the cause of charging. It is possible that the PLATC (2011) author came to know of the experiment through similar inclusions in other textbooks rather than by visiting Beaty's site directly (the sticky tapes first appeared in a couple of NCS grade 10 South African textbooks, not among the books analysed in this study).

Condition 2, need for dissimilar materials, does not fare better either. Only two textbooks, SS (1989) and OXFC (2011) (excerpts 3a and 9 in CT7), mention 'difference' in materials. SS (1989) refers to it in a very casual manner as a revision from Standard 7: "when different substances are rubbed together…" (SS, 1989, p.53), without justification for the claim of 'difference' in materials. In this context it is very easy for learners to overlook this condition, let alone to perceive it as a condition. As far as learners are concerned it might mean two different objects. The OXFC (2011) does offer some background to the claim of 'difference' by referring to "some materials have a greater attraction for electrons than others, so when two different materials are brought into contact…" (OXFC, 2011, p.154). However 'difference' is not highlighted enough as a requirement for charging linked to the attraction for electrons. Its mention is rather casual and learners are unlikely to perceive it as a condition.

Three CAPS books, SIYAC (undated), S&MC (2011) and OXFC (2011), as well as the S&MN (2005) include a triboelectric series and comment on it, though its inclusion is not stipulated in either the NCS or the CAPS curricula. This inclusion is a step ahead as it may help alleviate the problem of learners perceiving the charging process as a single-object affair, a problem that is discussed in detail in the following section 5.6.4. However the inclusion of the series has not prompted authors to stress the requirement for difference in materials as a condition for charging to occur, as in excerpt 7c from S&MC and S&MN "A list of materials ranked according to how strongly they attract electrons when rubbed" (S&MC, 2011, p.190) or in excerpt 6c from SIYAC "this triboelectric series can allow us to determine whether one material is likely to become charged from another material…so when two materials are chosen…" (SIYAC, undated, p.257). Nevertheless, the inclusion of the series may prompt learners to infer this requirement by themselves. Remarkably, none of the textbooks links the triboelectric series to the concept of electronegativity, a concept learners should be familiar with from Matter and Materials.

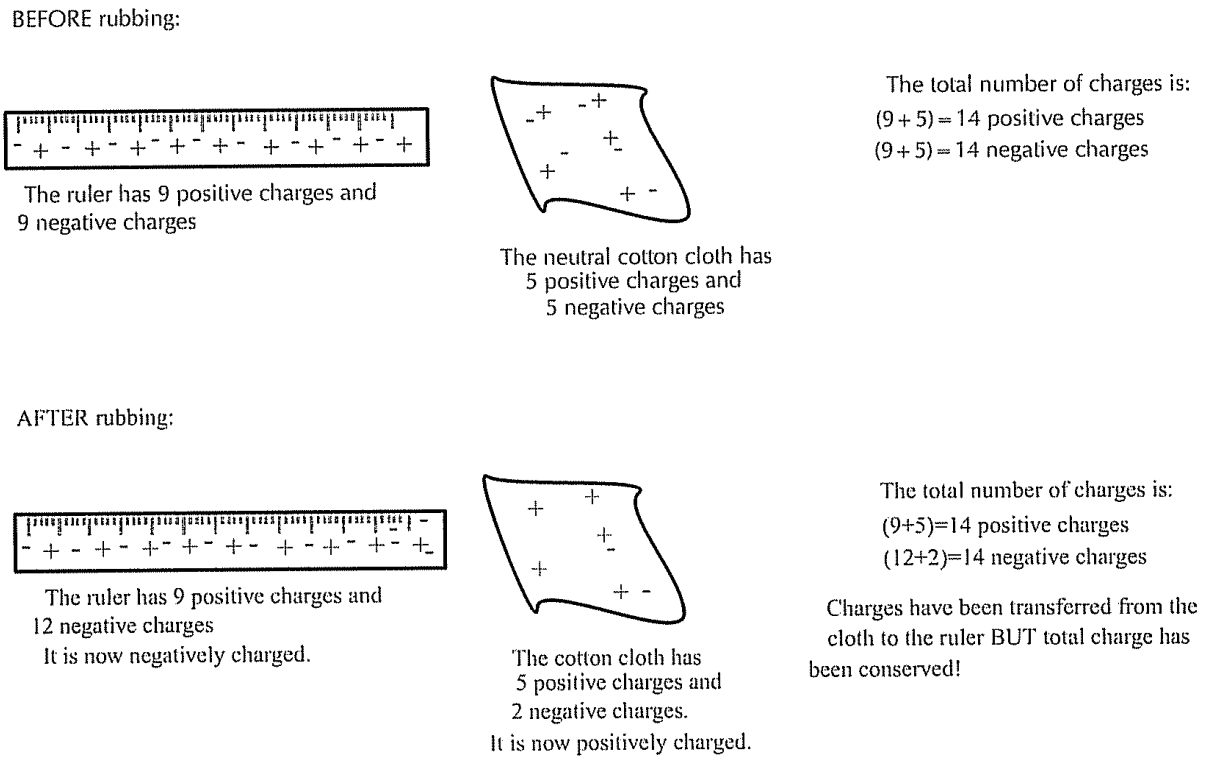
The process

All textbooks attribute the charging of objects, one way or another, to the transfer /movement /removal of electrons. But none of these accounts or claims is reminiscent of the scientific understanding of the process. Hence no ticks have been allocated in the fifth row of CT7 labelled "PROCESS", with the exception of OXFC (2011).

The OXFC (2011) is the only text that hints to contact and rubbing as facilitating the transfer of electrons rather than causing it, and in this context it has been allocated a tick. A few other texts attempt or hint to an explanation of the process, but they leave many doubts. Such problems are discussed in detail in section 5.6.4. PLATC (2011) (excerpt 4b) offers only macroscopic descriptions and inferences and only introduces electrons towards the end of the

chapter as a 'revelation' rather than adding insight "when we charge an object it is electrons that move onto or off the object…" (PLATC, 2011, p.139).

The sixth row in CT7 concerns the gain or loss of electrons during charge transfer in solids. All texts refer to transfer of electrons in the context of triboelectric charging, but none refers to the formation of ions on the surfaces of insulators. Hence, the seventh row in CT7, concerning the formation of immobile patches of ions on insulators, has no ticks allocated.



Source: SIYAC, undated, p.255

Figure 5.13 Triboelectric charging

The figure accompanying the SIYAC text (excerpt 5 in CT7), shown in Figure 5.13, does not even allow the notion of the formation of ions on the rubbed surfaces. In the neutral objects of the "before rubbing" diagram, learners would understand that positive and negative signs represent protons and electrons, because in the previous page of the SIYAC book they are shown a diagram with the same signs that come in pairs and are told that positive charges are

protons: “so in practice what happens is that the number of positive charges (protons) remains the same and the number of electrons changes” (SIYAC, undated, p.255). In this case, the lower diagram labelled “after rubbing” shows that some protons from the cloth have lost their electron. However, when a surface loses an electron, the electron is not separated from its proton, as suggested by the diagram, but from its atom/molecule. An atom may lose an electron, but it keeps all its protons and the remaining of its electrons. These positive signs cannot be protons. Hence, the message communicated in the diagram is erroneous. In essence learners are told that materials consist of loose pairs of protons and electrons rather than atoms and molecules; atoms are part of chemistry, not physics.

Considering that triboelectric charging in the textbooks is primarily associated with insulators, i.e. materials which lack mobile charge carriers, one should expect authors to justify somehow the transfer of electrons to and fro materials as well as to ‘locate’ these electrons or lack thereof on the materials. The former part is addressed in many texts as electrons being rubbed off. The latter is not addressed at all. All textbooks give the impression that the electrons involved are mobile with no hint of formation of ions, a concept that learners should be familiar with. Learners are prompted to picture electrons as moving between materials and find themselves loose on top of the material they end up as if they don’t belong there. In S&MC and S&MN (excerpt 7e in CT7) the notion of free/isolated electrons is communicated explicitly: “when the polystyrene balls touch the Perspex rod, electrons flow from the balls….the charges now repel each other...” (S&MC, 2011, p.193 and so in S&MN, 2005, p.97). This excerpt suggests that the author has no notion of distinction between conductors and insulators, in fact in the S&MC (2011) there is no reference to ‘conductors’ and ‘insulators’ at all, as has been discussed in CT5. A further consequence form the lack of ‘location’ of electrons in all books, is that learners get the message that

electrons may exist as free electrons in all types of materials. References to electrons flowing in the human body or ground, where free electrons should not be found, have been discussed in earlier parts of this study. We meet such references again in CT7 concerning the human body, as in excerpts 5a (SIYAN, 2010, and SIYAC, undated), excerpt 8b (S&MN, 2005) and excerpt 10 (OXFN, 2008).

Charge conservation

Textbook excerpts on charge conservation are not included in CT7 unless they concern the triboelectric charging directly. Textbooks that have not been allocated a 'tick' in the last row of CT7 may refer to the "conservation of charge" as an unrelated item. Textbook excerpts concerning the conservation of charge *in general* are shown in Table 5.7 (p.220).

The NCS curriculum calls for the conservation of charge to be directly associated with the "charging by contact" (see Table 5.5). Two of the three NCS books do so (excerpts 5b and 10). In the third one, S&MN (excerpt 7f), it is implied "…the energy used in rubbing has only separated the positive and negative charges already in the atoms" (S&MN,2005, p.91).

Table 5.5 indicates that in the NATED and CAPS curricula the conservation of charge is listed as a distinct item after the triboelectric charging. Most corresponding texts however do link the conservation of charge to examples of triboelectric charging. Only SPS (1997) and OXFC (2011) do not (see Table 5.7, p.220). In CAPS there is a call for applications: "Apply the principle of conservation of charge" (DoBE, 2011, p.41) which may imply links to examples. However it rather refers to the transfer of charge in conductors, which is listed immediately after and which is denoted implicitly as 'charge *sharing*' rather than *conduction*.

The comments included in CT7 next to the relevant excerpts highlight problematic expressions and possible erroneous messages. Such problems consistently relate to the tradition of confusing 'charges' and electrons, disregarding the science concepts *charge* and *net charge* and confusing the real and inferred worlds, along the lines discussed in CT4 (Charged and uncharged objects). Regarding charge conservation, because certain expressions and/or inclusions may be a cause of concern, these are discussed in more detail in section 5.6.5.

5.6.4 Issues arising from localised points of articulation in CT7: Communicating wrong ideas

The lack of consideration for the need for contact was first noted in the analysis of CT5 (section 5.5.3.2), where the air, the second object in contact with a conductor, was disregarded upon referring to 'leaking charge'. Such omission ought to have consequences on learners' understanding of electrostatics processes, as it prompts them to think in terms of isolated objects and misunderstand the mechanisms involved. Below, examples from the texts are discussed which reinforce wrong ideas, primarily emanating from wrong reasoning and failure to acknowledge the presence and role of a second object in contact with a first one.

5.6.4.1 Wrong idea 1 (WI-1): "Rubbing charges one object" (Physical systems of single objects)

In several texts the rubbed object receives all the attention disregarding the object/cloth which was used to rub it. This is done quite explicitly in some excerpts, as shown in Table

5.6 that lists relevant samples selected from CT7. In the excerpt from SPS (1987) for instance, "Positively charged objects: glass rubbed with silk, Perspex rubbed with silk…etc.*"* (p. 68) apart from confusing the notions of 'object' and 'material', the message sent is that the charged object is the object that was rubbed, glass or Perspex in this sample. The silk is disregarded and is given the subordinate role of the means to rub. In essence learners are told that rubbing charges one object. A reasonable learner would ask: "why use a silk cloth and not some other cloth?" But no answer is disclosed or even hinted in the text. Similar is the excerpt 8b "Using a cloth to rub a plastic rod is not a very satisfactory way to produce an electric charge*"* (S&MN, 2005, p.94) or the excerpt 4a "When you rubbed a ruler you gave it a charg*e*" (PLATC, 2011, p.134). Other texts do refer to rubbed objects becoming oppositely charged, but nevertheless the rubbed object is often at the centre of attention, as in excerpt 3a (SS, 1989).

TABLE 5.6 Rubbing charges one object

Text	Excerpts from CT7	WI-1
SPS (1987), p.68	1) Positively charged objects: glass rubbed with silk; Perspex rubbed with silk;… Negatively charged objects: polystyrene with wool;….ebonite with wool	Explicitly
BJ (1987), p.64	2a) What charge is produced on a polythene strip (or ebonite rod) when it is rubbed with a flannel cloth?	Implicitly at first, amended in later text
SS (1989), p.53	3a) …when different substances are rubbed together they often become oppositely charged…Perspex and glass become positively charged when they are rubbed with silk…..PVC becomes negatively charge when rubbed with cotton…	Focus on rubbed object
PLATC (2011), p.134	4a) When you rubbed the ruler you gave it a charge.	Implicitly. Isolated from further text
SIYAN (2010), p.305 SIYAC (undated), p.255	5a) Objects can become charged…by contact or being rubbed by other objects… can gain or lose negative charge.	Focus on rubbed object, amended in later text
S&MN (2005), p.97 S&MC (2011), p.192	7d) Plastics, ….are very good at picking up electric charge. We can illustrate this by rubbing a balloon against clean, dry hair.	Explicitly, isolated from previous text
S&MN (2005), p.94	8c) Using a cloth to rub a plastic rod is not a very satisfactory way to produce an electric charge…	Explicitly

5.6.4.2 Wrong idea 2 (WI-2): The cause of charging is the rubbing or friction

WI-1 "rubbing charges one object" furthermore suggests that rubbing (or in some texts friction) is the cause of charging. The communicated idea is that the charging process is the rubbing process - it involves an object to be charged and a rubbing action to charge it. The role of the cloth in the previous examples is being reduced to that of making the rubbing action possible. Inevitably learners are prompted to perceive rubbing not only as the essential condition for charging, but also as the cause of charging, both of which are erroneous notions. In some texts, WI-2 is promoted explicitly or almost explicitly as shown in Table 5.7, listing examples selected from CT7.

Table 5.7 The cause of charging is rubbing or friction

Texts	Samples from CT7	WI-2
S&M N (2005), p.91 S&MC (2011), p.190	7a) If you rub two materials together it is possible that electrons might be rubbed off from one material onto the other.	Explicit
S&M N (2005), p.94	8c) The friction between the rollers and the belt charges the belt…	Explicit
S&M N (2005), p.91 S&MC (2011), p.194	7f) The charge was not produced by rubbing the pipe. The energy used in rubbing has only separated the positive and negative charges already in the atoms	Explicit
SS (1989), p.53	3c) The protons are in the nucleus of the atom and are not affected by rubbing the substances together…when rubbed…electrons can be transferred…	Nearly explicit
OXF N (2008), p.60	10) Some atoms…attract electrons more than others. Rubbing moves electrons from your hand to the plastic. This is called charging by friction	Explicit

In excerpt 8c (S&MN, 2005, p.94): "The friction between the rollers and the belt charges the belt…" apart from the fact that neither friction nor rubbing is involved in the charging of the roller and belt (contact and separation of different areas of the objects happen in quick

succession without rubbing each other in the process), we note the use of the term "friction". The term had been removed from the NCS curriculum, but in the mind of the author friction with its energy connotations was essential, being the cause of charging. Indeed, in excerpt 7f we find an 'explanation' for this notion: "The charge was not produced by rubbing the pipe. The energy used in rubbing has only separated the positive and negative charges already in the atoms" (S&MN, 2005, p.91), an idea that has been sustained even in the CAPS version of the book, where we find the exact same excerpts. (The last excerpt also suggests an entire separation of positive and negative charge in the atom! This by itself may generate all sorts of unwanted ideas in the minds of the learners.)

In excerpt 10: "Some atoms…attract electrons more than others. Rubbing moves electrons from your hand to the plastic. This is called charging by friction" (OXFN, 2008, p.60) we understand something along the lines that 'rubbing dislodges or rubs off electrons from one material and moves them onto the other'. In addition we cannot understand how to link the claim that 'some atoms attract electrons more than others', which thus becomes irrelevant. The dominant idea is that rubbing/friction causes charging by moving electrons. In the CAPS version of the book (excerpt 9 in CT7), this idea has been amended to some degree "Some materials have a greater attraction for electrons than others. So when two different materials are brought into contact some electrons will transfer from the one to the other..." (OXFC, 2011, p.154) This time, 'contact' is implied as the cause that enables the transfer of electrons rather than as the cause of charging, which is a step ahead. However, both the mechanism and the cause of charging are still obscure and learners still have to decipher the role of the 'greater attraction for electrons' – what is its contribution, and is it a condition or a cause? Furthermore, the excerpt suggests that electrons transfer upon contact, not separation. This is firstly at odds with the scientific understanding where charging occurs upon separation, and

secondly prompts learners to imagine electrons in insulators as leaving their molecules and moving across attracted by the other material as if they are mobile. Despite the drawbacks, this improvement suggests evolution of thought and some reconsideration of the Electrostatics content in the series. Perhaps the only series that such comment can be made.

One might think that the five examples listed above are the 'worst' examples in the analysed texts. In fact they are the best in the sense that the authors have at least attempted to offer some insight on the charging process. No such attempt was found in the remaining texts. Such attempts or lack thereof indicate that the triboelectric charging is far from clear in the minds of South African authors and that their reasoning skills are also questionable. The examples furthermore suggest that authors have a more or less similar understanding of the charging process. One can infer from this that the only resources authors consulted when writing up their texts were restricted to other school textbooks. Nevertheless, the obscurity and confusion of conditions and causes detected in the texts prompts the inclusion of the following wrong idea:

5.6.4.3 Wrong idea 3 (WI-3): Use of empirical instead of inferential causes

WI-3 is integral to WI-2. It is not a wrong idea per se, but rather concerns unsuccessful causal reasoning that results in a failed scientific explanation and hence in multiple understandings. In the analysis of CT5 (on Distinction between conductors and insulators), instances of simplistic causal reasoning were detected in the texts and it was emphasised how authors presented the distinction between conductors and insulators in terms of contingent rather than primary (efficient) causes. The issue of causality resurfaces again in CT7 through the references to charging, rubbing and friction. The type of causal reasoning exhibited by

authors could be characterised as *common* reasoning according to Besson (2004). This type of reasoning is explained below.

For Ogborn (2008), a scientific explanation is a 'story' that aims at making the occurrence of a phenomenon *obvious*, i.e. a story that should leave no doubt. For Harré (1972, p.181, cited in Besson, 2004, p.114), "a scientific explanation is characterised by the fact that it describes the causal mechanism which produces the phenomena". Thus, Harré's (1972) notion can be understood as concerned with *how* to tell the 'story' for it to leave no doubt. In order to describe successfully the causal mechanism that produces a phenomenon however, Besson (2004) cautions to the need for distinguishing between two 'types' of cause, which are of relevance to this analysis: the *contingent* cause (or trigger cause) that triggers an event, and the *efficient* cause that effectively acts to produce it. Besson (2004) elucidates this distinction through an example of an object held above ground: "You are holding an object in your hand; you open your hand and the object falls. What is the cause of the object's fall: that you opened your hand, or the gravitational force of Earth?" (p.118). Although both of these options are causes, they have a different character. The first one 'enables/triggers' the event/fall by providing the right conditions for it to occur, the second one 'produces' the event/fall. For the scientist who attempts to explain a phenomenon, the efficient cause is the 'producing' cause. In this example it is the force of gravity. The opening of the hand is the contingent/trigger cause that enabled the force of gravity to 'produce' the fall. Thus for the scientist, a trigger cause can be also understood as a *condition* for the efficient cause to take effect. In contrast to the scientist, in daily life we are mostly concerned with trigger causes because these 'enable' things to happen and trigger events. To this effect, Besson (2004) refers to an analogous example of a criminal who argues to the judge that he was not the real cause of the victim's death, as all he did was to push him out of the window and that it was

gravity that caused him to fall (Besson, 2004). For the judge who represents common sense, gravity is of no concern. In common sense it is the criminal that caused the victim's death by pushing him out the window, and this is the cause that matters. "Common thought tends to concentrate on *contingent* cause and to identify it with *efficient* cause" (Besson, 2004, p.119).

Table 5.8 (p.228) lists the most relevant excerpts from the examples in CT7 that suggest or hint to some explanation of the process of triboelectric charging (or at least that send some message to this respect). In each case, an attempt was made to distinguish between efficient and contingent causes as they may be implied in the excerpts, even unknowingly, and these are shown in the last two columns. This task was not straightforward due to lack of substance and clarity in the texts, but nevertheless it gives an idea of the factors which authors have taken into account knowingly or unknowingly regarding the said process of charging. As shown in Table 5.8 (p.228), in nine out of ten grade 10 textbooks, rubbing, friction or contact is presented implicitly or explicitly as the 'efficient' cause of triboelectric charging. According to the scientific understanding however, rubbing is a contingent cause or a condition for charging to occur. It enables the making and breaking of bonds between two surfaces, but does not determine which surface ends up with excess electrons if at all. The efficient cause is the unequal strength by which two surfaces attract shared electrons. And for this to happen, a second condition is necessary, materials must be different (having different electronegativities). Based on the endorsement of a contingent cause as the 'efficient' cause of charging, one may infer that the relevant textbook authors have used *common reasoning* as per Besson (2004) to 'explain' the phenomenon.

However, regarding a scientific explanation, "using common reasoning" may imply that one is cognisant of other causes and yet chooses the wrong one as the efficient cause, perhaps due

to unawareness of the different nature of causes, or perhaps due to confusion between 'causes' and 'conditions'. This might easily appear to be the case with the falling object in Besson's examples. But the process of triboelectric charging is a more complex phenomenon. Did authors *choose* the wrong cause or were they unaware of other causes? Certain "attempts to explanation" in Table 5.8 (p.228) suggest that the latter is most possibly the case:

The SS (1989) refers to protons as not being affected by rubbing, implying that the nucleus plays no role in the charging process. This suggests that the author is unaware of the role of electronegativity in the process. The S&MN (2005) states clearly that friction causes charging. This implies that the author understands the process as friction transferring energy to electrons which can then jump out of the material. This is not the scientific understanding of the process. In both the NCS and CAPS versions of the book there are references to electrons being rubbed off, reminiscent of the 'role' of friction. And this despite references under the list of triboelectric series of "…how strongly they attract electrons when rubbed…", which implies a different cause that conflicts with the 'rubbed off' electrons. The SIYAC (undated) and OXFN (2008) also suggest two conflicting causes at different instances in the texts, as shown in Table 5.8 (p.228). The inclusion of the triboelectric series in CAPS (a few NCS textbooks had already included it as well) has necessitated expressions such as "type of materials" and "how strongly materials attract electrons". But it appears that the authors have not reconciled these into their understanding successfully. In their understanding it is still the rubbing that moves electrons by dislodging them somehow and thus allowing one material to attract them more than another during contact. Certainly the inclusion of triboelectric series has "shaken the waters" by drawing attention to materials, but once again we see that authors did not research the topic, instead they supplied own interpretations.

The OXFC (2011) is the only text that attempts an explanation closest to the scientific, but once again the author sees ‘contact’ as the means for electrons to transfer; ‘separation’ of surfaces is absent. This implies that the author does not really grasp how electrons transfer. Consequently the text communicates the message that *mobile* electrons leave one material and move onto the other *during* contact, which is erroneous.

Hence, regarding the causes of triboelectric charging in the textbooks overall, the distinction between *common* causal reasoning and *scientific* causal reasoning seems to be rather a matter of using *empirical* causes over *inferential* causes. “Empirical causes” is to be understood as causes involving some observable action (e.g. rubbing action), while “inferential causes” involve the action of inferred scientific entities (e.g. molecules attracting shared electrons). The use of empirical causes by the authors, it appears, is not a matter of erroneous ‘choice’ but is rather due to inadequate understanding of the subject matter content. But even more so it may be the lack of understanding of the nature of scientific models and their purpose. It has been pointed on several occasions during the analysis of the texts so far, that authors hold naïve notions on science models and do not seem to be aware of the inferred nature of their entities; even more concerning is that authors do not seem to understand what to do with them. Authors seem to try to justify the actions/presence of inferred entities via macroscopic descriptions rather than the other way round, which renders them obsolete. This is not done in an attempt to enlighten the reader on the construction of scientific knowledge, but as an attempt to justify their ‘existence’. The inferred entities seem to be the end product of science learning. They appear to be a complication that we have to learn rather than the means to understand a phenomenon. “Why should we care about inferred entities since they do nothing?” a reasonable learner would ask.

5.6.4.4 Wrong idea 4 (WI-4): Charge is 'produced' and charge is 'created'

The excerpts discussed under *Wrong ideas 1* and *2* send the message that it is the rubbing or friction that produces the charge on the rubbed object. In SPS this idea may be reinforced by a further statement that "positive charges develop on objects when electrons are removed…" (SPS, 1987, p.68) The word 'develop' in this context may suggest creation of charge. The notion of charge creation is particularly pronounced in excerpt 8b: "Using a cloth to rub a plastic rod is not a very satisfactory way to produce an electric charge. A good way of producing a lot of charge is to use a Van de Graaff generator…" (S&MN, 2005, p.94). In excerpts 8d (S&MN) and 9 (OXFC) we further find that charge can "*build-up*" on objects. On the one hand such expressions appear to conflict with the law of conservation of charge. On the other hand learners have not been introduced to the concepts "charge" and "net charge" as physical quantities (see CT4). What is the said 'charge' that is presented as being produced or developed or built-up on a single object?

Table 5.8 On conditions and causes of triboelectric charging in the textbooks

Source	Most relevant excerpts	Attempts to explanation	Efficient cause	Contingent causes (conditions)
SPS (1987), p.68	1) Certain substances can be electrically charged by friction.	Statement	Friction	--
BJ (1987), p.65	2b) During rubbing, electrons are transferred from the glass onto the silk.	Hinting statement	Rubbing	--
SS (1989), p.53	3c) The protons are in the nucleus of the atom and are not affected by rubbing the substances together…when substances are rubbed together, electrons can be transferred… When different substances are rubbed together they become charged because electrons move…	Attempt to explanation Hinting statement	Rubbing Rubbing	Proximity of electrons allows rubbing to move them Different substances
PLATC (2011), p.134	***Descriptions of observations only, macroscopic inferences, e.g.*** 4a) … when you rubbed the ruler…picked up little bits of paper…you gave it a charge…	Descriptive statements	Rubbing	--
SIYAC (undated), p.256-258	6b) The process of materials becoming charged when they come into contact with other materials is known as triboelectric charging. 6c) This triboelectric series can allow us to determine whether one material is likely to become charged from another material.	Statement Hinting statement	Contact Type of materials	-- Contact
SIYAN (2010), p.305 SIYAC (undated), p.255	5b) …if the cloth is used to rub the ruler, negative charge is transferred from the cloth to the ruler.	Hinting statement	Rubbing	--
S&MN (2005), p.91 S&MC (2011), p.190	7a) If you rub two materials together it is possible that electrons might be rubbed off from one material onto the other. 7c) (Triboelectric series) A list of materials ranked according to how strongly they attract electrons when rubbed.	Hinting statements	Rubbing How strongly attract electrons	-- Rubbing
S&MN (2005), p.94	8) …the friction between the rollers and the belt charges the belt	Hinted attempt to explanation	Friction	--
OXFC (2011), p.154	9) Some materials have a greater attraction for electrons than others. So when two different materials are brought into contact some electrons will transfer from the one to the other. The transfer is increased by rubbing the materials together.	Attempt to explanation	How strongly attract electrons	Contact facilitates transfer, but during contact. Different materials
OXFN (2008), p.60	10) We can explain the results in terms of our knowledge of matter. When two substances rub together, it is the electrons on the outsides of the atoms that are closest and can move from the one substance to the other if the conditions are right. The protons are tightly bound in the nucleus and are not free to move. Some atoms or groups of atoms called **molecules**, attract electrons more than others. In this case, rubbing moves electrons from your hand to the plastic. This is called **charging by friction**.	Attempt to explanation	Rubbing rubs off electrons Difference in attraction, but rubbing causes the move of electrons	Proximity of electrons allows to be rubbed off Unclear

5.6.4.5 Wrong idea 5 (WI-5): Charges / electrons jump off and are picked up …

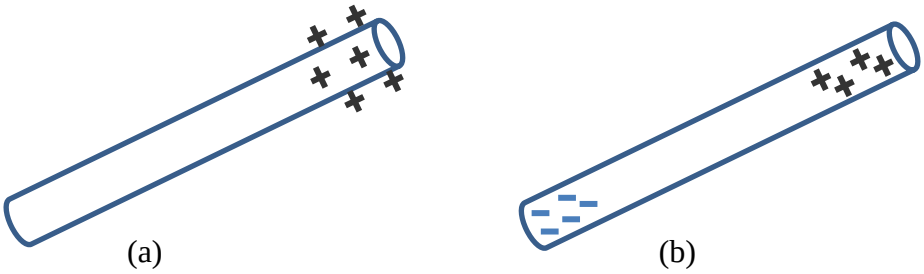
In several excerpts learners are prompted to picture 'charges' (or electrons) as leaping out of a material and into the space surrounding it or where objects can pick up charge from their surroundings. Such excerpts are listed in Table 5.9 below:

Table 5.9 Typical examples of "Wrong idea 5"

Excerpt from CT-7	Possible messages sent
4b (PLATC, 2011): When we charge an object it is electrons that move onto or off the object…we add / we remove electrons	Electrons are coming from or going to the surrounding space, or *we* add them / remove them at will, as if by injection.
7a (S&MN, 2005; S&MC, 2011): If you rub two materials together it is possible that electrons might be rubbed off from one material onto the other	Electrons are 'scraped off' an object (like fish scales) and then jump onto the other object. Hence, rubbed objects must end up positively charged.
7d (S&MN, 2005; S&MC, 2011): Plastics…are very good at picking up electric charge	Charge may exist free of materials and objects can pick it up.
8 (S&MN, 2005): …the charge leaks away…charge from the bottom of the cloud leaps down through the air… stay away from hilltops and trees or else you will pick up a stronger positive charge…	Charge leaks from objects (discussed in CT5) and leaps between objects. Hilltops and trees emit charges into space which we can pick up.

Learner interpretations of elementary electrostatics concepts and processes have not been sufficiently researched in the literature. How exactly do learners perceive the "charging of an object" by rubbing? The closest reference found in the literature comes from Furió *et al.* (2004), in which Spanish student responses on electrification by rubbing were classified into two categories: the '*electrics*' (if acknowledging the existence of charge in materials) and the

'*creationists*' (if charge appeared when work was done on the body during rubbing). An example given among the 'electrics' is that of a student who stated "If the straw is not charged, this means that there are neither too many nor too few positive and negative charges. It loses electrons and becomes charged on being rubbed." (Furió *et al.*, 2004, p.300). A representative drawing within this category of responses is also given showing a positively charged (plastic) straw, as in Figure 5.14a.



Source: Furió *et al.*, 2004, pp.300-301

Figure 5.14 Typical drawings done by 'electrics'

It was not in the aims of Furió *et al.* (2004) to further explore why the student/s decided that the plastic straw became positively charged. Yet it is possible that such responses emanate from notions of 'rubbing off' electrons from an object and the particular student seems convinced that "*it loses electrons on being rubbed*" hence the positive net charge of the object. In the same category of 'electrics', a second type of response was also detected, that electrification was due to a local separation of charge, as shown in Figure 5.14b. According to Furió *et al.* (2004), a possible reason for this wrong response was that students reduced the physical system to the rubbed object only. It appears that for these students 'charge separation' had to occur within the rubbed object since the object used to rub it with was ignored. This is in line with "Wrong idea 1" discussed earlier, promoted unwittingly in most South African textbooks.

5.6.4.6 Wrong idea 6 (WI-6): Contact is not always necessary

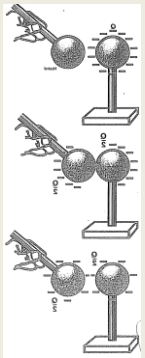
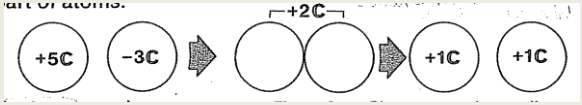
It appears that several authors, as in the last example in Table 5.9 (p.229) and also in the examples discussed in CT5 (section 5.5.3.2), do not consider air as a material being in contact with an object and playing a role in the transfer of charge between the two. The message sent is that charge could transfer to and fro an object even in vacuum. This type of examples may lead to the wrong idea that contact between objects is not necessary for charge to transfer. In the excerpts 5a and 6b from SIYA this idea is clearly evident: "Objects can become charged in many ways including by contact with…" (SIYAC, undated, p.255) and "The process of materials becoming charged when they come into contact with other materials is known as triboelectric charging" (SIYAC, undated, p. 257). The excerpts suggest that there are other ways to charge objects which do not involve contact, or that contact is not always necessary. Hence, although texts do not expand explicitly on the need for contact for charge to transfer, ideas regarding contact are communicated implicitly and usually these are erroneous.

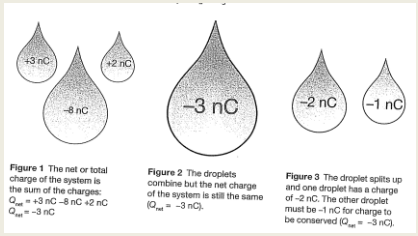
5.6.5 Issues arising from localised points of articulation on the conservation of charge

Table 5.10 lists all textbook excerpts referring to the conservation of charge irrespective of whether they are linked to triboelectric charging or not (hence some of these excerpts do not appear in CT7). Their inclusion and discussion here was decided upon the fact that in the NCS and CAPS textbooks, if the conservation of charge is not linked to triboelectric charging, it is not linked to any other process either. This is particularly puzzling in the case of the CAPS textbooks, considering that the CAPS document (see Table 5.5) demarcates the conservation of charge from the triboelectric charging while it hints towards linking it to the 'sharing of charge' between conductors, i.e. to the process of charging by conduction. None of the CAPS authors have done so, as shown in Table 5.10. It appears that authors did not understand the nonsensical expression appearing in CAPS: "…e.g. two charges making contact and then separating" (DoBE, 2011, p.41). In fact the SIYAC repeats the expression with no further comment (excerpt 6 in Table 5.10): "e.g. two charge objects making contacting and separating" (SIYAC, undated, p.260). The typing errors introduced in addition, signify that no editing and not much thought have been put in the text and learners' understanding was not a priority.

The NATED 550 curriculum is the only curriculum that did not call for linking the charge conservation to a particular charging process. Yet ironically, it is two of the NATED books (excerpts 2 and 3 in Table 5.10) that offer the richest variety of examples; richest in the sense that they include examples from both triboelectric charging and 'sharing of charge', while BJ (1987) in addition refers to charge conservation in chemical and nuclear processes.

Table 5.10 Excerpts on charge conservation

	EXERTPTS IN TEXTBOOKS	COMMENTS & NOTES
1)	SPS (1987), p.68: **The Principle of Conservation of Charge** is as follows: Charges cannot be created or destroyed; positive and negative charges are *separated* from one another during electrification.	Isolated statement as part of a brief revision from standard 7. It refers implicitly to triboelectric charging. Learners could get the message that charge is conserved only during triboelectric charging, or that the only electrification process is the triboelectric charging. What does it mean +ve/-ve charges are separated? Leaves much to speculate.
2)	BJ (1987), p.65-66 CONSERVATION OF CHARGE When an object becomes charged, charge is acquired by the transfer of charges from one object to the other. The charge is not created, but is merely *transferred* from one object to another. Before a neutral glass rod is rubbed with a neutral silk cloth, the sum of the positive and negative charges on each is zero. During rubbing, electrons are transferred from the glass onto the silk. The glass acquires a positive charge and the silk an *equal* negative charge. the sum of the positive and negative charges on the glass and silk remains zero. Charge has therefore been conserved. When neutral sodium metal (Na) is burned in neutral chlorine gas (Cl_2), ionic sodium chloride (Na^+Cl^-) is formed.the algebraic sum of the charges before the formation of ions was zero. During the reaction, each sodium atom donates an electron to each chlorine atom, thus forming the ionic structure of table salt. The algebraic sum of the charges remains zero. Charge has, therefore, been conserved. There are reactions in sub-atomic physics in which charge is created or destroyed. Two equal but oppositely charged particles are able to destroy each other and produce energy. The reverse process also occurs. Two equal and oppositely charged particles may be formed from neutral gamma rays. However, the charged particles are always created or destroyed in pairs. The algebraic sum of the charges before and after the reaction remains zero. When two charged conductive spheres of the same size are brought into contact, electrons move from the more negative sphere to the less negative till the charge is spread evenly over both. On separation, each sphere carries *half the total charge* of the two spheres. (Fig. 6.2) The examples above are all consistent with the **Law of Conservation of Charge**: *the algebraic sum of the electric charge in a closed system remains constant*. 	Links conservation of charge to different processes – physical, chemical, nuclear – and also to both triboelectric charging and charging by conduction (the only text to do so). How about if the conductors were positively charged , etc.? Reflects the preference of many authors for negatively charged conductors, discussed in detail under CT5, section 7.5.2. The quoted figure is also shown in Figure 7.11 of this study.
3)	SS (1989), p. 53: During the charging process, the total number of negative and positive charges remains constant. All that happens is that a transfer of charge occurs i.e. a movement of charge from the one substance to the other. This is an example of the Principle of Conservation of Charge. The total electric charge in an isolated system remains constant. Electric charge cannot be created or destroyed. Figure 2 shows another example of conservation of charge. In this case two charged spheres are brought into contact. The two spheres are of equal size and so the charge spreads over them equally. 	The 'charging process' refers to previous examples of rubbing objects where references to protons and electrons are made. What is the charge that transfers? For the author charge must mean a charged particle (electron in particular) and transfer of charge should mean transfer of electrons. What the excerpt communicates to learners however is that one substance loses charge and the other gains, i.e. one substance is left with little or no charge, while the other has more charge. It is reminiscent of the single-fluid model.
4)	PLATC (2011), p.139: CONSERVATION OF CHARGE Charge cannot be created or destroyed. We say that charge is conserved. That means that if an object becomes, for example, negatively charged by rubbing it with a cloth then the cloth must become positively charged. The number of electrons gained by the object equals the number of electrons lost by the cloth. If we place two identical conducting balls on insulating stands and let them touch, the charges on the two balls will spread out evenly on the surface of the balls.	The argument presented is that "because charge is conserved, one object becomes positive the other negative etc.". It should have been the other way round. All handling of charging has been done in terms of positive/negative charges. Now all of a sudden electrons appear on the scene of electrification. The two paragraphs are unrelated and remain unrelated in what follows in the book. Is the last part an example of charge conservation? Learners will never know.

5)	SIYAN (2010), p.305-306 and SIYAC (undated), p. 255-256 (referring to diagram in excerpt 5b in CT7) Now, if the cloth is used to rub the ruler, negative charge is transferred from the cloth to the ruler. The ruler is now negatively charged (i.e. it has an excess of electrons) and the cloth is positively charged (i.e. is electron deficient). If you count up all the positive and negative charges at the beginning and the end, there are still the same amount, i.e. total charge has been conserved!	So, charge is conserved as a result of us counting numbers of 'charges' and finding them equal. Surely there must be some more convincing justification? The number of 'charges' is not an *amount*. For the author, electrons are negative charge. Hence learners are told that only negative charge transfers. Learners are communicated the notion of a single-fluid model, with the electric fluid being negative.
6)	SIYAC (undated) only, p.260: CONSERVATION OF CHARGE In all of the examples we've looked at charge was not created or destroyed but it moved from one material to another. DEFINITION: Principle of conservation of charge The principle of conservation of charge states that the net charge of an isolated system remains constant during any physical process, e.g. two charge objects making contacting and separating. *(typos in original)*	Concepts of charge and net charge have never been introduced as physical quantities because for the author 'charge' means electrons/charged particles. Learners are told that "*Charge…moved from one material to another*". All the charge? Is one material left without charge? What is this charge? Learners are communicated the notion of a single-fluid model once again. And what happens when "*two charge objects making contacting and separating*"? Why are learners expected to understand this example if the author him/herself does not?
7)	S&MN (2005), p91: A PVC pipe becomes negatively charged when it is rubbed with a cloth. The cloth gains a positive charge. The charges on the pipe and cloth were separated, but the sum of the positive and negative charges is still equal. The charge was not produced by rubbing the pipe. The energy used in rubbing has only separated the positive and negative charges already in the atoms.	The excerpt only implies the conservation of charge, but learners will not come to this conclusion unaided. The same text is repeated in the CAPS version below.
8)	S&MC (2011), p.194: under CHARGE CONSERVATION A PVC pipe becomes negatively charged when it is rubbed with a cloth. The cloth gains a positive charge. The charges on the pipe and cloth were separated, but the sum of the positive and negative charges is still equal. **Law of Conservation of Charge**: The net charge of an isolated system remains constant during any physical process. The charge was not produced by rubbing the pipe. The energy used in rubbing has only separated the positive and negative charges already in the atoms.	The text reflects the casual way scientists and science educators could describe the charging of objects in terms of positive/negative charges in their everyday practice. But the question is, would learners who might not have the scientific insight of the concept of 'charge', interpret it in the same way? Charge as a physical quantity has been implied in the book but never introduced as such. 'Net charge' has never been introduced. The last sentence may suggest that energy from rubbing splits all atoms into +ve/-ve parts.
9)	OXFC (2011), p.158: CHARGE CONSERVATION Conservation means that a quantity stays the same. Principle of conservation of charge: The net charge of an isolated system remains constant during any physical process. Figures 1 to 3 illustrate the principle of conservation of charge in a system that initially consists of three charged water droplets. According to the principle of conservation of charge: $Q_{net} = Q_1 + Q_2 + Q_3$  **Figure 1** The net or total charge of the system is the sum of the charges: Q_{net} = +3 nC −8 nC +2 nC Q_{net} = −3 nC **Figure 2** The droplets combine but the net charge of the system is still the same (Q_{net} = −3 nC). **Figure 3** The droplet splits up and one droplet has a charge of −2 nC. The other droplet must be −1 nC for charge to be conserved (Q_{net} = −3 nC).	Although the numbers add up and initially it may seem as a good idea, charge seems to share in proportion to the drop size. This is not an example of charge transfer or separation, it is bulk splitting of drops carrying their charge along. We have not been told about liquids or ionic conductors. How can water be charged? What are the charge carriers in the drops? Is water a conductor or insulator?
10)	OXFN (2008), p. 60: TRANSFER OF CHARGE The plastic now has more electrons than protons and is negatively charged. Your hand becomes positively charged because it has fewer electrons than before. They are charged because there has been a transfer of charge. So, the sum of the negative charge on the plastic and the positive charge on the hand is zero and there has not been a change in the total amount of charge in the system. This is an example of **conservation of electrical charge** – *the total charge of a system remains constant, charge is neither created nor is it destroyed*.	The excerpt refers implicitly to the physical quantity 'charge', which has not been introduced. Hence, what is the meaning of the 'total charge'? What is 'amount' of charge? The hand in the example it refers to, accompanied by a figure, is implicitly presented as an insulator, showing +ve charges concentrated on its surface. On page 62 of the book, the finger or human skin is presented as a conductor (it can discharge an electroscope). This does not demonstrate *consistency*.

Excerpts in Table 5.10 are accompanied by brief comments on possible messages they might communicate to learners. One aspect that is not reflected in these comments but becomes evident from the excerpts is that the incorporation of the conservation of charge and its linking to examples has obligated authors to refer to *both* materials involved in the charging process on equal terms. The attention has been shifted from the rubbing and placed on the charge of both objects. It suggests that had the *conservation of charge* been kept in mind together with the *need for contact/separation* from the start of the accounts of triboelectric charging, some of the wrong ideas promoted, as discussed in section 5.6.4, might have been alleviated; most of these wrong ideas were associated with the notion of single-object systems. Furthermore, a variance in the texts can be noted, concerning whether triboelectric charging represents a *transfer of charge* or a *charge separation*. To this effect, Table 5.11 below summarises the variations exhibited by the excerpts on this matter.

Table 5.11 Conservation of charge in triboelectric charging: Variations in texts

excerpt	process represents a…	objects involved…	justification
1) SPS	Separation of **charges**	?	+ve and –ve charges are separated from one another
7) S&MN 8) S&MC	Separation of **charges**	one **gains** +ve charge one **gains** –ve charge	+ve and –ve charges in the atoms are separated
2) BJ	Transfer of **charges** Transfer of **charge** Transfer of **electrons**	one **gains** +ve charge one **gains** –ve charge	
5) SIYAN 5) SIYAC	Transfer of **negative charge**	one **gains** electrons one **loses** electrons	
6) SIYAC	Transfer of **charge** (moved)	?	
10) OXFN	Transfer of **charge**	one **gains** electrons one **loses** electrons	
3) SS	Transfer of **charge** (moved)	?	
4) PLATC	?	one **gains** electrons one **loses** electrons	
9) OXFC	Irrelevant example		

In triboelectric charging, electrons do not move from one object to another, released by rubbing, though this is the impression given by most textbooks as has been already discussed. The electrons which are involved in the bonding of two surfaces during contact tend to remain with the more electronegative surface upon separation. These electrons do not 'move' to the more electronegative surface, they just 'stay' with it upon separation of the surfaces. In this sense, it sounds more reasonable to accept that triboelectric charging represents a charge separation rather than a charge transfer. However for the scientist, this distinction is not crucial. Due to the abstract nature of the concept of "charge", being a physical property of matter without being a physical entity itself, the expression *transfer of charge* does not necessarily reflect a physical transfer of matter in the same direction. So for the scientist, if negative charge was to transfer to an object (gain of negative charge), positive charge would transfer to the other object involved (gain of positive charge) no matter if and what type of particles moved and in which direction for charging to occur; both objects gain opposite types of charge. It can be said that transfer of charge and transfer of charged particles /matter are two *ontologically different* transfers. Related to this is the case of electric circuits where we have retained the notion of (conventional) current in terms of movement of positive charge, though we accept that is electrons that move in the wires in the opposite direction and though both positive and negative ions move inside the battery in opposite directions. In semiconductors too, the positive charge of the "mobile holes", moves through movement of electrons in the opposite direction. Notions of movement of charge and movement of particles do not coincide.

As shown more clearly in Table 5.11, three excerpts relate triboelectric charging to a separation of *charges*. Most excerpts, five in all, support the idea of a transfer of 'something' between the two materials involved. This 'something' may be *charge* or *charges* or *electrons*.

Two of these excerpts (3 and 6), refer to the transfer of charge as a ‘movement’ of charge. Finally two of the CAPS books (PLATC, 2011, and OXFC, 2011) do not offer any insight on the matter. References to ‘charges’ and ‘movement of charge’ in Table 5.11, signal that the accounts in the corresponding excerpts cannot be without problems.

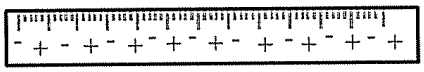
The analysis of the texts so far has shown that an explicit notion of charge (and consequently of net charge) as a physical quantity is conspicuously missing. The distinction of the terms charge and charged particle has been overlooked and authors use ‘charges’ as a short-cut for ‘charged particles’ as the norm. Yet, the notion of charge as a physical property is unavoidably present in the excerpts in Table 5.10, though learners might not perceive it as such. Accounts of electrostatics phenomena in terms of charge and in terms of charged particles can be very different. Mixing the two unthinkingly can be a recipe for sure confusion for learners.

To this effect, three excerpts from Table 5.10 are discussed in what follows. The first one from SIYAC (undated) reflects the confusion caused by various meanings of charge and its transfer. The second one from BJ reflects that even a reasonable account of charge conservation might be confusing to learners who do not have the background for the concept “charge”. The third one is from OXFC (2011), which presents a novice idea for introducing conservation of charge that initially may seem good, but which is missing the point of charge conservation.

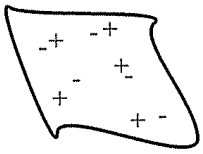
SIYA (excerpts 5 and 6 in Table 5.10)

5) SIYAC (undated), p. 255-256 and SIYAN (2010), p. 305-306

BEFORE rubbing:



The ruler has 9 positive charges and
9 negative charges



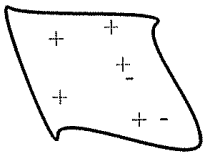
The neutral cotton cloth has
5 positive charges and
5 negative charges

The total number of charges is:
(9 + 5) = 14 positive charges
(9 + 5) = 14 negative charges

AFTER rubbing:



The ruler has 9 positive charges and
12 negative charges
It is now negatively charged.



The cotton cloth has
5 positive charges and
2 negative charges.
It is now positively charged.

The total number of charges is:
(9+5)=14 positive charges
(12+2)=14 negative charges

Charges have been transferred from the cloth to the ruler BUT total charge has been conserved!

Now, if the cloth is used to rub the ruler, negative charge (**many electrons***) *is transferred from the cloth to the ruler. The ruler is now negatively charged (i.e. it has an excess of electrons* (**gained negative charge**)) *and the cloth is positively charged (i.e. is electron deficient* (**lost negative charge**)). *If you count up all the positive and negative charges* (**signs in diagram**) *at the beginning and the end, there are still the same amount, i.e. total charge* (**sum of positive signs and sum of negative signs**) *has been conserved.*

6) SIYAC (undated), p.260: *in all of the examples we've looked at charge* (**charged particles**) *was not created or destroyed but moved from one material to another* (**movement of particles**).

* In the first sentence, a scientist would understand "negative charge" as a *physical property*. However the meanings added in the parentheses above reflect possible intended meanings of the author.

In the excerpt learners are prompted to understand "negative charge" as *electrons*, because in the previous page of the textbook "positive charge" is presented as *protons* and it is possible that this was the intended message. As discussed in CT4 (section 5.4.2.3), the SIYA author

considers negative charge to be synonymous to electrons. Hence for the author, a transfer of negative charge is synonymous to a transfer of electrons which is a movement/flow of electrons and hence, only negative charge transfers. This idea most possibly stems from a conviction that electrons are the only mobile charged particles in matter, held by other authors too (e.g. S&MN/C). From a scientific perspective the first sentence of the excerpt is erroneous. It is reminiscent of a single-fluid model of charge, with the 'electrical fluid' consisting of electrons and being negative. Stocklmayer and Treagust (1994), Simon and Llovera (2008) and Furió *et al.* (2004) referring to the history of electricity describe the single-fluid model as an imponderable fluid that would flow from one object to another and whose absence or presence in excess would account for the appearance of the negative and positive charge of objects respectively. This notion is particularly evident in excerpt 6: "charge was not created or destroyed but moved from one material to another" (SIYAC, undated, p.260). Excerpt 3 in Table 5.10 also suggests the notion of a single-fluid model: "All that happens is that a transfer of charge occurs i.e. movement of charge from the one substance to the other" (SS, 1989, p.53). And so does S&MN in the introduction to "Electric circuits"": "…if the charge is caused by extra electrons the dome has a negative charge…if the dome is connected to the earth by a wire…the extra electrons move down the wire…this movement of charge is called an electric current" (S&MN, 2005, p.102). The last excerpt implies that if the dome had a positive charge there would be no current, only negative charge flows; the misconceptions gathered in Electrostatics are now transferred to the following chapter on Electric Circuits.

At the end of excerpt 5 learners are expected to count 'the charges' to see that they are equal in numbers and thus to 'understand' that charge is conserved during the charging process. Such diagrams do not aid understanding, they are statements in pictorial form. The task of

counting is absurd; counting signs that somebody has drawn does not insight conservation of charge. The conservation of charge should have been *inferred* through the mechanism of the charging process that explains why objects appear charged. It is worth noting that in the diagram, the "total charge" is not given as *zero*, but as "*14 positive charges and 14 negative charges*". The notion of total charge (net charge) as a physical quantity with its own units, is completely absent from the account of the author. Problems with the depiction of positive and negative charges in objects in the manner shown in these diagrams have been discussed extensively in CT4, with a primary concern being the complete dissociation of these 'charges' (and hence of electrostatics) from anything learners have learned about matter so far.

The SIYA excerpt in discussion reflects ideas found in several texts which raise a number of concerns as follows:

a) Learners communicated the notion that only negative charge transfers will find it hard to understand why charge may transfer between two conductors, if for example, one is neutral and the other one is positively charged, or if both have unequal positive charges and so on. As has been discussed in CT5, authors avoid examples and diagrams of positively charged conductors, perhaps because they find them hard to explain themselves.

b) The notion that in triboelectric charging charge transfers by means of movement of particles may conflict with other knowledge. Textbook examples of triboelectric charging, involve materials that are primarily insulators. If we tell learners that negative charge moves from one such material to another, why do we then classify them as insulators? A preferred distinction between conductors and insulators in the books is that of allowing or not allowing charge to move (see CT6), which conflicts with this notion.

Electrons do not move during this type of charging, they are kept by one surface upon separation.

c) One misconception identified in the literature is that positive charge is acquired by the transfer of protons (e.g. Sarikaya, 2007). Such findings may be the reason why the CAPS curriculum refers explicitly to positively and negatively charged objects in terms of deficiency or excess of electrons. It may also signify that curriculum developers too, hold the notion that only negative charge transfers. In any case, using the notion of a fluid-like transfer of electrons from one material to another, caused somehow by rubbing, implies that electrons are the important charged particles in matter while protons play no role in the charging process. A positively charged object perceived as 'electron deficient' may suggest that there is 'something wrong' with it, yet an extra proton should be as good as an extra electron and should not be ignored; gaining of positive charge should carry the same significance as gaining negative charge. Only two excerpts in CT7 refer to protons in their account of triboelectric charging:

- Excerpt 3c in CT7: "The protons are in the nucleus of the atom and are not affected by rubbing" (SS, 1989, p.53), and
- Excerpt 10 in CT7: "it is the electrons on the outsides of the atoms that are closest … The protons are tightly bound in the nucleus and are not free to move" (OXFN, 2008, p.60).

In both of these excerpts the mention to protons is restricted to their inability to move. The message sent is that rubbing does not affect protons and that the nucleus is of no consequence to the transfer of electrons. Yet for the scientist, the nucleus is the agent of the efficient cause of charging. In order to avoid the idea of a proton transfer (although mobile hydrogen ions can be found in certain conductors), authors and curriculum developers ought to concentrate

on the mechanism of the charging process rather than imposing electron transfer as a statement.

BJ excerpt (from excerpt 2 in Table 5.10)

BJ (1987), p.65: *When an object becomes charged, charge** (**net charge /bulk property of object**) *is acquired by the transfer of charges* (**charged particles**) *from one object to the other. The charge* (**property at large**) *is not created, but is merely transferred* (**transfer of property**) *from one object to another.*

Before a neutral glass rod is rubbed with a neutral silk cloth, the sum of the positive and negative charges (**sum of charges of individual particles, or sum of net charges on objects,** not clear – either case means **property**) *on each is zero.*

During rubbing, electrons are transferred (**transfer of specific particles, unknown why**) *from the glass onto the silk. The glass acquires a positive charge* (**net charge /bulk property of object**) *and the silk an equal negative charge* (**net charge /bulk property of object**).

The sum of the positive and negative charges (**sum of net charges /bulk property of objects**) *on the glass and silk remains zero. Charge* (**property at large / net charge of the system**) *has therefore been conserved.*

* The inclusions in the parentheses reflect the possible understanding of a scientist.

The excerpt is presented as a wrap-up of 'charging by rubbing' in order to conclude that charge is conserved during the process. It was chosen because it is long enough for the term *charge/s* to appear several times. It is also (relatively) reasonable enough in its use of the term "charge" for meaning making by a science expert. The scientist has already an understanding of the charging process in terms of the behaviour of the particles involved and can 'picture' them and locate them in her imagination in each step of the charging process. Ogborn (2008) asserts that a science model is a world for which we know everything about, because it is a world that *we* have constructed. The scientist is familiar with this world. That glass acquires a positive charge and silk a negative charge and that the two are equal,

mentioned in the text, is not a revelation for the scientist, it is to be expected; not because the scientist knew it all along, but because it is a consequence of the behaviour of the particles involved. The scientist 'translates' the word *charge* in the text from the point of view of her understanding and her expectations. If her expectations are met, the text is 'reasonable'.

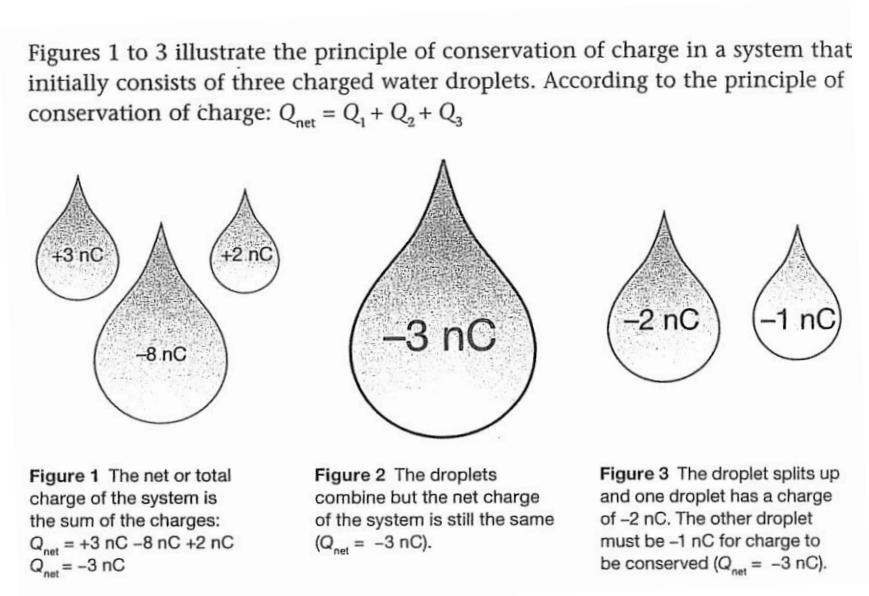
But such excerpts are not meant for science experts, they are meant for learners. What meanings would learners construct out of this excerpt if they do not have the understanding of *charge* as a physical property, nor have they been introduced to the charging mechanism? Would a learner, who possibly thinks of charge as a charged particle, an electron perhaps, decipher the subtle differences in meaning ascribed to *charge* in the excerpt? Would a learner understand that glass acquires positive charge without acquiring positive particles or how it is possible for the sum of 'charges' to be zero?

The meaning of charge is not something that can be physically described, it is like the concept of *mass*. The meanings of charge and charged particles are ontologically different. The transfer of charge may take place through movement or displacement of charged particles without being a movement by itself. Such ideas may be too complex and perhaps too philosophical for young and novice learners. Yet understanding of abstract concepts comes by using them rather than by definitions and *charge* should not be an exception, provided that it is used in a consistent manner. It goes without saying that a reasonable suggestion for the science educator would be to avoid referring to charged particles as 'charges'. *Charge* in singular and plural mode should be reserved to *only* mean the physical property charge of charged particles /objects. Expressions such as "the *charge* of an electron" or the "sum of the *charges* of all protons and electrons in the atom is zero" or "the *charge* of the positive ion formed is equal to the *charge* of one proton" and so on, may sound tedious, but they will help learners grasp the concept of *charge*. This is because they clearly delineate the notions of the

"charge of charged particles" from the "charged particles". In addition they enable learners to form clearer mental pictures of the actions of the entities of the micro-cosmos since they make it possible to *situate* specific charged particles within it, something that they cannot do with the very vague 'positive and negative charges'. Finally they may oblige the educator to actually remind learners of the micro-cosmos of the science models they have learned under Matter and Materials and in previous years and to actually use them.

OXFC (excerpt 9 in Table 5.10)

The OXFC presents "charge conservation" as an isolated item, dissociated from any previous or subsequent examples of electrostatics processes. Instead it presents a system of charged water drops, shown in Figure 5.15, in an attempt to 'illustrate' the conservation of charge in general terms.



Source: from OXFC, 2011, p.158

Figure 5.15 'Charge conservation', an example from a CAPS text

The diagram in Figure 5.15 represents three scenarios of water drop configurations and we, the readers, must assume that it should be 'read' from left to right. The initial three droplets first join into a big one, which then splits into two, resulting in drops of different size and charge. The impression given is that the charge of each of the three initial drops, and also of

the two final drops, is proportional to their size/volume, implying that their charge is distributed evenly within their volume, as if water droplets have a certain 'carrying capacity' for charge. But the drop in the middle is very perplexing, it does not abide by this 'rule'. We understand that all numerical values in the three scenarios add up to the same number, -3, and this is called charge conservation. But this is all we understand. Why does the middle drop have a charge of -3 nC? What happened to the +3 nC, +2 nC and -8 nC? There was lots of positive and negative charge in the initial drops but most of it disappeared. What happened inside the big drop to make charge disappear? How can we talk about conservation of charge? Learners may ask and very justifiably so.

The diagram is far from successful in representing conservation of charge because it describes a bulk splitting/movement of matter, carrying 'its charge' along, instead of describing a transfer of charge between objects and *explaining how* charge is conserved. Hence, the given diagram links changes in charge to changes in quantities of matter that firstly might unearth unwanted understandings and secondly it does not justify the law of conservation of charge. Unless the purpose of the author was once again to get learners to add numbers/charges of whatever that is. Furthermore, what are the mobile charge carriers in the water droplets, how they come to be and how do they behave? Learners have only been told of electrons, never of ions, hence another source of unwanted understandings.

5.7 ASPECT OF ANALYSIS 6: Charged attracts uncharged

5.7.1 Remarks on polarisation

We cannot tell whether an object is charged just by looking at it. We need to test it. One test for charge would be to bring the object near small pieces of paper and see if they are affected. Another test would be to bring the object near an electroscope and observe the behaviour of its leaves. From the onset of the introduction of learners to electrostatics phenomena, attraction of small bits of paper by charged objects may be the first effect they will encounter in all likelihood, either in their textbooks or as an experiment. One of the first building blocks of electricity knowledge learners will (or should) construct, is the macro-assumption that *charged objects attract neutral bits of paper*. However, Criado and Garçia-Carmona (2010) assert, based on their findings, familiarity with a phenomenon, which may be due to the recurrence of an experiment in textbooks or in teaching, does not seem to help learners (student teachers in the particular case) with the interpretation of the phenomenon. The question 'how is it possible for charged objects to attract uncharged?' is a crucial one in Electrostatics and can only be answered through considering the doings of inferred entities of the micro-cosmos. Research points to the fact that this is far from straightforward as indicated by scholars (Criado & Garçia-Carmona, 2010; Park *et al.*, 2001; Petridou *et al.*, 2009), who have dealt with student responses on electrostatics processes involving polarisation and charge induction. Criado and Garçia-Carmona (2010) refer to studies confirming that students may hold unscientific notions for the concepts *charged body* and *neutral body*, and multiple notions of these concepts may be held simultaneously. "For example, we observed that the

same student …. may identify "neutral" with "balance of positive and negative charges", and at the same time believe that "its particles are not shaking about, but are staying still"." (Criado & Garçia-Carmona, 2010, p. 772). This is already a stumbling block in any attempt to understand the interaction between charged and uncharged objects. The analysis of the texts in CT4 on charged and uncharged objects and particularly the analysis of the accompanying inscriptions (section 5.4.2), clearly reveal that texts communicate multiple unscientific notions of charged and uncharged objects. Regarding the effect of prior knowledge, Criado and Garçia-Carmona (2010) refer to further concerns in responses of students relating to the interaction between charged and uncharged objects, from the occasional likening of electric dipoles to magnets, to the impact of the rule '*like charges repel, unlike attract*' which is so deeply entrenched in the students' thinking that it often presents an obstacle in their interpretations, believing that for attraction to occur, both objects must be charged, or both neutral-polarised. The latter beliefs would persist in some students even after instruction, and which according to Criado and Garçia-Carmona (2010) constitute the greatest obstacle to the learning of electrostatic induction.

Petridou *et al.* (2009) note the difficulties student-teachers face in providing scientifically accepted answers using a microscopic model, with some even being unaware of the attraction between charged and uncharged, which is in tune with the belief that only charged (or polarised) objects may attract, stressed by Criado and Garçia-Carmona (2010). Petridou *et al.* (2009) stress in particular the difficulty of students to *predict* events involving polarisation, an aspect usually overlooked by scholars, and attribute student difficulties to the staticness and other drawbacks of pictorial models found in undergraduate textbooks. A computer simulation especially designed to address the formation of a dipole and the forces it experiences before applying to the microscopic representation of insulators, had considerable

impact on the predictions of students who interacted with it. The study reflects the importance of a carefully thought, ascending sequence of pictorial representations of the micro-cosmos for learners understanding. As far as simulations are concerned, these become increasingly available in South African classrooms nowadays, though a simulation does not necessarily guarantee quality of presentation.

One of the findings of Park *et al.* (2001) in studying the responses of middle school learners to observational evidence which ought to refute their prior ideas on electrostatic induction, was that instead of rejecting their hard core[1] preconceptions, most learners modified auxiliary ideas (the protective belt) that supported their hard core, unlike most college students who did the opposite. For example, auxiliary ideas relating to the hard core *electrostatic induction* could be notions of *conductors* and *insulators*, *charged* and *uncharged* objects, *charging*, examples of these, the purpose of using an electroscope, and so on. In Park *et al.* (2001) learners were asked to predict whether the leaves of an electroscope would move apart when rods of different materials were to be placed, one at a time, in-between a charged object and the electroscope, and then to test their predictions. Learners who predicted that insulator rods would not cause the leaves of the electroscope to move apart, but then observed the opposite, instead of the expected conclusion that insulators too have the same effect as conductors (i.e. reject their hard core preconception), they concluded that materials they initially thought to be insulators were conductors or that even insulators allow electricity or that all materials are conductors (i.e. modified auxiliary notions / the protective belt).

[1] Park *et al.* (2001) found that learners' responses to evidence showed a Lakatosian rather than a Popperian approach. Hence, Park *et al.* (2001) refer to the terms "hard core" and "protective belt" in the sense of the Lakatosian perspective, where a scientific theory consists of a hard core of basic principle and a protective belt of auxiliary assumptions and initial conditions around the core (Park *et al.*, 2001, p1221).

According to Park *et al.* (2001):

> The less the protective belt is well-structured or well-understood, the more the protective belt is modified, rather than the hard core is falsified. Therefore, to achieve successful conceptual change, we need to be concerned about the quality of students' understanding about the protective belt, as well as the hard core. In short, students' prior ideas should be considered as structured wholes.
>
> (Park *et al.*, 2001, p.1234)

This finding of Park *et al.* (2001) ought to have significant consequences in the teaching and learning of science. Apart from justifying why some wrong ideas persist after instruction, it signifies that badly understood background concepts and assumptions may hinder sound understanding of new more advanced concepts, because learners, in the event they are faced with a contradictory observation or statement, will modify auxiliary concepts rather than fundamentally change their core conception. This is of particular importance in this analysis of elementary Electrostatics, because this is the topic where the foundations of Electromagnetism are meant to be established. This is supported by research indicating that difficulties in Electromagnetism do not begin with advanced concepts, such as *electric field* and *potential*, but originate in the concepts of elementary Electrostatics (Criado and Garçia-Carmona, 2010). Yet none of the foundational concepts of Electrostatics have been dealt with successfully in the analysed texts so far. Concerning the present aspect of analysis, the protective belt around the core of *polarisation* has been badly structured in the texts, as discussed in the previous sections, and learners were not given the opportunity to gain the required scientific understanding.

5.7.2 Polarisation in the curricula

The NATED 550 curriculum does not refer to "polarisation of materials" and only hints to polarisation of metallic conductors through references to the electroscope, as shown in Table 5.12. The inclusion of the electroscope in Standard 7 is restricted to the testing for the presence of charge through descriptions of the behaviour of its leaves rather than explaining this behaviour. In Standard 10 the same is to be done as a brief revision from Standard 7, but it is phrased as "the influence of a charged object on an electroscope", where *influence* could suggest something more than just descriptions.

The NCS is the first curriculum to include the concept of *polarisation* explicitly, as shown in Table 5.12. It is not clear whether the curriculum stipulates the inclusion of polarisation of materials in general with a caution for teachers to stress that in the case of insulators it is the molecules that become polarised, or whether the curriculum stipulates to consider only the polarisation of insulators and to disregard conductors. Whatever the intention of the curriculum developers, the phrasing suggests the latter as more plausible, which is odd.

The CAPS curriculum maintained this inclusion as is, with a rational correction, indicated by the underlined expressions in Table 5.12. Once again, polarisation seems to concentrate on insulators. This oversight coupled with the omission of the section on "conductors and insulators" from Electrostatics, can only send the message that Electrostatics concerns insulators. The comment on polar molecules accompanying the NCS inclusion has also been maintained in CAPS unchanged. Such molecules would be better called *polar* molecules rather than *polarised*, as referred to in the curricula. The word 'polarised' suggests that an external charge causes the separation of charge in the molecule and hence its polarisation. It implies an imposed state on the object/molecule. Polar molecules are naturally polarised, their polarisation is a natural state.

Table 5.12 Polarisation in the curricula

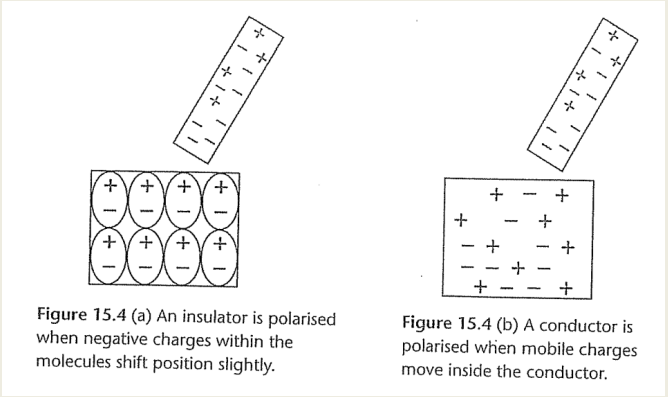
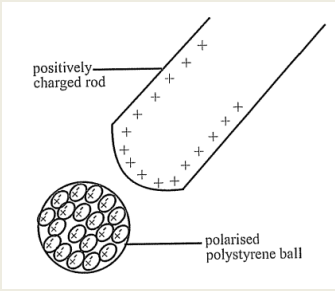
NATED 550 Std 7 (DoE&C, 1993, p.8-9)	1.1.5 The electroscope: Charging by contact; Indication of the presence and type of charge; Investigate the effect of an object on a neutral electroscope: 1. Neutral Perspex rod; 2. Positively charged Perspex rod; 3. Neutral PVC rod; 4. Negatively charged PVC rod Investigate the nature of an unknown charge using a charged electroscope.
NATED 550 HG Std 10 (DoE&C, undated, p.36)	2.1 STATIC ELECTRICITY: A brief revision (*i.e. from Std 7*) of the following: ….<u>The influence</u> of a charged object on a charged and uncharged electroscope.
NCS Gr 10 (DoE, 2006, p.29)*	Attraction between charged and uncharged objects (polarisation); Explain how charged objects can attract uncharged insulators <u>because of the movement of polarised molecules</u> in insulators. (Under "Comments, motivations and Links") In materials that comprise polarised molecules, these molecules may rotate when brought near to a charged object, so that one side of the object is more positive and the other side more negative, even though the object as a whole remains neutral.
CAPS Gr 10 (DoBE, 2011, p.42)**	Attraction between charged and uncharged objects (polarisation); Explain how charged objects can attract uncharged insulators <u>because of the polarisation of molecules</u> inside insulators. (Under "Guidelines for Teachers") In materials that comprise polarised molecules, these molecules may rotate when brought near to a charged object, so that one side of the object is more positive and the other side more negative, even though the object as a whole remains neutral.

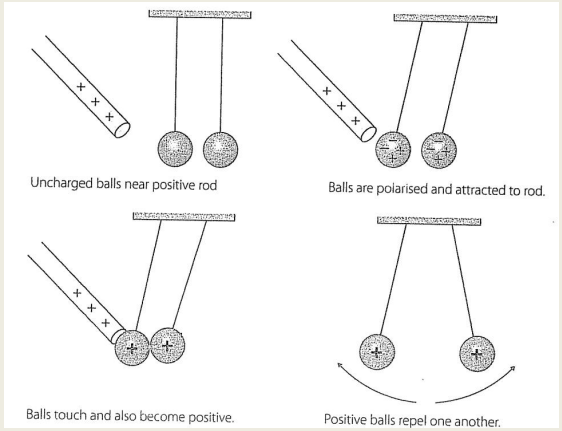
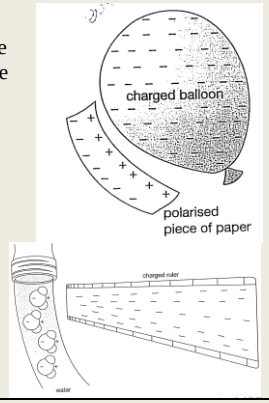
*In NCS, "Polarisation" is placed prior to "Conductors and insulators", the latter being the end of the topic Electrostatics.

**In CAPS, "Polarisation" is at the end of Electrostatics ("Conductors and insulators" have been removed).

Categorisation Table 8 CATEGORY: Polarisation of materials

	Theoretically grounded 'definitions'	SPS		BJ		SS		PLATC		SIYAN	SIYAC		S&MN	S&MC		OXFN	OXFC	
Polarisation of metal conductors	Attempt to include polarisation of conductors							✓	Incl. diagram See (1c)									
	In metals: **slight separation** of +ve and –ve charge in neutral object due to slight shift of the sea of electrons (or free electrons), producing /inducing a net or excess charge at opposite ends.							✓	Mobile electrons See (1c)									
	Explain why **not all** free electrons move to one side in terms of balanced forces (attraction, repulsion)																	
	The net force towards the charged object is the **polarisation force**. Explain in terms of different distances from charged object. Polarisation force on metal always towards charged object (attraction).																	
	Polarisation force arises because of separation of charge, not because charged object and metal are oppositely charged. Metal is **neutral**.							✓	Emphasis on neutral See (1d)									
Polarisation of insulators	Attempt to include polarisation of insulators							✓	Incl. diagram See (1a)	✓	✓	Incl. diagram	✓	✓		✓	✓	
	Two opposite charges with a slight separation between them form an **electric dipole**, such as a polarised atom/molecule.														Reference to poles			
	Some molecules are naturally polarised, called **polar** molecules, such as the water molecule.							✓	See (1b)	✓	✓	see (2c) and (2d)					✓	See (4c)
	Cause of polarisation: In an insulator, individual atoms become polarised. A charge near an atom polarises the atom, by causing the electron cloud to shift slightly (or centres of +ve and –ve charge separate slightly due to attractive and repulsive forces exerted by the external charge).							✓	Electrons in molecules shift See (1a)	✓	✓	but nuclei move as well, see (2b)			Wrong See (3a)	✓	✓	Not clear. Text, caption and diagram conflict. See (5) and (4a)
	Cause of attraction: Polarisation force is a **net** force of attractive and repulsive forces on all dipoles, always resulting in attraction (explain in terms of different distances from external charge). It arises from separation of charge, not because charged object and nearest side of object are oppositely charged.											Wrong See (2d)			Wrong See (3a)	✓	✓	See (5) and (4a)
	To stress: Polarised object is **neutral**.							✓	See (1d)	✓	✓	see (2b)					✓	Se (4a)

EXERPTS IN TEXTBOOKS	COMMENTS & NOTES
1) PLATC (2011), p.137-138: POLARISATION a) When a charged object, such as negatively charged tape, is brought close to a neutral object, the positive charges inside the neutral object will try to be closer to the charged object and the negative charges will try to move further away. In an insulator this can happen because the electrons inside the molecules can shift a little bit, just enough to make one side more positive and the other side more negative, as shown in Figure 15.4(a). b) Some molecules, such as water, naturally have one side more positive and one side more negative. These molecules can rotate to make the oppositely charged side face the charged object. c) In a conductor there are many mobile electrons that can move within the object to make one side temporarily more positive and the other side more negative, as shown in Figure 15.4(b).  Figure 15.4 (a) An insulator is polarised when negative charges within the molecules shift position slightly. Figure 15.4 (b) A conductor is polarised when mobile charges move inside the conductor. d) P.138: The neutral object is still neutral because the total number of positive and negative charges is the same, but one side of the object is more positive and the other side is more negative. We say the object is **polarised**. When the charged object is taken away, the charges spread out again.	The charges "will try to get closer" etc. is an anthropomorphic representation of charge and its interactions and it is not science. The representation of the polarised object in diagram (a) follows the norm of scientific representations of polarised molecules/atoms. However, the representations of the charged tapes and the polarised conductor in diagram (b) correspond to the quasi-macro model introduced earlier in the text, even though there is mention to mobile electrons, which appear for the first time in the text. There is no mention to the conductor as being metallic, yet there is mention to mobile electrons. If electrons are the "-" signs, then what are the "+" signs that appear to be as mobile? How would an ionic solution be represented? Inconsistent with science models learned in previous chapters of Matter and Materials (e.g. metallic bond, particles in solids). The text does not refer to forces to explain the said behaviours in the molecules or 'charges' in the objects. And it does not refer to the attraction of the charged and uncharged objects. What is the significance of polarisation? Why do we care?
2) SIYAC (undated), p.269-270; SIYAN (2010), p.312. POLARISATION a) Unlike conductors, the electrons in insulators (non-conductors) are bound to the atoms of the insulator and cannot move around freely through the material. However, a charged object can still exert a force on a neutral insulator due to a phenomenon called **polarisation**. b) If a positively charged rod is brought close to a neutral insulator such as polystyrene, it can attract the bound electrons to move around to the side of the atoms which is closest to the rod and cause the positive nuclei to move slightly to the opposite side of the atoms. This process is called *polarisation*. Although it is a very small (microscopic) effect, if there are many atoms and the polarised object is light (e.g. small polystyrene ball),it can add up to enough force to cause the object to be attracted onto the charged rod. Remember, that the polystyrene is *only* polarised, not *charged*. The polystyrene ball is still neutral since no charge was added or removed from it. The picture shows a not-to-scale view of the polarised atoms in the polystyrene ball:  c) Some materials are made up of molecules which are already polarised. These are molecules which have a more positive and a more negative side but are still neutral overall. Just as a polarised polystyrene ball can be attracted to a charged rod, these materials are also affected if brought close to a charged object. d) p.271: Water is an example of a substance which is made of polarised molecules. If a positively charged rod, comb or balloon is brought close to a stream of water, the molecules can rotate so that the negative sides all line up towards the rod. The stream of water will then be attracted to the positively charge object since opposite charges attract.	Implies that all the electrons in conductors are free. Polarisation is presented as applying to insulators only. In the previous section about the electroscope, there is reference to *inducing a charge* on the metal plate, and presumably *induction* for conductors is considered as the alternative to *polarisation* for insulators. Refers to electrons being attracted to one side of the nucleus as if the nucleus is stripped off electrons on the opposite side. This would be a very large shift of the electron cloud! The accompanying diagram may reflect a norm of a scientist's representation of a charged object and of polarisation of insulators. But the charged rod conflicts with previous diagrams of charged objects in the chapter where *net charge* is disregarded. Both written text and diagrams suggest the possibility that different sections of the chapter were written by different authors of different perspectives and background, without taking care to maintain some consistency in the chapter. **NOS**: "not to scale view" implies that learners are looking at reality. If it was to scale, would this be the view? d) Such molecules should be better called *polar* rather than *polarised*.

3) S&MC (2011), p.193; S&MN (2005), p.97: POLARISATION Plastics, particularly plastic and polystyrene, are very good at picking up electrical charge. We can illustrate this by rubbing a balloon against clean dry hair. The charged balloon will pick up small pieces of paper and attract a stream of smooth flowing water. Look at this simple experiment to explain this behaviour. Take two small polystyrene balls and hang them from wire by threads. Rub a Perspex rod with a cloth to charge it, and then move the rod close to the polystyrene balls to see what happens. a) At first the uncharged balls are attracted to the positively charged rod. The reason is that the atoms in the balls respond to the nearby electrical charge and realign themselves. All the atoms inside the balls line up with their negative sides towards the positive rod. As a result of the realignment, the side of each ball that faces the rod develops a slight negative charge and the side that faces away from the rod develops a positive charge. This process is called polarisation because the balls develop a negatively charged pole and a positively charged pole. In our example of the polystyrene balls, the negative poles of the balls are attracted to the positively charged rod, so the balls move towards the rod.  b) (*CAPS version*) When the balls touch the rod, electrons flow from the balls to the rod and the balls become positively charged. The charges are now the same and they repel each other and the rod. c) (*NCS version*) Once the balls have touched the rod, all sides of the balls are positively charged so they are no longer polarised. They then pull away from the rod and from each other.	Confused purpose: The author presents this experiment to illustrate that polystyrene and other plastics are very good at "picking up electrical charge", despite the fact that this is placed under the heading of "Polarisation". Nonetheless, polarisation is involved and there is even reference to the atoms, but polarisation is presented as an intermediate stage to further phenomena that lead to 'like charges repel'. What exactly is the goal of this passage? Atoms are presented as already polar and hence able to 'realign' upon responding to the external charge. After atoms realign, one side of the balls develops a positive charge (showing in red), the other a negative charge (showing in blue), called *poles*. No attempt to draw parallels to magnetism or to distinguish from magnetic poles however. The cause of attraction is wrong. And then the polystyrene balls are presented to behave exactly as conductors. In the first diagram there is no interaction (and balls are shown purple). In the remaining diagrams the implied forces seem to be the same on both balls and both balls end up with exactly the same charge, and in the NCS version we see that they are no longer polarised because they are charged….. Causes, effects, interactions, explanations, are all unsuccessful and confused. A reader is not guided to see the point the author is trying to make and perhaps there is none.
4) OXFC (2011), p.156-157: POLARISATION a) Although charges in an insulator cannot move from atom to atom, they can spend more of their time on one side of an atom or molecule than on the other. Figure 13 shows how the negative charge on the balloon repels the electrons into the paper. This makes the side nearest the balloon slightly positive and the other side slightly negative. We say that the piece of paper has become **polarised**. Remember that the object as a whole remains neutral. Caption: Polarisation in a solid. Electrons move to one side of the atoms and molecules. b) There is a stronger force on the unlike charges that are close to each other than on the like charges that are far apart, so the piece of paper is attracted to the balloon. c) Figure 14 explains why water is attracted to the negatively charged ruler. Each molecule of water is a dipole. One side of each molecule is slightly positive and the opposite side slightly negative. The water molecules turn so that unlike charges are closer to the ruler and the water is attracted to it. d) Margin: **polarisation**: process of causing an object to be polarised. Margin: **polarised (electrostatics)**: object with an uneven distribution of charge.  	a) The author calls the electrons 'charges' and this causes wrong ideas concerning the 'charges' in the atom "*charges spend more time on one side of the atom…*" "*Charges in an insulator cannot move from atom to atom*", but electrons in a metallic conductor do not move from atom to atom either, as implied. Text refers to electrons moving freely inside the paper. The caption implies one side of atom is denuded of negative charge, and the diagram shows something different; text, caption and diagram are uncorrelated. Diagram shows that "-" signs have moved to one side of the paper. Charge on balloon is shown spread evenly all over. b) It should have been clearer what like and unlike charges are. c) "*molecules turn so that unlike charges…*" Do they turn in order to be attracted? They know! The argument should have been more precise, in terms of attracting/repelling forces resulting in molecules turning. The resulting attraction is not only due to unlike charges attracting. d) The 'definition' of *polarisation* says nothing about the process. No substance. The definition of *polarised* should have been in terms of one side more +ve, the other more –ve, <u>not</u> a general uneven distribution. Not a precise argument.
5) OXFN (2008), p.63: POLARISATION Where did the paper obtain its charge? Figure 7 exaggerates the thickness of the paper to show what is happening in the individual atoms and molecules. Although charges in an insulator cannot move from atom to atom, they can spend more of their time on one side of an atom or molecule than on the other. If the outside charge is negative, they are repelled. In effect, the nearest surface becomes positive. There is a greater force on the charges that are closer to each other than on those that are far apart, so the piece of paper is attracted to the bag. (*Refers to a similar figure, as the one with the balloon shown in OXF-CAPS above*)	First sentence implies that polarised paper is charged and it is not rectified in what follows. The figure does not show what happens to atoms and molecules as claimed in the text. Also see comments for 4(a) above.

5.7.3 Analysis and interpretation of data in CT8: Polarisation of materials

The NATED texts do not address polarisation as it was not stipulated in the NATED 550 curriculum. They all include the electroscope as a test for charge, which does involve polarisation of metallic conductors (discussed in the next section 5.7.4), but no attempt was found in the standard 10 texts to explain the behaviour of the leaves of the electroscope. Hence, CT8 only reflects NCS and CAPS texts. Of these, PLATC (2011) is the only text that addresses polarisation of conductors, discussed below.

5.7.3.1 Polarisation of metallic conductors in the texts

The PLATC text begins the section on polarisation with a cartoon-type illustration in which a teacher, addressing a question from a learner, replies that "a charged object can attract an uncharged object by making it polarised" (PLATC, 2011, p.137). Excerpt 1 in CT8 follows the cartoon and is supposedly the complete response of the teacher.

Up to the introduction of polarisation in the PLATC text, Electrostatics phenomena have been accounted for through macro-descriptions or in terms of nondescript 'charges' (quasi-macro). However very abruptly in this section, the PLATC text refers to conductors as having "many mobile electrons…as shown in Figure 15.4(b)" (PLATC, 2011, p.137 & excerpt 1c in CT8). Yet, the figure to which we are directed, shown in Figure 5.16b, does not show electrons, and its caption refers to *mobile 'charges'* which *move*. In the diagram of the conductor provided, both positive and negative 'charges' seem to behave in the same way, hence we understand that they must be equally mobile, because they are both shown randomly placed, even though in straight lines.

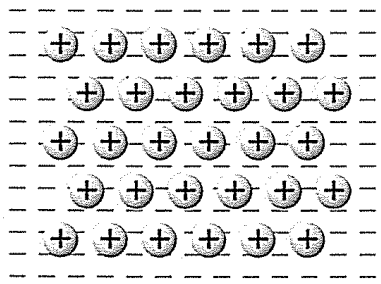


Figure 5.13 The 'electron-sea' model of a metal showing the positive metal cations and the 'sea' of negative electrons

a) Representation of metal in Matter and Materials (PLATC, 2011, p.50)

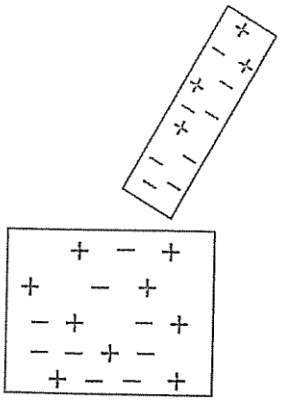


Figure 15.4 (b) A conductor is polarised when mobile charges move inside the conductor.

b) Representation of metallic conductor in Electrostatics (PLATC, 2011, p.138)

Figure 5.16 Representations of metallic conductors in different topics conflict and reflect different levels of complexity and cognitive demand

Furthermore, for a learner/reader, the representation of a conductor in Figure 5.16b, apart from conflicting with the written text, is no different from the representation of the charged object (shown above the conductor), which is supposedly an insulator, perhaps a negatively charged tape according to the written text (excerpt 1a in CT8). In this type of representation, the charged object could be easily perceived by the learners as polarised too – it shows a separation of charge. It is worth noting the representation of the charged object as having both positive and negative 'charges' rather than representing the *net charge*. This is in agreement with the unfortunate idea communicated earlier in the text: "when an object is charged, it does not mean that it has only one kind of charge…" (PLATC, 2011, p.135). The author feels very strongly of the importance of stressing that charged objects have both positive and negative 'charges', to the detriment of the most important concept of elementary Electrostatics, the *charge* (in its scientific sense as a property and a physical quantity). If learners had been given an appropriate background on the meaning of charge and its origin in the atom, perhaps there would be no need to keep on reminding them of the existence of two

types of *meaningless* ‘charges’ in objects. The given diagram, rather than endorsing meaningful understanding of the process of polarisation, is a source of confusion and unwanted ideas. Furthermore, the text does not give an account for the cause of polarisation in conductors, neither for the cause of the resulting attraction between the two objects. Perhaps the author feels that it is obvious that the negatively charged object repels electrons. This however is neither a complete (refer to the theoretically grounded definitions in CT8) nor an obvious explanation and the provided diagram of ‘charges’ is an extra hurdle.

Nevertheless, for the author the diagram shown in Figure 5.16b seems to represent a metallic conductor, since under the section ‘sharing of charge’, metallic conductors are also called conductors and are represented in the same way. But learners have already met another representation for metals under “Metallic bonding” (in Matter and Materials) earlier in the textbook, shown in Figure 5.16a. Under this earlier topic, learners dealt with concepts such as valence electrons, sea of electrons, cations, electrostatic forces, metal networks, and so on. An obvious question arising is: Why in Matter and Materials learners are considered capable of understanding the metallic bond model and the more sophisticated representations and concepts they are presented with, but in Electrostatics, where the metallic bond is needed, learners are presented instead with compromised inferior author models (discussed in detail in section 5.4.3), which apart from communicating and instigating erroneous ideas are of such low cognitive demand, that even the word *electron* is avoided, being considered too challenging for learners to be mentioned?

Instead of considering knowledge attained in Mater and Materials as *prior knowledge* to use and build upon, grade 10 Electrostatics texts demonstrate complete dissociation from grade 10 Matter and Materials (the latter considered as ‘chemistry’ in the CAPS curriculum). The

above example demonstrates clearly that there are double standards in the cognitive levels addressed in Electrostatics and in chemistry presentations in the South African textbooks, with Electrostatics being at a major disadvantage. Electrostatics presentations in the examined texts do not cater for conceptual understanding. Is the poor level of Electrostatics presentations an isolated occurrence or is it the case with other physics topics in SA textbooks as well? How does the level of complexity and cognitive demand of grade 10 Electrostatics texts compare to that of texts addressing lower secondary school Electrostatics? Do presentations of other physics topics allow for understanding of fundamentals? Such emerging concerns are serious for the quality of science education of our learners, their future and the future of the country and call for further and systematic research.

5.7.3.2 Polarisation of insulators in the texts

CT8 indicates that all NCS and CAPS texts address polarisation of insulators, in the sense that one way or another they refer to happenings in atoms or molecules. The NCS and CAPS versions of each series are essentially identical with the exception of OXFN and OXFC (excerpts 4 and 5 in CT8), where the CAPS version has been extended to include the case of the water molecule. Concerns raised in the comments accompanying each excerpt in CT8 concentrate on individual texts/series, hence in what follows, a more general discussion attempts to highlight possible trends.

A) Polarisation of atoms, its cause and the electric dipole

The row concerning the "Cause of polarisation" in CT8 has ticks allocated in all but one series. The ticks were allocated because these texts refer to electrons or 'charges' in the atom as shifting or moving towards one side in the presence of an external charge. However none

of the texts has justified this movement in terms of forces to signify an interaction with the external charge. In this sense, *the cause of polarisation is missing* from all texts. Instead the texts give the impression that electrons or 'charges' in the atoms somehow 'know' what to do in the presence of an external charge. The PLATC assigns to 'charges' anthropomorphic intentions, as 'trying' to move: "the positive charges inside the neutral object will try to be closer to the charged object and the negative charges will try to move further away" (PLATC, 2011, p.137).

Ways in which texts account for polarisation are listed as a brief overview in Table 5.13. OXFC and PLATC (excerpts 4 and 1 in CT8) do not apply the concept of polarisation to atoms/molecules, but only to objects, in a macro tradition. The SIYAC and SIYAN (excerpt 2 in CT8) is the only text referring to polarisation of atoms, but it also communicates that polarisation is a process restricted to insulators, which is not correct. For the SIYAC and SIYAN text, the alternative process to polarisation for conductors is *charge induction*, accounted for under the "Electroscope". Presentations of the Electroscope are discussed in section 5.7.4.2. The S&MC and S&MN (excerpt 3 in CT8) communicates the wrong idea that atoms (in general) are polar, though the term *polar* is not mentioned, and it is when atoms realign that objects become polarised. This excerpt is discussed separately because of its unique account, also evident in Table 5.13. None of the texts elaborate on polarisation by referring to *charge separation* in an atom or object.

Table 5.13 Brief overview of what polarisation entails in the texts

Text	External charge near object	Neutral object	Significance
PLATC	Objects generally: Positive charges and negative charges try to move towards or away from external charge	Still neutral Object is polarised Charge taken away: charges spread out.	Charged attracts uncharged
	Insulators: Electrons in molecules shift a bit		
	Conductors: Mobile electrons move.		
SIYAC SIYAN	Bound electrons and nuclei in atoms move. Atoms polarise.	Still neutral Object is polarised	Charged attracts uncharged
OXFC OXFN	Charges spend more time on one side of atom or molecule. Electrons move to one side of object (paper). Electrons move to one side of molecules.	Still neutral Object is polarised	Charged attracts uncharged
S&MC S&MN	Atoms line up (implies already polar).	Object is polarised. Develops two poles.	Polarised object can pick up charge

Texts do not refer to polarised atoms/molecules as *electric dipoles*. Only OXFC refers to the water molecule as a dipole and this is the only reference to the term in the texts. None of the texts includes a diagram representing an unpolarised and a polarised atom/molecule for learners to compare, or as a key to accompanying diagrams representing dipoles, the latter found in two series (SIYAC, undated, and SIYAN, 2010 and PLATC, 2011).

Table 5.13, though brief, suggests that in certain texts there is scope for confusion due to imprecise and inconsistent use of the terms *charges* and *electrons*, and due to the mingling of micro and quasi-macro accounts. For example the PLATC text (excerpt 1 in CT8) begins with a quasi-macro narrative of positive and negative charges, both moving in *objects*, but immediately after it continues with micro accounts of *conductors* and *insulators* where only electrons move. The two accounts sound conflicting. What may be the point of such an approach? Is it to make the transition 'from the easy to the complex', or is it to make allowance for the case of ionic conductors for example? Considering that ionic conductors have never been considered in the texts, it is rather a case of the former. However, accounts

involving the nondescript positive and negative charges are not 'easy', as discussed extensively in section 5.4.2, because they represent a model of no internal consistency and explanatory power and cannot lead to coherent understandings. Table 5.13 suggests that in OXFC/N too there are discrepant messages regarding the notions of charge and the movement of electrons in insulators. This is discussed in what follows.

B) Correlation of written text and diagrams

PLATC and SIYAC/N include diagrams displaying many dipoles in an insulator, shown in Figure 5.17a & b, but learners are not given the guidance to understand what the oval shapes shown in the diagrams represent and the meanings of "+" and "-" signs, which are now different from previous representations provided in the texts. The charged objects shown above the insulators may also be a source of confusion for learners. In PLATC, as discussed in 5.7.3.1, the charged object may be understood as being polarised as well. The charged rod in the SIYAC/N diagram shows *net charge*, but other charged objects earlier in the chapter are represented as having positive and negative 'charges' rather than a net charge, and in any case the concept of the *net charge* is missing from the texts.

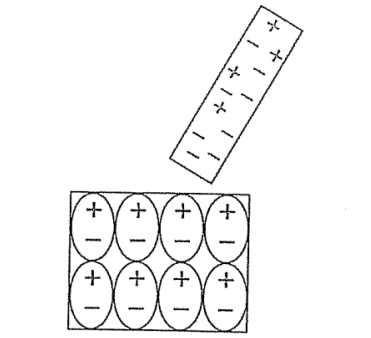
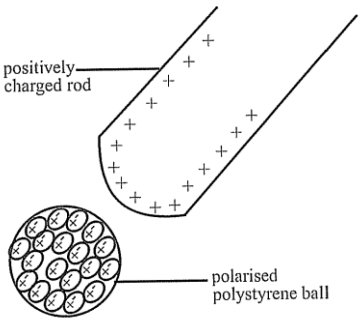


Figure 15.4 (a) An insulator is polarised when negative charges within the molecules shift position slightly.

a) PLATC (2011), p.138



b) SIYAC (undated), p.270
SIYAN (2010), p.312

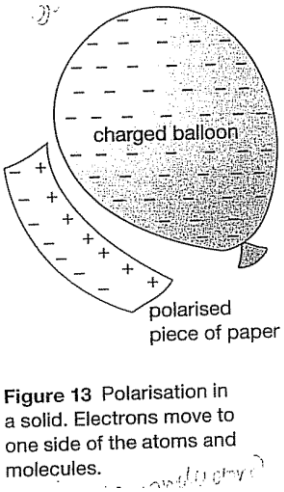


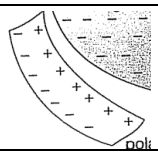
Figure 13 Polarisation in a solid. Electrons move to one side of the atoms and molecules.

c) OXFC (2011), p.156

Figure 5.17 Micro and quasi-macro representations of polarised insulators in the texts

In the OXFC (2011) and OXFN (2008) (excerpts 4a and 5 in CT8), the written text refers to 'charges' but also to electrons and the impression given is that these two entities behave differently in insulators and in a piece of paper respectively. The conflict continues with the accompanying diagram and its uncorrelated caption, as demonstrated in Table 5.14.

Table 5.14 Conflicting variances in three lines and a diagram

no	**From OXFC (2011), p.156-157 excerpt 4 in CT8**	**Variant ideas emerging**
1	Although charges in an insulator cannot move from atom to atom…	Insulators have no mobile charges. Author considers charges to be electrons…
2	…they (charges) can spend more of their time on one side of an atom or molecule than on the other.	…and electrons to be the only charges in the atom. The charge of the nucleus is disregarded. Learners may ask: What else is there in the atom? What is on *the other side* of the 'charges'?
3	Figure 13 shows how the negative charge of the balloon repels the electrons into the paper.	Paper has mobile electrons. Learners may think that either charges and electrons are two different entities or that perhaps paper is not an insulator.
4	Diagram 	If electrons are the "-" signs and the only charges, then what are the "+" signs that seem equally mobile?
5	Caption: Electrons move to one side of the atoms and molecules.	The diagram does not show atoms and molecules as claimed, but a piece of paper. Would learners realise that the caption (or diagram) is amiss? Or would they see it as a special molecule?

In the first two rows of Table 5.14 it can be noted how the OXFC and OXFN author avoids the term *electrons* in favour of 'charges' resulting in irrational messages. The practice of avoiding the term *electron*, as has been stressed on several occasions in this analysis, far from making the text less intimidating for learners, is wrong and breeds confusion and

unacceptable understandings. It also demonstrates how the author tacitly communicates the idea that negative charges are far more important than positive charges, the latter being of no consequence to electrostatics phenomena, the 'remnants of the doings of negative charges' at best. It is obvious that the scientific concept *charge* does not exist in the mind of the author while the role of the nucleus is utterly unrecognised, and learners are left to pay the consequences.

Diagrams b (SIYAC & SIYAN) and possibly c (OXFC) in Figure 5.17, indicate that the illustrations in the textbooks were not produced in conjunction with the written text. They were perhaps chosen or drawn by persons other than the authors and added at a later stage of the production of the textbooks. Hence they are in dissonance, in the SIYAC/N case with previous text, in the OXFC case with previous and accompanying text. It demonstrates that publishers of science textbooks might not consider diagrams as equivalent and essential to the written text, items that need to be developed as part of the text, but rather as 'nice to have' and 'if space permits'. This is detrimental to physics teaching and learning as conveyed in studies concentrating on the use and role of diagrams in science and science education (e.g. Han & Roth, 2005; Lemke, 1998). Physics textbook authors, as is also discussed in the next section, ought to produce their own diagrams during the writing of the text, and ought to have the first saying on 'how many' and 'where they go'.

Considering that learners may have difficulties with concepts in their protective belt for the hard core of *polarisation*, as per Park *et al.* (2001) discussed in 5.7.1, and they may also be fixated with the mistaken belief that attraction between two objects can only occur if both objects are charged due to the high status of the rule 'like charges repel, unlike attract', as has been stressed by Criado and Garçia-Carmona (2010), conflicting representations of charged

objects in diagrams illustrating polarisation cannot possibly help learners reach desired understandings on what causes the resulting attraction between charged and uncharged objects. According to Park *et al.* (2001), with the first difficulty they will face, learners will attempt to modify their protective belt rather than work on the core conception.

C) The cause of attraction in the texts

The process of polarisation explains why a charged object may attract an uncharged one, with the *attraction* between the two being the key outcome. This needs to be emphasised for learners and the cause of attraction needs to be made clear. A description of how a neutral object polarises in the presence of an external charge is only half the story and the resulting attraction is not as straightforward as implied in the texts. Without guidance, learners are likely to concentrate on the attraction between the external charge and the side of the object nearest to it, at best, and considering the poor background they have been given in previous sections on charged and uncharged objects and the process of charging (poorly structured *protective belt* according to Park *et al.* (2001)), they might even develop ideas on the possibility that the polarised object becomes charged somehow in order to be attracted to the external charge (Criado and Garçia-Carmona, 2010).

However in CT8, it is only the OXFC and OXFN texts that have been allocated a tick in the row "cause of attraction". This is because these are the only texts to refer to unequal forces acting on the polarised object, thus acknowledging the interaction of the whole neutral object with the external charge, though not as explicitly. Ways in which examined texts deal with this attraction, extracted from the excerpts in CT8, are indicated in Table 5.15. The same Table includes the special case of polar molecules, an inclusion which is suggested by the NCS and CAPS curricula (refer to Table 5.12).

Table 5.15 indicates that PLATC communicates implicitly that the attraction between charged and uncharged objects is self-explanatory due to 'positive charges try to get closer' and 'negative charges try to move away' from the charged object (excerpt 1a in CT8). The author's idea on the cause of the attraction however becomes evident in the passage on polar molecules, shown in Table 5.15 (from excerpt 1b in CT8), where the attention is placed on the *oppositely charged side* of the molecule facing the charged object. This suggests that the author perceives the attraction between the two objects to be the attraction due to the rule 'unlike charges attract'. This is a misconception.

Table 5.15 Cause of attraction between charged and neutral objects in the texts

Texts	Cause of attraction	Attraction of polar molecules
PLATC (2011), p.137-138	*Implies self-explanatory*	These molecules can rotate to make the oppositely charged side face the charged object. (MISCONCEPTION)
SIYAC (undated), p.269-270 SIYAN (2010), p.312	…It can attract the bound electrons…cause nuclei to move to opposite side … If there are many atoms and the polarised object is light…it can add up to enough force to cause the object to be attracted onto the charged rod. (UNCLEAR)	The molecules can rotate so that the negative sides all line up towards the rod. The stream of water will then be attracted to the positively charged object since opposite charges attract. (MISCONCEPTION)
OXFC (2011), p.156-157 OXFN (2008), p.63	There is a stronger force on the unlike charges that are close to each other than on the like charges that are far apart, so the piece of paper is attracted to the balloon.	(*Only in OXFC*) The water molecules turn so that unlike charges are closer to the ruler and the water is attracted to it. (MISCONCEPTION)
S&MC (2011), p.193 S&MN (2005), p.97	The negative poles of the balls are attracted to the positively charged rod, so the balls move towards the rod. (MISCONCEPTION)	*Implies irrelevant* *(all atoms are polar)*

The polarisation force is a net force, arising from the addition of attractive and repulsive forces, which, in the case of insulators, act on each and every dipole. Because the attractive force on a dipole's end nearest to an external charge is slightly larger than the repulsive force on the dipole's end further away from the charge, the net force on the dipole is always towards the external charge. Hence, a neutral object near an external charge experiences a net force towards the external charge, which is the polarisation force and results in attraction. The entire neutral-polarised object attracts and is attracted to the external charge, and not just its side which is nearest to the external charge.

In the second row of Table 5.15, the SIYAC and SIYAN texts refer to a vague '*it* can add up to enough force', leaving unclear what are the forces which add up. The notion of force, as *attraction*, is only associated with bound electrons: 'it can attract the bound electrons'. No notion of force, as *repulsion*, is associated with positive nuclei: 'cause positive nuclei to move slightly'. The discrimination against repulsion may communicate to learners that it is the attraction forces that 'add up'. Indeed in the passage on polar molecules this erroneous notion is stated clearly 'the stream…will be attracted…since opposite charges attract'.

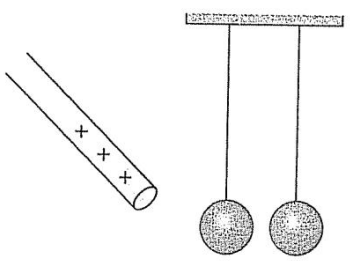
The third row in Table 5.15 concerns the OXFC/N series, the only texts as mentioned earlier that are given a tick in CT8 for the "cause of attraction". However, the passage on water molecules, which is added in the CAPS version of the books, conflicts with the earlier text: 'molecules turn so that unlike charges are closer to the ruler and the water is attracted to it'. The passage communicates clearly that the attraction between water and charged ruler is due to 'unlike charges attract' disregarding other interactions.

The same misconception is also found in S&MC and S&MN, as indicated in the last row of Table 5.15. However the entire &MC and S&MN excerpts in CT8 are discussed in what follows.

It can be noted that the passages in the right-hand column of Table 5.15, on polar molecules, are quite similar. All relevant texts refer to molecules *rotating* or turning in the presence of an external charge, but none attempts to justify why. The impression given is that the molecules *know* how to turn or *detect* the external charge and rotate at will '*so that*…', which is a somehow anthropomorphic attribute to molecules. Finally all texts make clear that attraction occurs due to 'unlike charges attract', which is a misconception.

D) Killing two birds with one stone? (excerpt 3 in CT8)

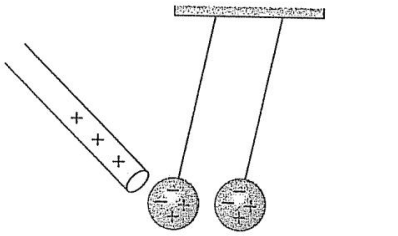
The S&MC (2011) and S&MN (2005) presentations (excerpt 3 in CT8) is nothing short of calamitous for learners' understanding, and despite its heading, 'polarisation', its purpose is unclear. What may be the purpose of this text? According to the start of the text, polystyrene picks up charge easily, e.g. balloon picking up pieces of paper. (In S&MC, two cartoons follow this part, one showing a balloon with stuck bits of paper, another with a balloon attracting a stream of water). But already this is nonsensical – balloons are not polystyrene and charge is not pieces of paper. The author then embarks to explain *this* behaviour. What is *this* behaviour? Picking up charge or picking up papers? Or is it the same? Learners might ask. Below, the diagrams of excerpt 3 in CT8 are discussed with the remaining excerpt from S&MC (2011).



Uncharged balls near positive rod

The first diagram, shown alongside, (from S&MC, 2011, p.193), is unreasonable because it shows no interaction. The text claims: "Atoms in the balls respond to the nearby electrical charge and realign themselves…with their negative sides towards the positive rod" (S&MC, 2011, p.193 & excerpt 3a in CT8). Are we waiting for the atoms to realign? How long does it take?

Why do atoms realign? Are some obvious questions for which there is no answer. The presentation can be seen as a case of sequential reasoning (e.g. Duit & Rhoneek, 1997/98): 'First the rod is brought near, then the atoms in the balls realign, then the balls experience a force, then they are attracted'. However, such episodes ought to be perceived as *simultaneous*. Furthermore, learners are given the wrong idea that atoms have already negative and presumably positive sides and so they realign. Learners might also ponder whether this is a case of aligned domains in magnets, as learned in the previous chapter.

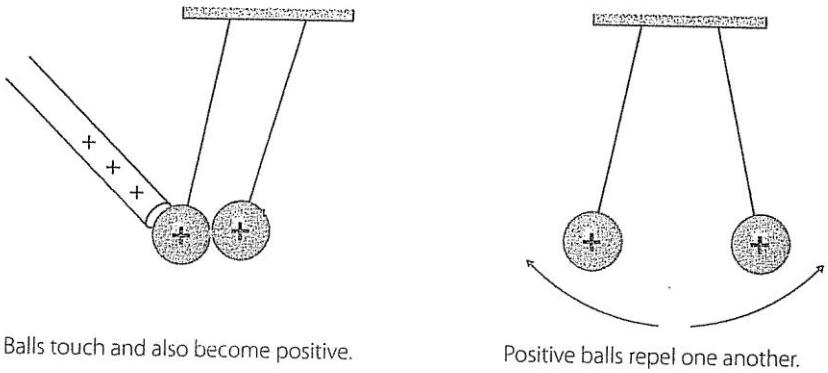

Balls are polarised and attracted to rod.

In the next diagram (alongside, from S&MC, 2011, p.193), we see that balls are eventually attracted to the rod and that they are attracted equally, which is also unreasonable. Now the balls have two *poles* according to the text, one negatively charged which is blue and one positively charged which is red (unlike the balls in the previous diagram which are purple) and this is called *polarisation*. Learners are very likely to understand this as the formation of two magnetic poles, and the use of vocabulary and colours in the diagrams which resembles the representation of north and south poles in magnets reinforces this wrong idea. The possibility of learners likening magnetic and electric dipoles ought to have been anticipated. This is a common tendency of learners, identified in the literature (e.g. Criado & Garçia-Carmona, 2010) but no effort is evident in the text to dispel the erroneous notion.

The text continuous with the statement "…the negative sides of the balls are attracted to the positive rod so the balls move towards the rod" (S&MC, 2011, p.193). However this is wrong because it ignores the repulsive interaction between the charged object and the far end of the polarised object. The rod does not attract the negative side of the balls, it attracts the entire

balls and vice-versa. Furthermore, the S&MC text involves two balls, which is another complication for learners, disregarding the different distances of the balls from the charged object much as it disregards the interaction between the two balls. Obviously the authors' interest was not to help learners understand polarisation, but to proceed with the 'picking of charge'.

Indeed in the next two diagrams of the excerpt, shown in Figure 5.18, the balls are shown to touch the charged rod and then to repel. The text (excerpt 3b in CT8) claims "when the balls touch the rod, electrons flow from the balls to the rod …the charges are now the same…" (S&MC, 2011, p.193), In effect learners are told that charge conducts between insulators, which is a serious misconception and therefore unacceptable.



Source: S&MC, 2011, p.193

Figure 5.18 Notion of conduction in insulators: "Electrons flow from the balls to the rod…"

The notion of electrons flowing between insulators is in conflict with the notion of insulators having no free electrons. But then again, the S&MC (2011) in the Electrostatics chapter has never referred to the distinction of materials into conductors and insulators (discussed in CT5), and the excerpt 3 in CT8 refers to plastics and polystyrene in particular rather than to insulators. In the next page of the S&MC (2011) textbook, learners are introduced to

'sharing' of charge between conducting spheres, and learners meet a very similar scenario, shown in Figure 5.19.

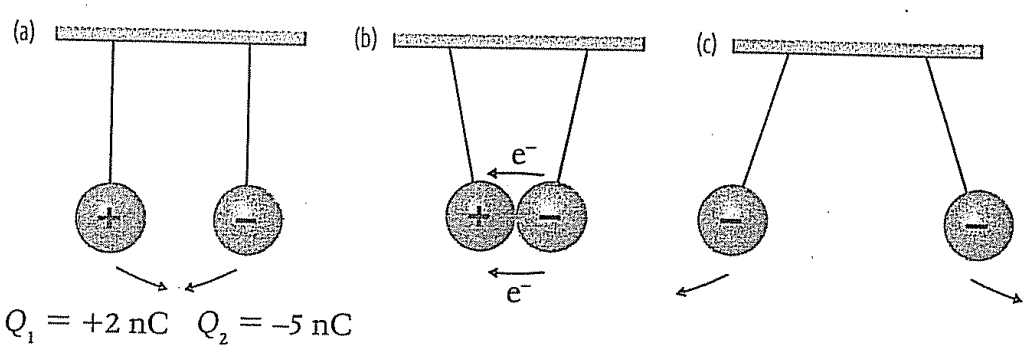


Figure 5.19 **Conduction in conductors: "electrons will flow from the negative ball to the positive ball"** **(**Source: S&MC, 2011, p.195)

Learners are given no reason to perceive a difference in the transfer of charge between the two scenarios of polystyrene balls and conducting spheres, shown in Figures 5.18 and 5.19 respectively. One may ask, what is the point of referring to the spheres shown in Figure 5.19 as 'conducting', since according to the communicated message, polystyrene balls behave in exactly the same way?

Thus, according to S&MC (2011) (and also S&MN, 2005) excerpt 3 in CT8, polarisation is the means by which polystyrene and plastics or perhaps substances in general 'pick up charge' from a charged object and as a proof of this, the two polystyrene balls repel.

The point of an educator introducing polarisation, is to explain how it is possible for a charged and an uncharged object to attract, an important phenomenon in Electrostatics, which appears to defy the postulate ' like charges repel, unlike attract', so entrenched in learners' minds according to Criado and Garçia-Carmona (2010). In doing this, the educator needs to

use a scenario where the two objects, charged and uncharged, are not allowed to touch and to stress that the neutral object remains neutral during its interaction with the charged object since there was no means for charge to transfer between the two (transfer of charge requires contact). Or else, learners may attempt to form own ideas or scenarios of possible transfer of charge to the neutral object in order for it to become charged and interact with the charged object. The S&MC (same for S&MN) excerpt in CT8, apart from presenting an incomplete and incorrect account of polarisation, instead of highlighting the attraction between charged and uncharged objects, highlights the 'picking up' of charge and the interaction of two charged balls encouraging learner misconceptions. This is not what learners need to understand polarisation.

5.7.4 The leaf electroscope in the texts

5.7.4.1 Electroscope in the NATED 550 texts

The NATED textbooks do not include "polarisation" since it is not referred to explicitly in the NATED 550 curriculum. The phrase "the influence of a charged object on a charged and uncharged electroscope" (DoE&C, undated, p.36) in the Standard 10 NATED 550 curriculum (Table 5.12), which could be perceived as a hint to polarisation in metallic conductors, was not perceived as such in the texts. BJ and SPS refer to the electroscope as a bullet and/or question-type revision from Standard 7, where learners are asked to 'explain', e.g. "With the aid of sketches, explain how you would charge an electroscope by contact" (BJ, 1987, p.64) or "Explain how the type of charge on a charged electroscope can be determined" (SPS, 1987, p.69). The SS (1989) includes a more substantial passage, part of which is shown in Figure 5.20.

You can also use an electroscope to find out if the charge on an object is positive or negative. For example, Figure 6 shows a charged electroscope. A charged object is brought close to the metal disc. If the gold leaf rises still further, the object has the same charge as the electroscope. If the gold leaf drops, the object is oppositely charged. Can you explain why?

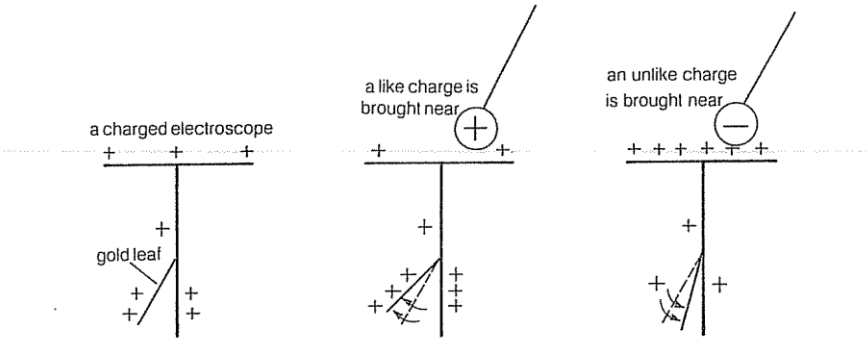


Figure 6 Use a charged electroscope to find out the sign of charges

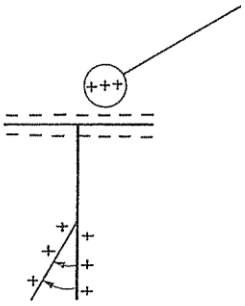


Figure 5 The gold leaf of an electroscope moves when charge is brought near

Source: from SS, 1989, p.54

Figure 5.20 Revision of the electroscope from Standard 7

It appears that in Standard 7 the electroscope had been introduced as a test for charge by having learners memorise the behaviour of its leaves rather than explaining this behaviour (which for this level may be justifiable). This is suggested by the example in Figure 5.20, where the text accompanying the diagrams describes how the leaves of the electroscope are expected to behave depending on the charge of the nearby object, as a revision from Standard 7. It is the learners who are asked to explain this behaviour. Since the diagrams show 'charges' perhaps the expectation was for learners to respond along the lines that the 'positive charge' of the electroscope is attracted to or repelled by the charge of the nearby object, causing it to move to and fro the leaves. But, movement of positive charge is in conflict with prior background learners are given, which is that charge is static, protons do not move, electrons transfer by friction and not a mention to the characteristics of conductors or insulators. Learners are expected to invent polarisation or charge induction unguided. The diagrams too may be a source of confusion for learners because they show two types of

representation: one for charged objects showing only positive charge (net charge) on the electroscope, the other for polarised objects, showing both positive and negative charge in the (neutral, but not mentioned) electroscope, with the latter in addition showing more negative than positive signs (charge conservation ought to be observed in diagrams).

5.7.4.2 NCS and CAPS texts

The "electroscope" was removed from the NCS curriculum and this omission was sustained in CAPS. Yet the electroscope is still present in all examined NCS textbooks, in a prominent manner under its own heading. Apparently NCS authors felt that the electroscope is an indispensable feature of electrostatics. The trend indicates that if authors have a strong conviction of how things should be done they stick to it. This 'author-power' however did not prevail in the CAPS texts where from, with the exception of the SIYAC (undated), the electroscope has been removed. The omission of the electroscope from the last two curricula may be seen as a sensible decision due to the difficulty of its interpretation (e.g. Criado and Garçia-Carmona, 2010). Elucidating how the leaves of the electroscope behave is a complex task, especially so if the necessary background is missing or not well understood. Criado and Garçia-Carmona (2010) assert that it is not easy to adapt the general explanation for electrostatic *induction* (in the sense of polarisation in either conductors or insulators) to the case of the electroscope. They discuss the difficulty student teachers in Spain faced when interpreting the electroscope, with half of them unable to even distinguish between a charged and an uncharged electroscope to draw charges on them correctly, despite frequent exposure to it. Based on other studies they refer to two possible sources of difficulty. Firstly the top to bottom asymmetry of the electroscope, along which separation of charge occurs, the top consisting of one rigid item (usually a metal disc or a ball), while the bottom consisting of

two mobile leaves that can share charge of the same sign. Secondly, the "mobile effect" is only observed at the leaves at the bottom, as opposed to a 'ball electroscope' (the latter referring to a neutral, light ball hanging from a string which can be attracted to a nearby charged object and move as a whole).

The full NCS and CAPS excerpts on the electroscope are shown in Appendix D, while Table 5.16 was compiled to summarise the main features of these presentations. The excerpts in Appendix D reveal that the presentations of the electroscope in the South African texts, with the exception of SIYAN/C, are nowhere near the level that would allow a discussion based on the general explanation of polarisation/induction and the difficulties arising from the asymmetry of the instrument, as anticipated by Criado and Garçia-Carmona (2010). Nevertheless, guided by the information in Table 5.16 and the full excerpts in Appendix D, certain remarks can be made on elements concerning the purpose of the inclusions, consideration for learners and adopted teaching strategies in the texts.

Table 5.16 Presentations of the "electroscope" in the NCS and one CAPS texts

Textbook	S&MN (2005)	OXFN (2008)	SIYAN (2010)	SIYAC (undated)
Purpose of inclusion	- To explain why a charged rather than uncharged electroscope determines type of charge	- To explain how to test for charge - To tell how to charge an electroscope	- To explain how the electroscope detects the presence of charge - To explain how the electroscope is charged and discharged by grounding	
The uncharged electroscope	Is not very useful	Is used to detect presence of charge	Is used to detect presence of charge	
How it is charged	By touching with charged object of known charge (picks up charge)	By touching with charged object/insulator	By induction and grounding	
Use of charged electroscope	To determine type of charge	No reason given	No reason given	
Explanation of behaviour	Leaves 'pick up charge' and move	Repelled electrons Charge transfers from object	In terms of interactions of charge and transfer of negative charge	
New ideas/concepts involved (implicitly or explicitly)	The term 'conductor'	In conductors electrons move from atom to atom Polarisation (implied)	- Inducing a charge and polarisation - Human body /earth as a reservoir of charge (implicitly) - Two conductors in contact behave as a single conductor (implicitly) - Charging by induction and grounding / Discharging by grounding	
Previous background in text	- Charged-uncharged in terms of protons-electrons - Forces between charges - Electrons transfer by rubbing - Triboelectric series	- Charged-uncharged in terms of protons-electrons - Electrons transfer by rubbing - Conservation of charge - Forces between charges	- Charged-uncharged in terms of +ve & -ve 'charges' - Unit of charge - Conservation of charge - Charging by rubbing - Only negative charge transfers - Force between charges - Arrangement of charge on surface of conductors - Conductors & insulators, with first reference to electrons	- Charged-uncharged in terms of +ve & -ve 'charges', repeated in terms of protons & electrons - Only electrons transfer - Triboelectric charging - Triboelectric series - Force between charges - Conservation of charge - Conductors & insulators - Arrangement of charge on surface of conductors - Quantisation of charge - Unit of charge - Sharing charge in conductors (algorithmically)
Following sections in text	- Polarisation (unspecific) - Conductors-insulators	- Unit of charge - Conductors & insulators - Polarisation of insulators	Polarisation of insulators	

A) On the purpose of the inclusion of the electroscope

All NCS texts and the SIYAC refer to the *uncharged electroscope* as a means to detect the presence of charge (casually so in S&MN), and in this sense the electroscope is presented as a testing instrument. When it comes to the *charged electroscope* however, texts concentrate on the process of charging it, neglecting the purpose of charging it, with the exception of S&MN. The OXFN instructs learners how to charge an electroscope "so that it remains charged" (OXFN, 2008, p.62) with this being the end. The apparent aim in OXFN (2008) is to "learn how to charge the electroscope" instead of "how to use a charged electroscope to determine the type of charge". The message sent is that the electroscope, rather than a tool, is part of the theory of Electrostatics that must be learned. The two SIYAN/C texts do not associate a purpose for the charged electroscope either. Under the heading "Grounding", the SIYAN/C texts explain how to charge an electroscope followed by how to discharge it (the only texts accounting for the discharging of the electroscope). Through these processes the SIYAN/C texts introduce new concepts, not stipulated in the curricula. It is not clear whether the electroscope is used as a vehicle to bring in the new ideas or whether the new ideas are brought in to explain the behaviour of the electroscope and a possible message sent is that the new ideas associate only with the electroscope.

Upon comparison of the examined NATED and NCS (and also SIYAC) texts, based on their accounts of the electroscope, the following can be noted:

a) The NATED texts present the electroscope as the means to test for presence and type of charge, in accord with the NATED 550 curriculum. The NATED texts have a goal determined by the curriculum. In contrast, the NCS texts exhibit neither a common purpose nor a clear rationale for their inclusion of the electroscope, though the S&MN follows the

NATED paradigm. Unlike the NATED authors, the NCS authors include the electroscope out of their own accord, which, as mentioned earlier, demonstrates a strong 'author conviction' defying a curriculum. But on the other hand, the lack of curriculum guidance on the electroscope appears to have contributed to the failure of authors to project a clear rationale and/or a convincing objective for the inclusion of something which they consider quite indispensable from Electrostatics, and this sounds odd. The inability of authors to justify their uncalled for inclusion meaningfully without guidance from the curriculum indicates that perhaps their 'conviction' for the necessity of the electroscope was not a matter of conceptual conviction, but rather a matter of habitual conviction. The electroscope was a staple feature of science textbooks for generations, and for this reason alone authors may have found its omission from the NCS curriculum absurd, an oversight perhaps. But the introduction of the CAPS curriculum cleared the confusion, the electroscope was out indeed, and so it was from the CAPS textbooks as well.

b) In the NATED texts, accounts of the electroscope appear to be *descriptive*, with learners prompted to memorise the behaviour of the leaves in order to draw conclusions for the charge of tested objects. Although Standard 10 texts ask learners to 'explain', no evidence of explanations was found in the texts themselves (apart from the positive and negative signs shown in the diagrams of SS, in Figure 5.20). In contrast, in the NCS texts we find instances in all texts, were attempts are made to *explain* the behaviour of the leaves. For example, "Electrons are repelled from the disc and move down the rod..." (OXFN, 2008, p.62) or "Because the metal is a conductor, the charge can move freely..." (SIYAN, 2010, p.311 & SIYAC, undated, p.268). Whether such attempts are comprehensive, successful or unsuccessful, they signify an intention to make learners understand how the electroscope works.

Ironically, the NCS curriculum does not mention the electroscope and yet authors include it and even attempt to explain it. This is remarkable, because attempts to explanations are atypical in the chapter of Electrostatics, as the analysis of the texts has revealed so far. Hence on one hand NCS authors feel strongly about the electroscope, but on the other hand, they are not clear/sure as to why should they include it or what to do with it.

B) On consideration for learners

In OXFN (2008) and S&MN (2005), in what precedes the section on the electroscope, learners are told that charge transfers by rubbing, that the charge that transfers is electrons and that the rubbed objects end up oppositely charged. Under the electroscope that follows immediately after, learners are given a very different story, that charge transfers by a simple 'touch' of the top of the electroscope with a charged object, that the electroscope acquires same charge as the object and that this charge ends up at the leaves. The S&MN (2005) even refers to the *leaves* 'picking up' the charge, so straightforwardly. Both texts describe the parts of the electroscope as *conductors*, with the term appearing for the first time, as if this designation alone makes the repulsion of the leaves obvious. The OXFN (2008) adds "this means that electrons can move freely from atom to atom" (OXFN, 2008, p.61) as if learners are already familiar with this characteristic of conductors (which in any case is erroneous). Yet in both texts, the section on conductors and insulators is introduced after the electroscope, in S&MN (2005) at the end of the chapter, and when this is done, it is in terms of conductors *allowing charge through* rather than in terms of the existence of mobile charged particles/electrons. Furthermore, since texts generally claim that only negative charge transfers because only electrons move, ever so conveniently, charged electroscopes in diagrams are shown to be negatively charged, implying that their charge was transferred from an external charged object, following the tradition discussed in section 5.5.3. Can an

electroscope ‘pick up’ positive charge? Once again this is left to the learners to figure out along with the characteristics of conductors. It is possible that some learners may come up with the idea that positively charged electroscopes cannot exist. Learners in their attempts to interpret how the electroscope is charged and how it works, are given nothing to hold on other than *like charges repel*, *unlike attract*, and hence they are forced to base all their understandings on interactions of isolated charges. Incidents of drawbacks of such type of reasoning in the texts have been discussed in section 5.5.3.

C) On conceptual teaching strategies

The SIYAN and SIYAC texts on the electroscope are identical, with the CAPS version presented as an “Investigation”, though it is not (refer to Appendix D). Apparently authors felt that the section should be incorporated somehow, and the heading “Investigation” justified its inclusion without demonstrating disregard for the curriculum. Unlike all other examined NATED and NCS texts, the SIYAN and SIYAC texts place the electroscope after learners are given some background on the distinction between conductors and insulators, signifying acknowledgment for the necessity of a basic understanding of materials before attempting to explain its behaviour. However, a background on conductors is still not sufficient, and indeed the SIYAN and SIYAC texts further introduce the notions of *charge induction*, and *grounding* to address the “charging” and “discharging” of the electroscope (discharging is overlooked in all other examined texts). The concern however is that the notions of *charging by induction* and *grounding*, being associated with charge transfers in conductors, are central processes of Electrostatics, processes which themselves are in need of careful introduction through well thought, level appropriate diagrams/inscriptions, before deploying them for predictions or explanations such as in the case of the behaviour of the leaves of the electroscope. Hence, the SIYAN/C texts addressing the electroscope, which at

first glance may appear quite detailed relative to other texts, are in fact far too brief and condensed for meaning making. As an example to this end, the excerpt on "Grounding" from SIYAN/C is discussed in what follows. (The full text including accompanying diagrams can be found in Appendix D - Table b.)

Excerpt from SIYAC (undated), p.268-269 (same in SIYAN, 2010, p.311)

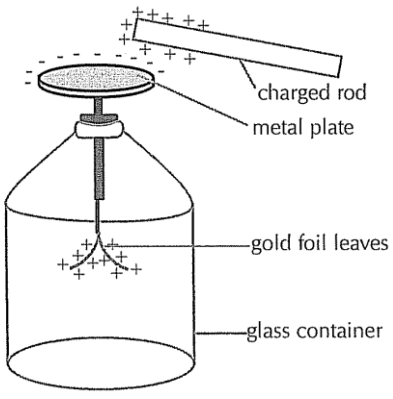
Grounding

(a) If you were to bring the charged rod close to the uncharged electroscope, and then you touched the metal plate with your finger at the same time, this would cause charge to flow up from the ground (the earth), through your body onto the metal plate. Connecting to the earth so charge flows is called **grounding**.

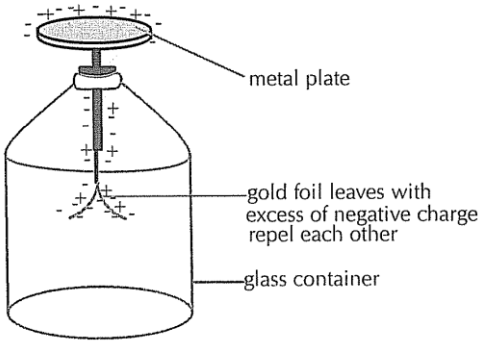
(b) The charge flowing onto the plate is opposite to the charge on the rod, since it is attracted to the charge on the rod. Therefore, for our picture, the charge flowing onto the plate would be negative.

(c) Now the charge has been added to the electroscope, it is no longer neutral, but has an excess of negative charge. Now if we move the rod away, the leaves remain apart because they have an excess of negative charge and they repel each other.

(d) If we ground the electroscope again (this time without the charged rod nearby), the excess charge will flow back into the earth, leaving it neutral.



(A) (SIYAC (undated), p.268)



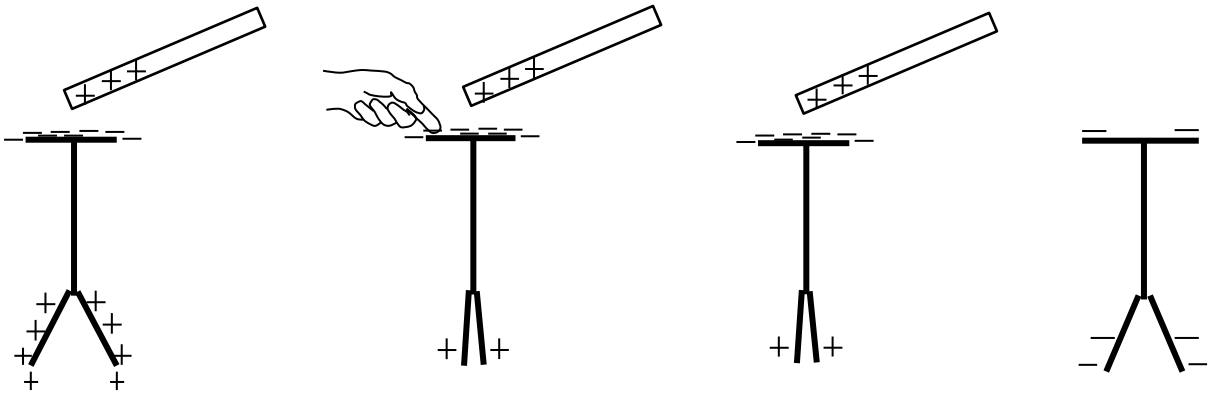
(B) (SIYAC (undated), p.269)

Figure 5.21 Representations of electroscope in the SIYAN/C texts. The "+" and "-" signs represent different concepts in the two diagrams.

For simplicity, the following discussion refers to SIYAC text, bearing in mind that the SIYAN written text and diagrams are identical.

Only careful reading through the SIYAC excerpt would suggest that all this time the author was referring to a diagram of the electroscope, shown in Figure 5.21A, which in the textbook is placed at the start of the previous section and so it appears unrelated to the section on "Grounding". Yet there is no explicit reference to it, and the only clue that the author refers to a particular scenario is found half-way through the excerpt, in part (b) of the excerpt, *therefore, for our picture…* which might go easily unnoticed by learners. An understanding of how the electroscope works revolves around the behaviour of its leaves. To the learners, this behaviour would give clues as to what happens to the charge of the leaves, but in the excerpt, paradoxically, the behaviour of the leaves is disregarded. It is only in part (c) of the excerpt where the leaves are said to *remain apart*, the only reference to the leaves, corresponding to the final result of charging the electroscope. A diagram representing a negatively charged electroscope is placed at the very end of the excerpt, but there is no reference to it either. This is shown in Figure 5.21B. In Figure 5.21, diagram A shows only one type of charge on the disc and the leaves, presumably to be understood as the induced excess charge on them. Diagram B does not represent excess charge in the same way. It shows positive and negative 'charges' in unequal numbers, mingled together, suggesting that the "+" and "-" signs are charged particles, as in several previous diagrams representing charged objects in the textbook (discussed in previous sections). Upon comparing the numbers of 'charges' shown in diagrams A and B, a learner would understand that many negative 'charges' have entered the electroscope, while the number of positive 'charges' remained unaffected in the process. The text confirms "Now that charge has been added to the electroscope… has an excess of negative charge" (SIYAC, undated, p.268). The author suggests that the charge that flew into the electroscope is the excess charge, as if it was

isolated. The message sent is that the electroscope itself had no involvement in this transfer of 'charge'. Furthermore, the idea of positive and negative signs as being particles called 'charges', transfers to diagram A, which in this context is likely to be interpreted as showing a complete separation of positive and negative particles in the material, with positive particles being as mobile as the negative. The confusion of charge and charged particles in the two representations can only be a source of conflicts and unwanted understandings for learners. The reference to the leaves in the text as *remaining apart* implies that no change in their behaviour took place during the charging process (in Figure 5.21, from scenario A to scenario B). This is incorrect, as shown in Figure 5.22 and also misleading. For comparison, Figure 5.22 was drawn to illustrate roughly the expected behaviour of the leaves during the charging of the electroscope by induction. The type of charge of the charged rod in Figure 5.22 has been selected positive to match the SIYAC scenario. The interpretations of the behaviour of the leaves at each step shown in Figure 5.22 are included in Table 5.17, compiled to elaborate on the steps shown in Figure 5.22, and to indicate procedural features and behaviours of leaves that are missing from the SIYAC excerpt.



Step 1 Step 2 Step 3 Step 4

Source: By researcher

Figure 5.22 Behaviour of electroscope leaves during charging by induction

Table 5.17 Charging a leaf electroscope by induction

Action / steps	Behaviour of leaves	Significance	Interpretations and inferences
1. Charged object near (but not touching) the disc of a neutral electroscope	Leaves move apart	Leaves repel due to same type of induced charge on them	Electroscope is being polarised (sea of electrons shifts slightly) resulting in induction of opposite excess charge at its ends, i.e. disc and leaves.
2. While charged object is near, a person touches the disc with a finger	Leaves collapse (may stay very slightly apart) *MISSING*	Leaves have very little charge. They appear to have 'lost' their induced charge.	Polarisation still takes place, but in a much bigger conductor, i.e. the system of electroscope and person together. Leaves are no longer the far end of the system.
3. Finger is removed while charged object is still near *MISSING*	Leaves remain as in step 2 *MISSING*	No change to the charge of the leaves Leaves do not regain any charge	The removal of the finger did not affect the leaves. The pre-touch state of the leaves has not been reinstated. This indicates that excess charge from the leaves transferred to the human body ('lost' charge) and is no longer part of the electroscope.
4. Charged object is taken away	Leaves first collapse and then move apart *MISSING*	Leaves lose any remaining induced charge and then gain new charge of the opposite type. The fact that the leaves first collapse, indicates that their new charge is of opposite type to the previous one.	Polarisation stops and charge induction ends. The leaves spread apart signifying that the electroscope is left with an overall net charge, which now spreads throughout, including the leaves (via readjustment of the sea of electrons) causing them to repel. However, before the leaves spread apart, they first collapse completely as they lose their previous induced charge with the end of the polarisation. The net charge of the electroscope must be of the type of charge induced on the disc during polarisation, which is now in excess, since the leaves lost their own share of opposite charge to the human body where it was transferred during grounding.

If learners are given the chance to perform the process of charging the electroscope by induction practically in class, or simply watch a video of the process, which is not uncommon in today's South African classrooms, they will observe an important intermediate behaviour of the leaves, omitted from the SIYA excerpt: that at the moment a person touches the disc of the electroscope with a finger, the leaves *collapse* and maintain this position when the finger is removed while the charged rod is still near (steps 2 and 3 in Figure 5.22 and in Table 5.17). A discernible interpretation of this behaviour (the collapse) of the leaves is that the leaves have 'lost' their charge, signifying that their charge was transferred elsewhere. But in part (a) of the SIYAC excerpt it is claimed that charge came/flew into the electroscope "this would cause charge to flow up from the ground…onto the metal plate" (SIYAC, undated, p.267), which appears to contradict this behaviour of the leaves. Why are we told that charge comes into the electroscope since the leaves show clearly that charge went away? Learners may be wondering and puzzling.

Learners observe that the electroscope 'loses' charge (leaves drop) upon grounding. It is easier for them to accept that this 'missing' charge transfers from the electroscope to the earth, rather than the other way round as they are told. Whether the charge on the leaves was positive or negative, it was a property that 'left' the leaves upon grounding. The action of grounding signifies exactly that: *to send charge to the ground*. The behaviour of the leaves indicates the absence or presence of the property charge. Since this is an observable behaviour it would make sense for the educator to pick up from there. The difficulty in the interpretation of the electroscope is an example of how important it is for the educator to distinguish between the *transfer of charge*, i.e. the transfer of a property, and the *transfer of charged particles*, i.e. the physical transfer of matter by which the transfer of charge is accomplished (also stressed in 5.6.5 under "conservation of charge"). This distinction relies undoubtedly on the correct and consistent use of the term *charge*. The analysis of the texts

has revealed that the norm is for texts to stress that only negative charge transfers, being electrons, while the concept of charge as a physical quantity is disregarded. 'Charge' in the texts is used as an abbreviation for 'charged particle'. Adding 'charges' is reduced to the addition of positive and negative particles, an addition that cannot lead to a value of *net charge*, as is the example of Figure 5.13. The SIYAC author has in mind negatively charged particles, possibly electrons when referring to the negative charge flowing into the electroscope, but the behaviour of the leaves clearly favours an argument in terms of the property *charge* transferring away from the leaves.

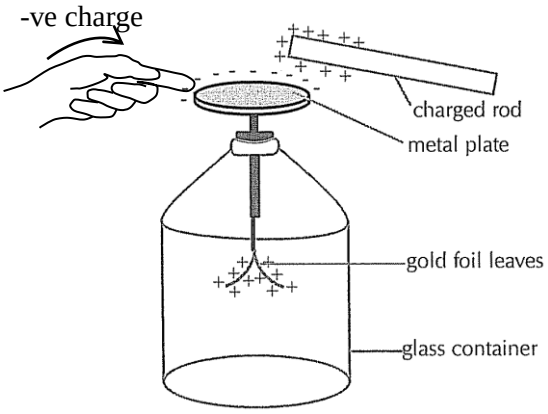
Although the notion of the non-physical *charge transfer* is so very abstract, the problem that surfaced above suggests that it may be wiser to introduce an electrostatics process in terms of transfers of charge as a property first. Such a transfer could then be justified, as a next step, by the physical movement and actions of charged particles. The latter explains the transfer of charge. The effect of such suggested strategies however need further research in the context of the classroom.

D) On addressing counterintuitive claims

It was suggested above that a major difficulty in the interpretation of the electroscope lies on the lack of a clear distinction between the non-physical transfer of charge and the physical transfer of charged particles. However this is not the only problem learners may face regarding the charging of the electroscope by induction. The process of grounding the electroscope, as in step 2 in Figure 5.22, is inherently counterintuitive and an educator who cares about learners' understanding ought to anticipate this and address it.

In the SIYAC excerpt on "Grounding" for example, it is claimed: "…touched the metal plate with your finger… the charge flowing onto the plate is opposite to the charge on the rod, since it is attracted to the charge on the rod" (SIYAC, undated, p.268). Learners, as directed

by the text, will imagine a finger touching the negatively charged disc, in a similar scenario to the one illustrated in Figure 5.23 (where the 'finger' has been added to illustrate a possible mental image of learners).



Source: from SIYA, undated, p.268, with the addition of a 'finger' by the researcher

Figure 5.23 Counterintuitive explanation for the charging of the electroscope relying on "like repel, unlike attract" assumption for isolated charges.

It is highly unlikely that a learner would find this claim palatable. How is it possible for negative charge to flow from the finger onto the disc, even if it is attracted to the positive rod, since the disc is already negative and should repel it? Does it matter where the finger touches the disc? These are the first questions learners would ask. The claim in the text is not as straightforward as presented, it is utterly counterintuitive and clearly cannot be explained by a simple 'like charges repel unlike attract' reasoning. Could this difficulty be the reason why essential diagrams illustrating the process of grounding have been omitted from the text, to divert learners' attention from unwanted hard questions and direct them straight to the final scenario where the electroscope is charged? If this is the case, the effective aim of the excerpt would be for learners to only know that *if you touch the disc you charge the electroscope and this is called grounding*. But then what is the point of including incongruous references to flows of negative charge feigning an 'explanation' in an attempt to make the process look

straightforward? It is more likely that the SIYAC author's intention was to incorporate *charge induction* and *grounding*, processes which are central in Electrostatics but disregarded in the South African curricula. These processes are indeed the essence of understanding the electroscope, but the electroscope is not the ideal platform for their introduction. As discussed earlier, the electroscope requires the understanding of such processes in advance and according to Criado and Garçia-Carmona (2010) referring to charge induction in particular, even then their application to the electroscope is not as straightforward. Perhaps the SIYAC author had all the good intentions for the presentation of the electroscope. But the overwhelming task had to be reduced to fleeting references of new ideas, thinking that a few statements and claims of known interactions would suffice as long as they sound reasonable. And even so, the electroscope excerpt in the SIYAC textbook is already the longest excerpt in the chapter of Electrostatics. It is possible that the author was well aware that this presentation was nowhere near sufficient for meaningful understanding, but adopted a strategy of *better something than nothing*. However, the superficial understanding encouraged by this strategy results in conceptual conflicts and below is an example from within the same excerpt on "Grounding".

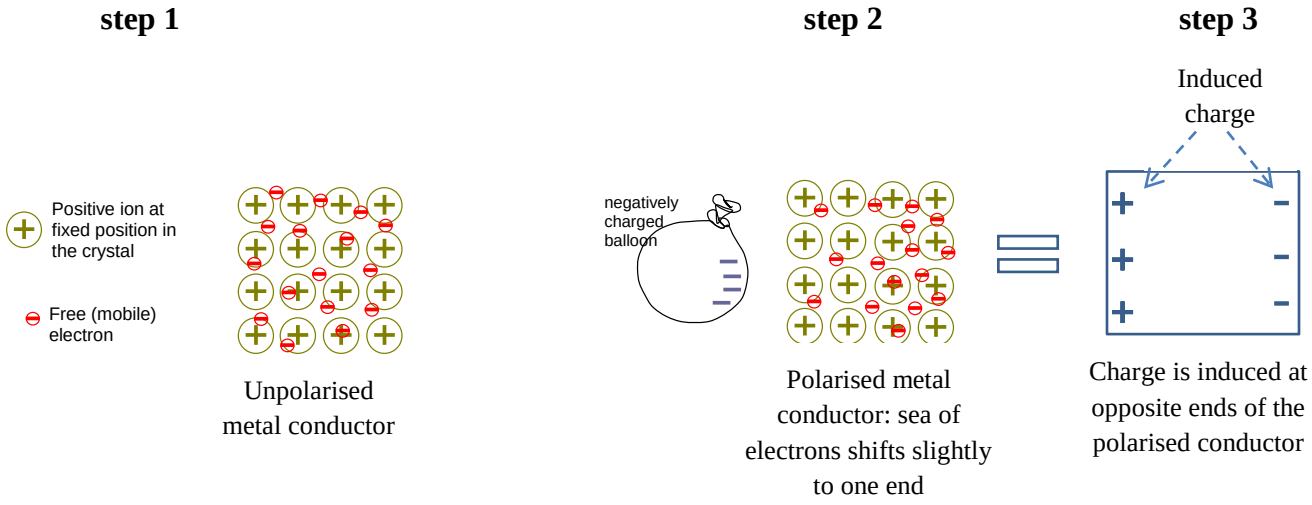
The excerpt ends with the final discharging of the electroscope, which is presented as another straightforward event: "If we ground the electroscope again (this time without the charged rod nearby), the excess charge will flow back into the earth, leaving it neutral" (SIYAC, undated, p.268-269), so straightforward that no explanation is supposedly necessary. Once again, the claim is not unreasonable, and yet it seems at odds with the first grounding of the electroscope. In the first grounding (as in Figure 5.23), according to the excerpt, it was the charged rod that attracted the negative charge from the earth and caused it to flow through the finger (which was already counterintuitive). But why does the charge flow in the second grounding? There is nothing to attract it. Are the two groundings different processes?

Learners may ask. Obviously now learners need to think from a different perspective, perhaps from the perspective of two conductors in contact. This is possibly the expectation of the author, since learners are familiar with 'sharing of charge' from the previous section which involved metal spherical conductors of equal size. But then why 'sharing of charge' was not considered in the first grounding? The first grounding was hastily justified by the easy escape of the stalwart 'like repel unlike attract' of isolated charges. Or is it that learners are expected to think in terms of negative charges 'repel and spread'? But then why would the electroscope end up with no charge at all? To make matters worse, throughout the chapter there is no reference to the human body or the earth as conductors (which is also the case with all other examined texts).

E) On the use of diagrams

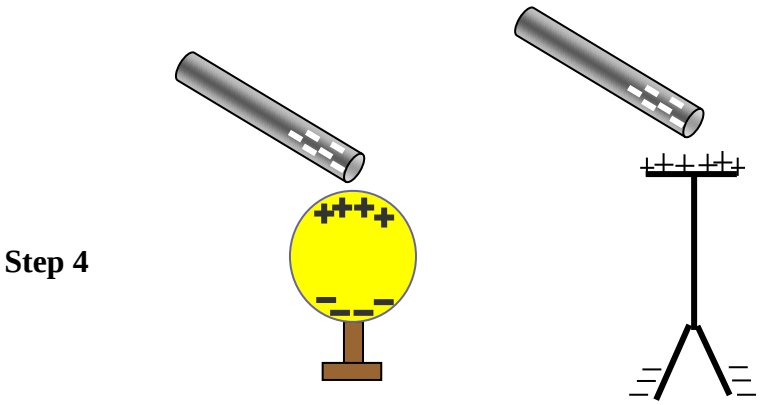
In science education it is an art to find a simple rational way to explain a complex process. For the physics educator, there is no tool more powerful than diagrammatic representations to achieve such a task. In section 5.4.2.1, the role of "inscriptions" (Han & Roth, 2006) as visual representations was discussed, as playing a central role in the making and understanding of science. Diagrams however (considered in this analysis as inscriptions with embedded written text such as labels, keys, notes, even captions), if they are to serve their role in meaning-making, must be deployed in ways that direct learners to a particular understanding, thus limiting unwanted interpretations. Hence the inclusion of diagrams requires thought and planning. Insights from the literature, discussed in 5.4.2.1, point to the need of a practice where science texts are developed with written text and diagrams in conjunction to one another. For Lemke (1998) for example, meaning-making cannot be adequately realised with just one semiotic modality and points to the incommensurable nature of codeployed modalities in science. In science communication, written text and diagrams are two semiotic

modalities. If these are to be incommensurable it implies that in science textbooks, it is the authors who ought to be drawing their own diagrams, if possible, as they go along with the writing of a chapter. This would enable them to refer to particular features in a diagram or change them as required, and also maintain a consistency of symbols and meanings throughout the chapter. It is believed here, and this is a claim that needs further research, that during this process of authors moving back and forth between diagrams and written text, due to their engagement with the finer details of their 'custom made' diagrams, the understanding of the authors themselves would enhance and possibly would enable them to anticipate stumbling blocks, such as counterintuitive scenarios, that learners might encounter when reading or interacting with the text. Regarding the complexity of the interpretation of the electroscope, suitable diagrams at each step of the way from the introduction of background concepts to their application to the electroscope should be considered indispensable. Figure 5.24 for example (author's diagram), illustrates polarisation in metallic conductors, a crucial background towards understanding the electroscope, while Figure 5.25 (author's diagram) may link this background knowledge to the electroscope.



Source: By researcher

Figure 5.24 **Representation of polarisation of a metallic conductor resulting in induction of charge at opposite ends.**



Source: By researcher

Figure 5.25 Linking polarisation of the electroscope to previous knowledge

None of the examined texts under the chapter of Electrostatics include anything similar to the representations shown in Figures 5.24 or 5.25 to justify behaviour of free electrons in metallic conductors, nor was there any link to the metallic bond model addressed in the topic Matter and Materials. Despite such omissions and lack of links, there are claims of electrons or 'charges' moving freely in a conductor, such as the electroscope, e.g. "because the metal is a conductor, the charge can move freely from the foil…onto the metal plate" (SIYAC, undated, p.268), or "the disc, rod and gold leaf are all conductors of electricity. This means that electrons can move freely…" (OXFN, 2008, p.61). Why are learners expected to know that electrons move freely in a material just because it is called a *conductor*?

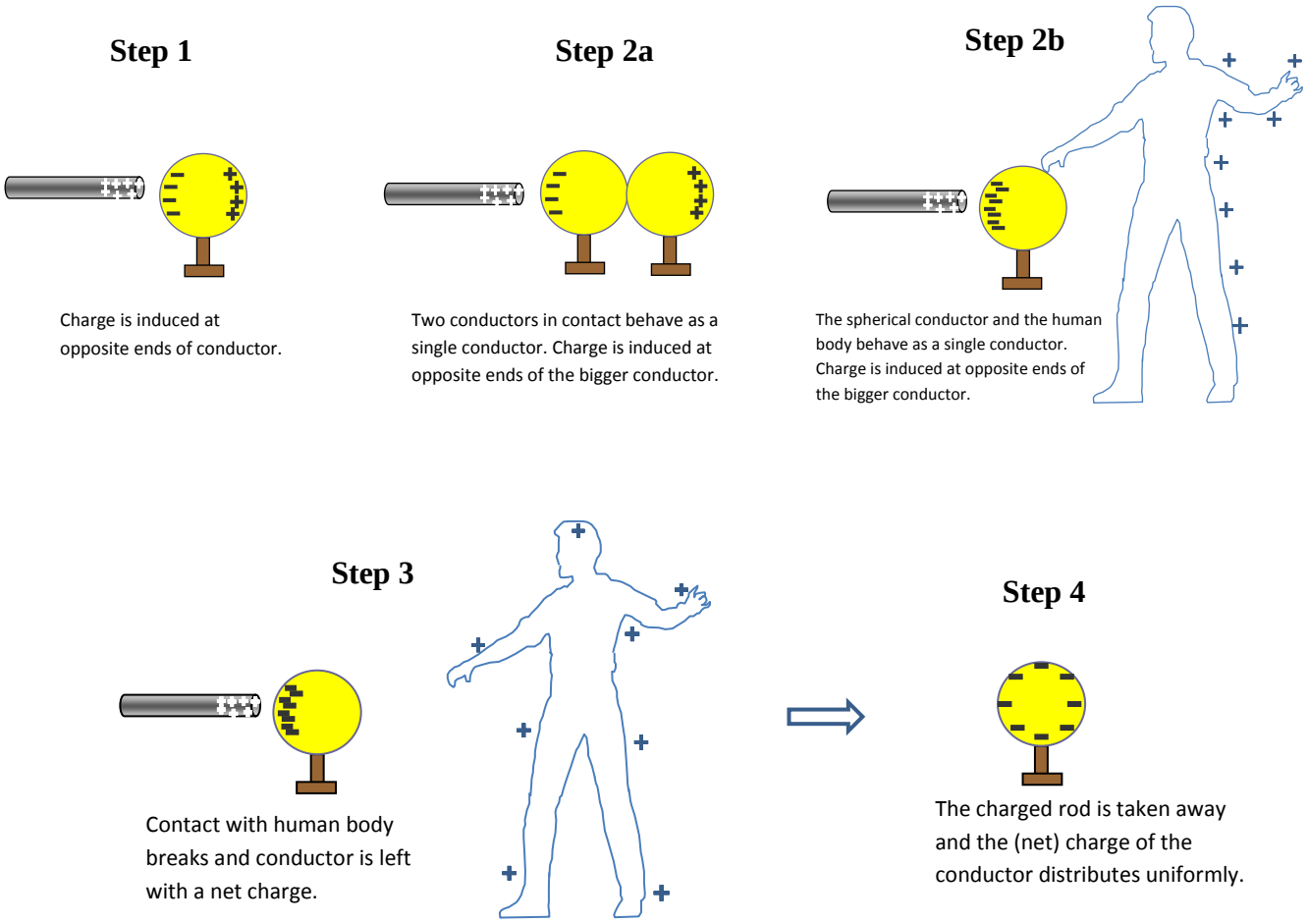
A representation such as step 1 in Figure 5.24, could have been included and discussed with the introduction to conductors, referring to metallic conductors as a special class of conductors where the mobile charged particles are electrons. This could be linked to the *metallic bond* model addressed in Matter and Materials. Authors of Electrostatics and Matter and Materials ought to take care to include like representations of metallic conductors for learners to grasp the links. Learners should not be prompted to think of Matter and Materials as 'chemistry' and disparate from physics, but rather as the foundation for the understanding

of properties and behaviours of matter, electrostatics phenomena being part of it, brought about by the introduction of powerful science models for use to explain such phenomena. Curricula ought to guide authors of Electrostatics by indicating suitable science models to use in order to link macro to micro, much as they do for other macroscopic phenomena included in Matter and Materials called 'chemistry'. The general impression given by the NCS and CAPS curricula is that models of the micro-cosmos are chemistry models and only concern chemistry (as for example in the Overview of the Chemistry Component in the NCS curriculum (DoE, 2006, p.13-15)). This is erroneous and, as evidenced by the treatment of Electrostatics in the textbooks, it is detrimental for the teaching and learning of physics and for the learners' understanding. Such concerns and discrepancies need further research.

Steps 2 and 3 in Figure 5.24, represent the polarisation of a metallic conductor, involving the concept of induced charge as a consequence of the polarisation. An author could use such representations as a starting point to introduce polarisation in metals, through which the concept of *induced charge* would emerge. Steps 2 and 3 in Figure 5.24 could also help learners to grasp the distinction between *charged particles* and (induced) *charge*, since in the diagrams the two concepts are represented differently. The inclusion of similar representations would in addition allow authors, and teachers who use the textbook, to formulate conceptual questions based on the diagrams for learners to think about, for example, "why not all electrons are shown to move to one side of the metal?" etc. It is bewildering why polarisation of conductors has not been included in the curricula and textbooks, while polarisation of insulators is. Polarisation in conductors could be the precursor to the polarisation of insulators, the former representing a slight shift of the sea of electrons within the material, the latter of the electron cloud within a molecule.

Charging the leaf electroscope by induction is yet another example of a process which is unlikely to be understood by learners without the help of step-by-step diagrams, as illustrated by Figures 5.26 and 5.27 (author's diagrams). The counterintuitive claim illustrated in Figure 5.23 is avoided in step 2 of the Figures 5.26 and 5.27 by referring to transfers of charge as a property and by stressing that the human body in contact with the metallic conductor behave as a single much larger conductor that is being polarised. Learners should be guided to see the whole human body as a much larger conductor than the electroscope, acting as a reservoir of charge. A textbook author or teacher could extent this notion of 'reservoir of charge' to the case of the earth and grounding. Furthermore, learners themselves could be asked to draw parallels between Figures 5.26 and 5.27, and so engaging them to interact with the text.

Thus, it is suggested here as a matter of a conceptual teaching strategy, that diagrammatic representations could play a primary role in the text, guiding the written text rather than being subordinate to it. Authors could base their account of a difficult process or concept on a series of diagrams, specifically designed for the purpose, representing and building the process/concept step by step from relevant previous knowledge. Authors could elaborate at each step by referring to the diagram/s, as opposed to relying on verbal text all the way till the end where learners are finally directed, if at all, to a compromised figure along the lines 'and this is shown in the figure', the usual practice in the examined texts. Figures 5.24 to 5.26 furthermore indicate how many important notions and processes that concern conductors, such as polarisation, conduction and induction, pivotal in Electrostatics, have been disregarded by the South African curricula. Based on this analysis of Electrostatics in textbooks, the state and choice of physics topics in the South African curricula may be in need of a systematic in-depth reconsideration.



Source: By researcher

Figure 5.26 Charging a conductor by induction

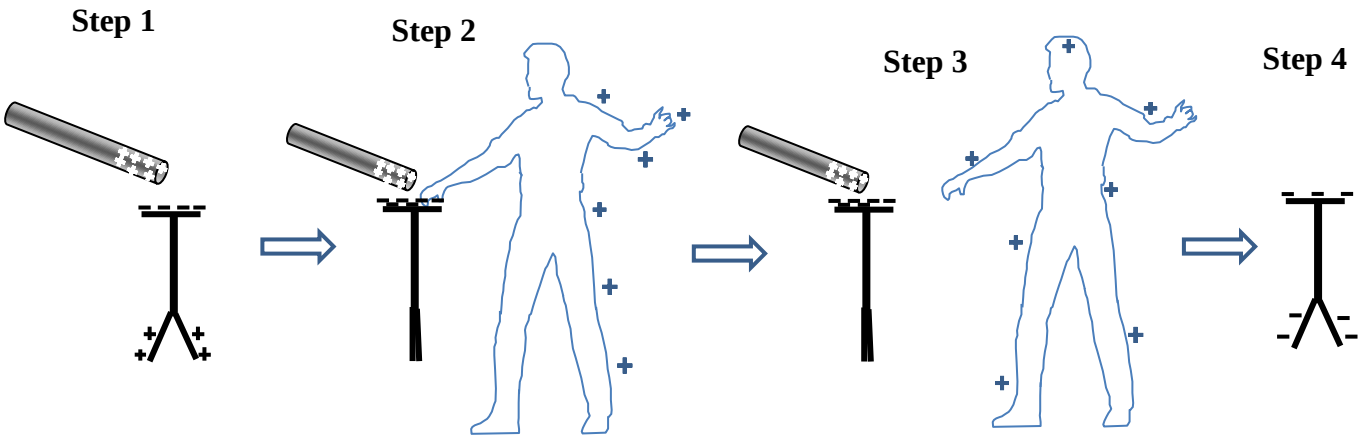


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Figure 5.27 Charging an electroscope by induction (human body not in scale with electroscope)

CHAPTER 6

SUMMATIVE REPORT ON FINDINGS AND CONCLUSIONS

6.1 General impressions from the presentations of Electrostatics in FET SA textbooks

Advancements in typesetting and access to information technology over the past twenty years had an impact on the appearance of the textbooks addressing the last two curricula, NCS and CAPS, as expected. Science textbooks produced for the NCS and CAPS are far more pleasing to the eye than their NATED counterparts, with the inclusion of more pictorial features and the introduction of colour. One would have also expected easy access to information technology to have an impact on the subject matter content of textbooks as well. Yet the analysis of elementary Electrostatics in South African textbooks has shown that this was not the case. The subject content of Electrostatics has been neither affected by the world-wide-web nor by reformed curricula. The plethora of scholarly articles on learner misconceptions and difficulties, twentieth century understandings of concepts and processes, ideas for new approaches incorporating the nature and history of science, distinction between common and scientific reasoning are among items that seem to remain largely unknown to textbook authors and have been disregarded in the texts. Instead, the analysis revealed that the texts themselves incorporate, communicate and prompt unscientific understandings and erroneous ideas, some of which ideas, according to Furió *et al.* (2004), may be classified as primitive, predating Faraday's times.

The first impression a reader gains from the grade 10 texts addressing Electrostatics is the lack of substance and the low cognitive level. Texts are too brief, statement-like, fragmented, ambiguous and internally conflicting. Texts are so brief that if one was to take the bullet-list of Electrostatics contents in the CAPS document, add some pictures and a couple of

examples, would not be far away from the main body of the texts. Attempts to explanations are scarce and ineffectual and not a single link was found to previous related knowledge from other topics or grades (apart from the NATED texts which are a revision from Std 7). Especially knowledge gained in Matter and Materials, preceding the topic Electrostatics in the CAPS curriculum, where important science models, necessary for the explanation of Electrostatics phenomena are put in place, is wholly disregarded. But perhaps a greater concern is that Electrostatics authors do not even seem to be aware that they need such models. It is hard to find a sentence that does not present some problem, whereas accompanying diagrams are exactly that, 'accompanying'. In most cases diagrams do not correlate with the text, and instead of clarity, they introduce or encourage a multitude of unwanted understandings and conflicts. (The analysis of the texts in Chapter 5 has paid particular attention to diagrams). Most disconcerting is the overconfidence that authors exhibit in their presentations, who seem engrossed to certain ideas on how to present the content and demonstrate utter unawareness of what else is there to say or what to do when something does not quite make sense even to themselves.

Though the NATED texts were supposed to be a 'brief revision' from the low secondary school and hence lack of substance could be somehow justified, the NCS and CAPS texts were not. The latter were supposed to address electrostatics as a build-up on knowledge acquired in low secondary schooling. The NCS texts were addressing a modern curriculum which proclaimed "*high knowledge high skills*" (DoE, 2003, p.3) and where a *spiral approach* was to be implemented in the sense that concepts were to be revisited and studied in greater depth as learners' cognitive development would enable them to cope with greater complexity and cognitive demand (DoE, 2006, p.4). The CAPS curriculum maintained the call for "*high knowledge high skills*" and referred to progression from simple to complex as

well as "*application of scientific models…in order to explain and predict…*" (DoBE, 2011, p.4 and 8 respectively). Yet no difference in the level of complexity was evident between NATED, NCS and CAPS texts and no scientific models have been applied to explain or predict electrostatics phenomena. The announcement of the Minister of Basic Education in November 2009 for the need of new textbooks of excellent quality developed by experts (Motshekga, 2009), which resulted in new submissions of textbooks for approval, made no difference to the FET electrostatics. The 'new' textbooks offer no new insights to the topic as compared to previous textbooks and do not raise the level of complexity from that of the low secondary. In fact the 'new' CAPS approved textbooks are not at all new in the sense that they were rewritten afresh. The NCS and CAPS versions of SIYA and S&M texts are identical with minor reshuffling and some additions or omissions to abide with the order of items as appearing in the respective curricula. The OXFC (2011) shows more signs of revision, though many parts remain identical to its NCS version and the level of complexity remains low. The NCS version of PLATC (2011) was not available to compare with its CAPS counterpart. But ironically, the electrostatics chapter of the PLATC grade 8 (CAPS) textbook - not part of this study as it addresses a lower grade - includes more insights and attempts to explanations at the microscopic level than the PLATC grade 10, the latter accounting for charge and charging only in terms of macroscopic descriptions, more suitable to primary school level. The general similarity of the NCS and CAPS versions of the texts was the reason why in the deductive categorisation tables of the analysis (Chapter 5), textbooks have been paired per series rather than grouped per curriculum. The similarity of NCS and CAPS series in addition suggests the possibility that the NCS textbooks had an impact on the CAPS curriculum developers, more so than the NCS curriculum itself and that curriculum developers have not consulted modern scholarship. De Posada (1999) quotes a similar claim: "*…textbooks have been shown to have a tremendous impact on curriculum…*"

(p.425), though such claims need further research. Abd-El Khalick *et al.* (2008) refer to a strong 'author effect' in comparison to a 'publishers effect', implying that if authors are convinced on a certain view-point on how things are or should be done, they stick to it. Similar instances were found in the analysed SA texts, such as for example the persistence of the expression "static electricity", or the inclusion of the "electroscope" in the NCS texts, though such items have been removed from NCS and CAPS curricula, but also the general similarity of the texts.

The analysis of elementary electrostatics in the South African texts has exposed several author tendencies and areas where authors seem to lack expertise and/or are in need of guidance: lack of adequate content knowledge of the topic, lack of familiarity with horizontal and vertical curricula, misunderstanding of the structure of Electromagnetism, erroneous notions of science models, failure to consult and incorporate relevant, let alone modern scholarship. Several scholars (e.g. Abd-El-Khalick *et al.*, 2008; de Posada, 1999; Slisko & Hadzibegovic, 2011) have raised concerns such as that textbook authors do not research the topics they write about and that they only consult other textbooks when doing so. The analysis of the texts suggests that the same trend exists among South African textbook authors as has been pointed out on several occasions in Chapter 5. According to Slisko and Hadzibegovic (2011), on the one hand textbooks do not undergo any rigorous peer review because of the perception that textbook authors write about other people's 'discoveries' rather than their own. So errors, if undetected by editors and reviewers, considering that thousands of such books may be sold per year, become *accepted truths* by the wider educational community, which sees textbooks as authoritative documents. On the other hand, lack of research seems to be a prime characteristic of a certain author/teacher culture, the *teaching culture* as opposed to a *research culture* that has been allowed to dominate the teaching

profession at all levels by the teachers themselves. Slisko and Hadzibegovic (2011) point to how unethical it is to misinform students, on any aspect of knowledge, a practice that would be seriously penalised in other professions.

Inevitably, some errors or shortcomings in textbooks ought to be expected. Authors are human beings and their knowledge and understanding evolve over time. But such errors would be distinctive or 'once-off' and found in particular textbooks. The major shortcomings of the analysed texts are not the 'once-off' type. They are collective repetitive shortcomings, 'accepted truths' resulting in a norm, the *textbook science*, which employs scientific terms, without regard to their meaning or to the epistemology of science. 'Textbook science' misrepresents science and its practitioners.

An expert science educator, who cares about what learners learn, might be tempted to dismiss such texts as 'useless'. But in science education research, ignoring such texts would be a mistake. It would imply that such texts are of no consequence to learning. The analysis of the texts in this study suggests that their consequence to learners' confidence, understanding and attitudes towards science may be detrimental.

6.2 Key findings on communicated ideas

Due to the nature of the texts being so brief and superficial, it is easy for an expert educator to fall into the trap of skimming through them quickly, thus missing crucial shortcomings in the communicated messages. The systematic, fine grain analysis of the texts exposed aspects in need of attention that otherwise would have gone unnoticed, and they should not. A learner who strives to understand and learn from the textbook would read it very carefully, much like a researcher doing fine grain analysis. How do textbooks stand against this scrutiny, how do

they cater for our learners and what do they communicate to them on Electrostatics and science? To this end, Tables 1 to 7 in Appendix E list in brief findings in need of attention emanating from the analysis of the texts, as undertaken in Chapter 5. Findings listed, concern the majority if not all of the texts unless otherwise stated.

In what follows, an account of what are considered in this study *key findings* is given, which may be at the root of most of the shortcomings and the unwanted interpretations and confusion. These relate to erroneous understandings held by authors or ideas communicated in the texts.

6.2.1 Global idea of Electrostatics: The *Electric field* is not part of it

Findings from the first aspect of analysis on the perceptions of authors on the topic Electrostatics and notions of Static Electricity are listed in Table 1 in Appendix E. It reflects the main idea communicated to FET learners on what Electrostatics entails and its main players. The overarching idea communicated is that Electrostatics concerns static charges and the forces they exert on one another. It culminates with Coulomb's law, which enables the 'calculation' of these forces.

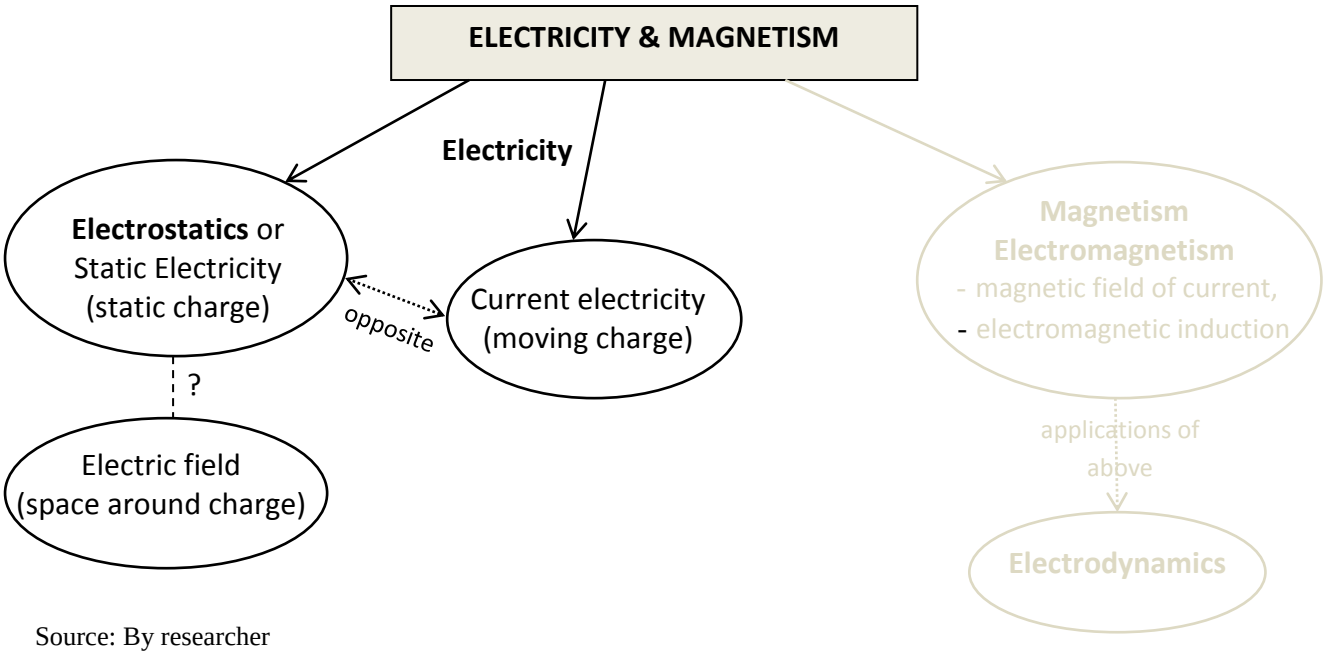
According to the texts, the ultimate purpose of studying Electrostatics is to learn how to calculate forces. The concept of the *electric field* is wholly dissociated from notions of Electrostatics, whether in introductions to the topic or in any other references associated with the term *Electrostatics*. This was found to be the case with textbooks from all curricula, even though in all curricula the electric field is included under the umbrella heading "Electrostatics" and even though in the textbooks of the relevant grade, the section on the

"Electric field" occupies the largest portion of the chapter. The above perception of Electrostatics, being restricted to static charges and the Newtonian notion of their interactions (action-at-a-distance), isolates the topic from the rest of Electromagnetism. In this sense, textbooks project the pre-Faraday and pre-Maxwellian perspective of *Static electricity* rather than the *Electrostatics* of the Classical Electromagnetic Theory described in Chapter 2. The textbook perspective of the old notion of 'Static electricity' does not make allowance for seeing the symmetry, draw parallels and look for links between Electrostatics and the other parts of Electromagnetism. The fact that the term *Magnetostatics* is also missing from the curricula makes it even harder for authors to perceive and concede this symmetry.

Although a systematic analysis of the presentations of *electric field* in the textbooks was not part of this study, the sections had to be read carefully nonetheless, in order to form a global picture of the authors' notions on Electrostatics and its place within Electromagnetism. This endeavour indicated that overall authors lack a proper understanding of the concept *electric field*, which is undoubtedly a difficult concept, as has been pointed out in the literature (e.g. Furió & Guisasola, 1998; Furió *et al.*, 2003; Pocovi & Finley, 2003). Most authors do not seem to perceive *electric field* as a fundamental physical entity, reflecting a state of space, which is the scientific understanding. Also none of the authors seem to be aware that the introduction to the electric field represents a shift from the Newtonian model of the Coulomb force to a new (Maxwellian) perspective of looking at interactions. Texts and also the NCS and CAPS curricula refer to the electric field as a region in space where forces act on charges and some texts confuse it with the non-contact forces or with the 'lines of force'. Learners are given the idea that electric field is just a name for a region where non-contact forces act. Its significance and usefulness have been reduced to that of an auxiliary item that aids visualisation. If authors fail to project electric field as providing a fundamentally different

and worthwhile perspective to that of the action-at-a-distance model for looking at electric interactions, learners are likely to disregard it in their reasoning in favour of Coulomb forces. Why would learners reason with a concept of a field that is presented as "an unnecessary abstract version of the Newtonian" model, as Furió *et al.* (2003) assert. Perhaps this type of understanding is the reason why authors too disregard the electric field in their introductions to Electrostatics in favour of Coulomb interactions.

Figure 6.1 represents how textbook authors perceive Electrostatics within the broader context of Electricity. It is to be compared with Figure 2.1 (Organisation of Electricity and Magnetism in NCS and CAPS curricula).



Source: By researcher

Figure 6.1 Authors' idea of the organisation of Electricity

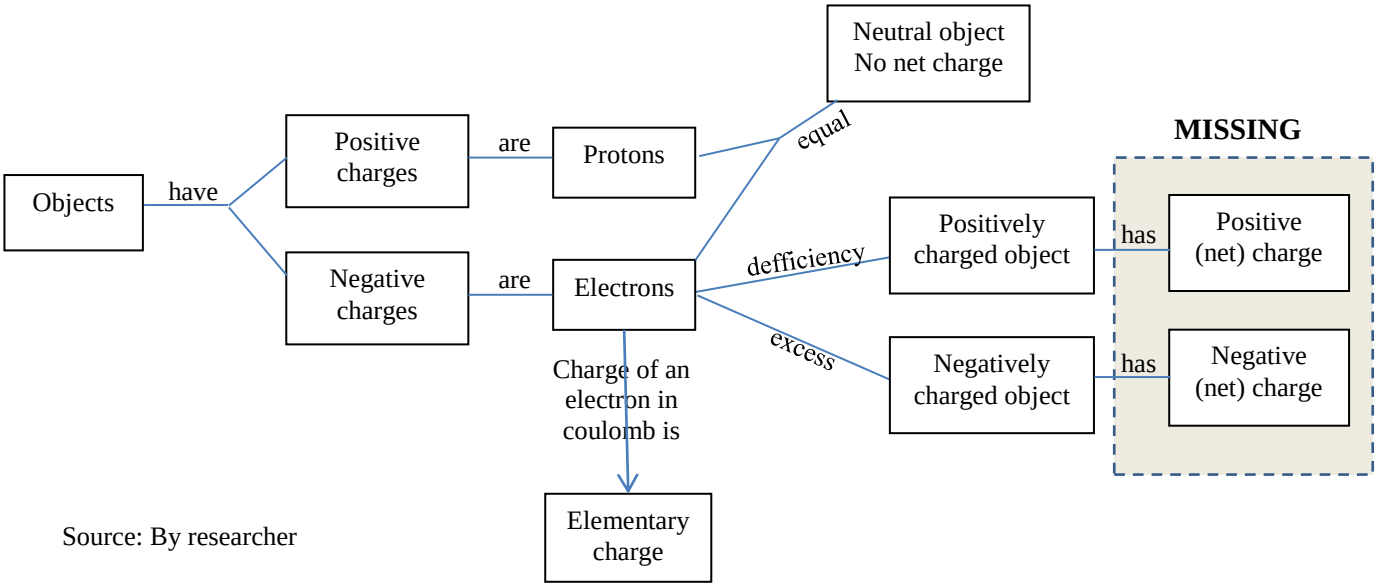
Figure 6.1 portrays the isolation of the concept "electric field" from the rest of "Electrostatics". In addition, Figure 6.1 includes the terms "static electricity" and "static charge". A prime corollary of the emphasis on the 'staticness' of charge is the erroneous

notion that static electricity or electrostatics is the opposite of current electricity, a notion which some authors espouse with explicit conviction, along the lines previously we studied electricity at rest, now we study electricity on the move. Instead of attempting to link the two, Electrostatics and Current electricity are presented as two disparate fields of study (item 4 in Table 1, Appendix E). Furthermore, because static charge is not associated with *excess* charge on objects, the message send is that if a quantity of charge moves we get a current, but if it stops it causes Electrostatics phenomena, which is absurd and the source of unwanted understandings for learners. None of the curricula refer to 'static charge' and NATED 550 was the last curriculum to refer to "Static electricity" (DoE&C, undated, p.36). Yet all authors stress that Electrostatics phenomena are due to static charge, while the term 'static electricity' still persists in more than half of the NCS and CAPS textbooks. This is particularly remarkable as regards the CAPS texts where authors (and publishers) strived to abide to the exact specifications of the CAPS document, often to the detriment of the flow and sense of the content. It signifies that the effect of a strong author conviction may override a curriculum.

6.2.2 The concept "charge" is missing

In Electrostatics there are two fundamental physical entities, *charge* and *electric field*. In the texts, the concept *electric field* is not recognised as such as discussed above. This was somehow expected based on concerns raised in the literature (e.g. Furió & Guisasola, 1998; Furió *et al.*, 2003; Pocovi & Finley, 2003). An unexpected finding however was that the concept *charge*, the main player in Elementary Electrostatics, is missing too. Charge is not presented as a physical entity and as a property of matter (also refer to Figures 5.1 and 5.2). Despite the plethora of references to 'charge' and 'charges' and 'charged objects', the

concept of *charge* as a property of matter, a physical quantity in its own right, with its own units and symbol, is essentially missing from the texts. The analysed texts communicate that 'charge' is a charged particle and particles are 'charges' as a norm.

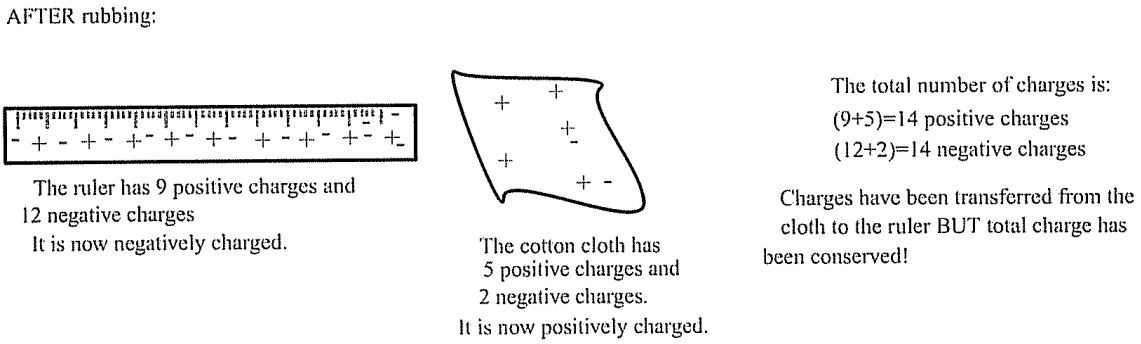


Source: By researcher

Figure 6.2 **The norm in textbook presentations of "neutral and charged objects" and the "elementary charge"**

Figure 6.2 illustrates the overall manner in which texts refer to 'charge' and account for neutral and charged objects. Figure 6.2 indicates that *net charge* or simply *charge* is not associated with charged objects. At the onset of the analysis the omission of *charge* as a physical entity was thought to be an oversight, that perhaps authors took the notion of charge for granted and neglected to introduce it formally or link it to previous knowledge. But soon as the analysis of the texts progressed it became apparent, especially so in the NCS and CAPS texts, that the concept *charge* was far from clear in the minds of the authors, while the concept *net charge*, in the sense of the "*charge* of a *charged* object", is non-existent as indicated in Figure 6.2. For example, "When an object is charged it does not mean that it has only one kind of charge. Every object has both positive and negative charges" (PLATC,

2011, p.135). In this example, apart from the confusing use of the term ‘charge’, there is no allowance for the notion that a charged object has a *charge* (or a non-zero net charge). In fact it implies that such notion is obsolete: “it does not mean that it has only one kind of charge”. Another example is shown in Figure 6.3, addressing conservation of charge in triboelectric charging. According to Figure 6.3, the charged objects do not have a particular *charge*, they have both positive and negative ‘charges’ in unequal numbers.



Source: SIYA, undated, p.256

Figure 6.3 The concept “net charge” or the “charge” of a charged object is missing

It is of concern that such examples are not isolated. Paradoxically this is the case even in texts where ‘net charge’ appears in accompanying figures, though not mentioned in the written text, discussed extensively in the previous chapter for the erroneous messages they transmit (sections 5.4.2.2 and 5.4.2.3). Possible reasons for the omission of the concept *charge* are given below:

First reason: Authors in their effort to stress that objects have both positive and negative ‘charges’, implying protons and electrons, neglected or perhaps avoided reference to the actual *charge* of the charged objects in fear that learners might think that objects contain only one type of ‘charge’. (This alone demonstrates the necessity for an educator to clearly distinguish between the notions of *charge* and *charged particle*.) The fact that a charged object exhibits certain behaviours due to a newly acquired property, the *charge*, was

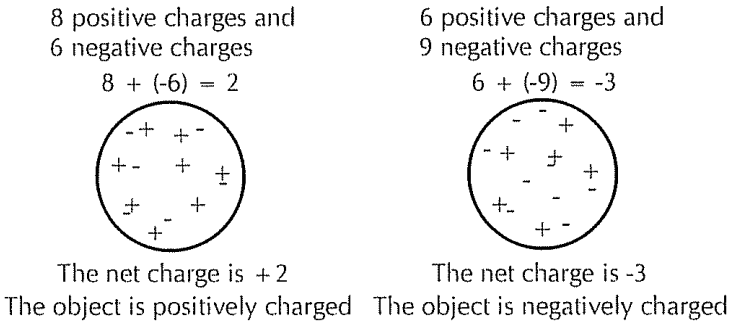
apparently less important or unthought-of. Had authors stressed that the origin of charge lies within the atom, there would be no need to keep reminding learners of objects having both positive and negative nondescript ‘charges’. But then, one might ask, did all authors and editors and reviewers forget or ignore the *charge* of a charged object at the same time? This is highly unlikely. This is rather a case of what-other-textbooks-do, it is an “accepted practice”.

Second reason: Perhaps authors themselves are unaware that a charged object has a *charge*, which can be either positive or negative, not both. This is because they are not familiar with the concept of charge as an inherent property of matter. For these authors, charge means charged particle/s, and so, even a neutral object has lots of charge, both positive and negative. In any case this is the actual message communicated in the analysed textbooks. For the scientist, a neutral object has no charge, hence the communicated message is scientifically erroneous.

Third reason: Authors are aware that charge is a physical entity in science, but for the ease of expression they have used ‘charges’ as a short-cut for ‘charged particles’, underestimating the consequences of this replacement. In this case, authors did not put enough thought in the topic they embarked to write, assuming that it is quite straightforward. Scientists do use short-cut, even slang expressions, but they know what they are talking about. Educators cannot afford to do the same, they need to use *precise terms* and use them *consistently* or else coherence is lost, and learners, who do not have the background of the scientist, will be left utterly confused.

Fourth reason: Authors who refer to charged particles as ‘charges’, tried to add numbers of positive and negative ‘charges’ in an object to get to the *net charge*, but noticed that this was mathematically absurd (what do we get if we add 6 protons and 3 electrons?!) Hence very conveniently they left the concept out, underestimating its importance. (This might explain

why net charge is only associated with neutral objects, as shown in Figure 6.2). Figure 6.4 is an example from a text whose author failed to notice this absurdity. Had authors introduced the concept of *charge* and the unit *elementary charge* correctly, and at the start, this problem could have been avoided. The elementary charge is introduced too late in the texts (and in curricula).



Source: SIYAN, 2010, p.305 & SIYAC, undated, p.254-255

Figure 6.4 Absurd inclusion of "net charge"

Charge is not synonymous to *charged particle* and an electron is neither negative charge nor the *elementary charge*. Using these terms interchangeably, in essence we tell learners that:

charge = particle = unit

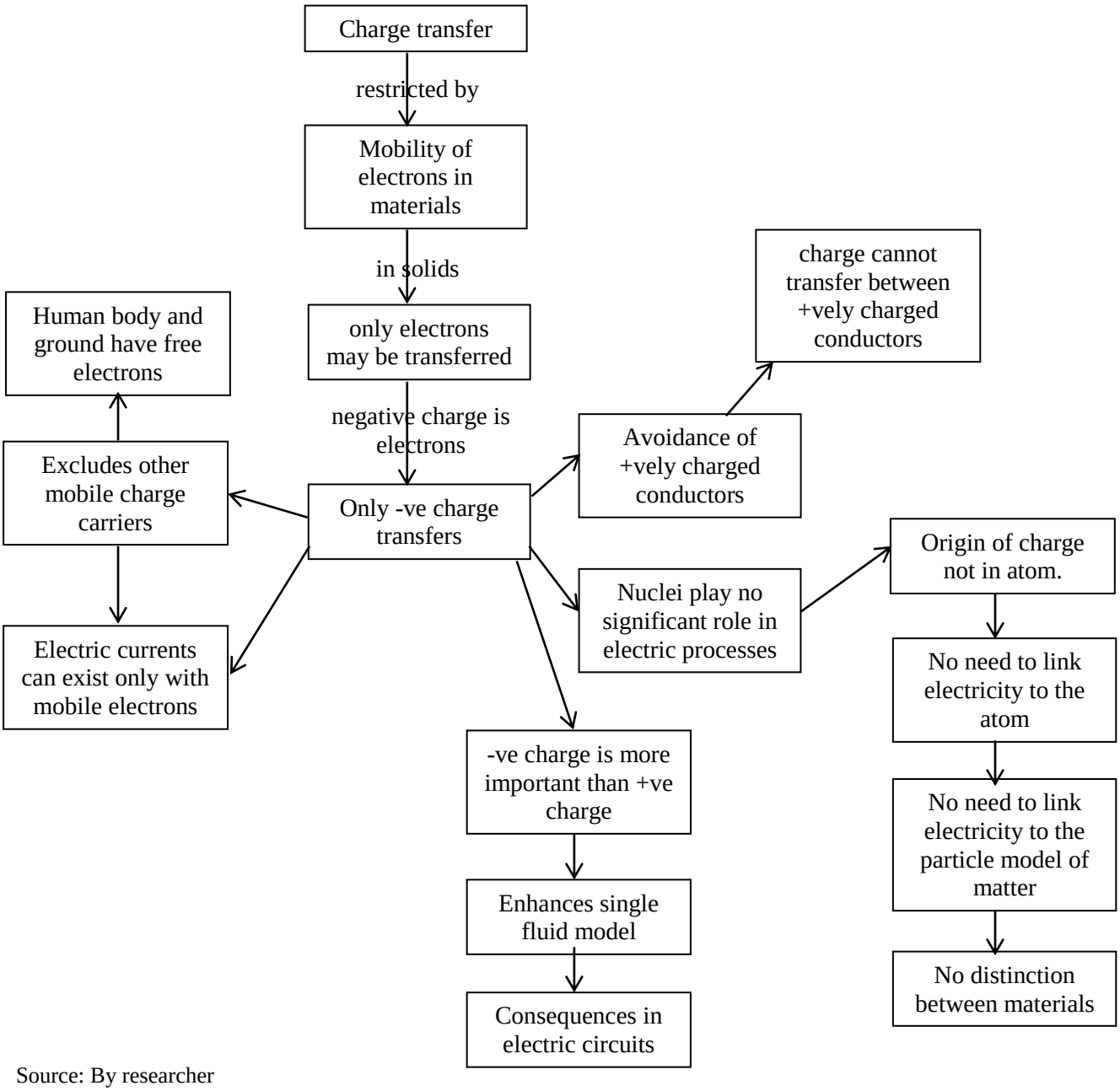
Even so, authors appear to perceive elementary charge as 'a value in coulomb'. They do not seem to realise that the elementary charge itself is a unit of charge with symbol "*e*" and they do not take advantage of this unit. It is possible that they introduce elementary charge as a means to express electrons in coulomb (or at least this is the message sent since electrons are 'charges'), and thus 'launch' the coulomb to prepare learners for the calculations to come. Indeed, in two of the NATED texts the elementary charge is introduced with Coulomb's law, while in CAPS texts it serves the 'sharing of charge' in conductors (given as a ready-made equation to apply, as per CAPS curriculum, with no introduction).

Whatever the reason/s for the omission of *charge*, the baseline is that authors exhibit inadequate understanding of the elementary concepts of Electrostatics and they may not be aware of it. Furthermore they have not put enough effort and thought in their writing, which is unprofessional and unfair to learners.

6.2.2.1 Consequences of the omission of "charge"

A major drawback of equating charge to particles is the restriction of its transfer imposed by the mobility of electrons. Considering that it is electrons that may be generally transferred in solids, authors transmit the erroneous idea, and explicitly so, that only negative charge transfers. As a result, examples in texts, very conveniently for the authors, are of the type where *electrons*, or more often, *negative charge*, may be referred to as being transferred or rubbed off or spread or leak. As a norm, positively charged conductors are not discussed or depicted in diagrams. There are instances in the texts where electrons are even presented to move in insulators in order to justify transfer of charge, such as in all accounts of triboelectric charging or in the charging of an electroscope 'by contact' (whatever that is). This assigned behaviour blurs the distinction between conductors and insulators.

Figure 6.5 illustrates a network of erroneous understandings, all communicated in the texts, produced as a consequence of disregarding the meaning of the foundational concept *charge*. The conceptual network shown in Figure 6.5 is not necessarily produced in the linear fashion depicted in the Figure and is by no means inclusive. However it hopefully gives an idea of how erroneous notions multiply in the texts, with each one having the potential to give rise to new pathways of erroneous ideas which may even permeate further topics. Considering that the ideas included in Figure 6.5 are in conflict with scientific understandings, one can conclude that textbook science content is of concern, in fact that it is not science.



Source: By researcher

Figure 6.5 Network of erroneous understandings originating in the omission of the concept *charge*

6.2.3 The "scientific model" and its use is misunderstood

From the moment primary school learners are introduced to electrical phenomena they learn about 'charge'. Charge is then *something* that appears on objects when rubbed and behave in a different way, like picking up small pieces of paper. The rubbed objects are described as 'charged' objects and the rubbing action is described as 'charging'. The charge an object can get is described as either 'positive' or 'negative'. There are a whole lot of simple practical activities young learners can do to produce a whole lot of macro-assumptions on the behaviour of charged objects, yet all this time, the term 'charge' remains a *descriptive term* for something that appears on objects. And then, young learners come of age to be introduced to the particulate model of matter and the atomic model. The origins of charge, its transfer and the behaviour of charged objects, which could not be explained before, can now be understood in terms of atoms and the actions of their charged particles. Charge is not a *something* anymore, it is an inherent property of electrons and protons, it is an ingredient of matter, much like mass. This order of things sounds very straightforward and is what in science education we would refer to as "making the macro-micro connection". And this would be the realm of Elementary Electrostatics. But in science teaching and learning, linking micro and macro is a complex endeavour and has proven to be far from straightforward (Han & Roth, 2006). The widely held notion that scientific models and associated representations mirror the 'real' world (e.g. Abd-El-Khalick *et al.*, 2008; Smit & Finegold, 1995) and the failure to recognise and address the ontological gaps that exist during translations between different representations (Roth & Tobin, 1997), have been identified as primary culprits for the difficulties learners often face in learning science.

The analysis of Electrostatics in South African textbooks suggests further reasons for concern. In Chapter 5 it has been stressed on several occasions, that authors hold naïve

notions on science models and do not seem to be aware of the inferred nature of their entities. Even more concerning is that authors do not seem to understand what to do with them. Authors attempt to justify the presence and actions of inferred entities via macroscopic descriptions rather than the other way round, which renders them obsolete (refer for example to Figures 5.5 and 5.6, in section 5.4.3). This is not done in an attempt to enlighten the reader on the construction of scientific knowledge, but as an attempt to justify their 'existence'. The inferred entities are presented as the end product of science learning. They appear to be a complication that we have to learn rather than the means to understand a phenomenon. In accounts of Electrostatics this may be done along the lines "…and these charges are in fact protons and electrons" or "…it is actually the electrons that transfer", revelations that signal the end of an account. Authors are under the naïve impression that by following this path which ends to a mention of protons and electrons, they have taught science because they have 'explained' the insides of the object/s involved by giving a simplified picture of 'how they look like'.

It is possible that this trend links to the notion that learning should proceed *from the familiar to the unfamiliar*, or *from the known to the unknown*, reflected in the constructivist perspective for meaningful learning (e.g. Glynn, 1994). As science educators we assume that the 'familiar' is the real and observable phenomenon and we tend to equate it with the 'known'. We tend to associate science models with the 'unknown'. Charging objects and getting them to pick up bits of paper would be the 'familiar'. Why however do charged objects exhibit this behaviour? This ought to be the 'unknown', rather than the science models which we may use to explain this behaviour. For Ogborn (2008), the inferred cosmos is a world for which we know everything about, because it is a world that *we* have constructed. For grade 10 learners, the science models needed in Electrostatics are or should

be already familiar, they should be the ‘known’. Familiar everyday phenomena are not necessarily ‘known’. The real world is a complex one that we strive to understand.

Learners communicated the notions of science models found in textbook Electrostatics (albeit implicitly), may find science quite fruitless, because scientific entities appear to serve no purpose other than being ‘introduced’. Furthermore, in FET Electrostatics, it is absurd to ‘introduce’ protons and electrons, since relevant models, such as the atomic model, have been already introduced under Matter and Materials of Grade 10, some even earlier, in Grades 8 and 9, with relative detail. However, authors of Electrostatics, as discussed previously, do not seem aware of what has been covered in other chapters or Grades, and in any case they do not seem knowledgeable enough to know which models are appropriate to use and where or indeed that they need to use such models, models which in curricula are considered ‘chemistry’.

6.3 Conclusions

How do Electrostatics texts in South African textbooks stand against the specific research questions this study was set about to find answers? The analysis and discussion in the previous chapter and above leave no doubt that the answers to all questions are far from favourable. In short,

1 Consideration for learners

Analysed texts not only ignore possible misconceptions and common ways of reasoning of learners, they introduce them clearly. Inherent difficulties and counterintuitive ideas go unnoticed and are supplemented with extras, introduced by

internally conflicting, inconsistent, fragmented accounts. Texts are too brief, aimless, simplistic and of low cognitive demand.

2 *Understanding and incorporating the nature of science*

Authors have inadequate understanding of the nature of science knowledge and the purpose of science products. They fail to grasp the inferred nature of science models and of their entities. They consider such entities real and existing irrespective of a model, while the notion of a science model is reduced to a simplified sketch to help visualise the real entities that are too small to see. This perception affects their accounts of electrostatics by failing to see science models as tools to explain reality. Hence, scientific explanations are missing from the texts. This has consequences in their causal reasoning as well, which is at best a simplistic causal. Furthermore, as discussed in section 5.6.4.3, authors fail to recognise the efficient cause of phenomena (efficient causes are based on the actions of inferred entities, the start of an explanation) in favour of contingent ones. The latter represents a common or everyday reasoning, expected from learners, which should be addressed, but authors are not aware of the problem.

Yet paradoxically and unwittingly, authors promote other inferior models with no internal consistency or explanatory power, but do not recognise them as such. Such models are discussed in sections 5.4.3 and 5.5.3. This type of models are possibly remnants of the pre-Maxwellian fluid models, which have persisted as the norm in electrostatics textbooks of the 20th century, though this claim needs to be researched.

3 Attention to subject matter content

Authors have inadequate understanding of the subject matter content, which, given the above discussion on the nature of science, is to be expected. Rigour and coherent argument, preciseness and consistency were not characteristics found in the analysed texts. A plethora of careless narratives characterise the texts, in fact it is hard to find a rational sentence. A science educator ought to be an example of *preciseness* and *consistency* of expression, more so than a scientist, as a matter of conceptual teaching strategy. This is not restricted to language but also to the choice of pictorial representations and symbols. Unlike a teacher in front of a class, a science textbook author has the time to scrutinise his/her expression in a text and improve it. Inconsistency in science textbooks demonstrates an unprofessional conduct and disregard for learners. An alarming possibility that emerged from such instances, in need of further research, is that mediocre science texts may filter out learners who want to make sense and who might otherwise have excelled. If this is even partially correct it would be a great loss for science and the country. Texts encourage superficial study, although the notion of 'study' may not even be applicable in the analysed texts, as there is no much substance or reason to be found.

Perhaps the word *elementary* in 'elementary' Electrostatics, which is typically the Grade 10 Electrostatics, is mistakenly taken by some educators and publishers to mean 'easy' or 'rudimentary' according to the most common sense of the word. Perhaps it is the least experienced authors who undertake to write the chapter. In the context of Electromagnetism, elementary Electrostatics signifies the foundations of Electricity where fundamental concepts originate and where observed behaviours find an explanation. This necessitates the deployment of theoretical models to link observed phenomena to their explanations through

the actions of inferred entities of the micro-cosmos. Thus, it requires that the science educator be knowledgeable enough to select an appropriate model for each class of phenomena, to get to the root-cause of a phenomenon via appropriate causal reasoning, and to be very clear on what a scientific explanation is. Elementary Electrostatics, far from being easy, is perhaps one of the conceptually hardest topics of Electromagnetism to teach and to learn. The understanding of Electric Circuits and the reasoning involved are based on the understanding of conductors and related processes in Electrostatics. Yet *conductors*, the focus of Electricity, have been removed from the CAPS curriculum, giving the impression that electrostatics concerns insulators, or that all materials have the same electric properties.

The above point to the fact that we have allowed a flawed simplicity to dominate our textbooks for far too long and it has become the norm. We have lost the science and the reason and we have left little for learners to admire, appreciate and strive to learn. How do we expect them to become thinkers if we do not give them the chance to make sense? Intellectual satisfaction should be one of the goals of teaching and learning science. Ironically, we have come to the position of trying to defend it.

6.4 Implications and recommendations

There is clearly a necessity, not to mention an obligation, for authors to *research the topic* they write about, to become familiar with relevant and modern scholarship. This would allow authors to firstly learn more and upgrade themselves as professionals, and secondly to incorporate new ideas in their writing, triggering an upgrade of textbooks and a much needed evolution of the subject content. A culture of research should be instilled from a young age to student-teachers, as new textbook authors are likely to come from this pool (in any case any teacher should adopt a culture of research).

A most important realisation that surfaced from the analysis of the texts is that the nature of science, especially the inferred and tentative nature of science models, *cannot be isolated from the science teaching and learning*. It is integral to the subject matter content, it allows for correct explanations and appropriate reasoning. Both teachers/authors and learners should be aware of using a science model. This has implications on the training of student-teachers.

Concerning textbook authors in particular, or educators who would aspire to write school science learning materials, an ideal situation would be for universities to offer a postgraduate certificate course, preferably topic specific (a foundational topic), designed for the purpose. The course could incorporate parts and tasks such as:

- The nature of science and the nature of science models whose integration with subject matter content would be highlighted during the course
- Guidance on selecting appropriate models for appropriate processes or phenomena
- The meaning of a scientific explanation and the causal reasoning involved (the construct shown in Figure 3.2, on the "Science Educator's Thought", necessitated from the analysis of the texts, could serve as a model for a scientific explanation)
- Tasks requiring searching the literature on a regular basis aiming at developing learning materials or surveys. For example, on learner difficulties and misconceptions in specific topics.
- Tasks requiring consulting historical accounts for the development of case-study type of learning activities, which would also enhance the participants' own understanding on the nature of science.
- Examples of texts could be given, which participants would practise analysing. Such an activity would get them to pay attention to critical details and reasoning and give them new insights. This activity would also involve searching the literature to support their

claims. But participants could be also encouraged to produce a paper of their own based on their analysis.

- Another type of task relating to the previous one, could be to construct deductive categorisation tables for analysing a text or even inductive ones from given texts and so on…

The Deductive Categorisation Tables, the construct shown in Figure 3.2, the findings from the analysis of the texts, but also the analysis itself, as in Chapter 5, could serve as a source of inspiration, knowledge, ideas and guidelines for future authors, science educators and curriculum developers. It has opened my eyes and has brought unexpected insights. Perhaps some ideas and comments of the analysis may seem exaggerated or unusable, and perhaps they are. However, if some of these ideas find their way in future curriculum materials and teaching, it would be a step towards breaking the stagnation that typifies the science content of electrostatics for years. A start in an evolution well overdue, as long as there is change, there are science educators who think. It would be a huge achievement.

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APPENDIX A

References for the South African FET Physical Sciences textbooks addressing Electrostatics

BJ (1987), 'Physical Science', Juta & Co, Standard 10, 1987 (5th impress. 1991)

OXFN (2008), 'Successful Physical Sciences', Oxford University Press, Grade 10, 2nd impress. (revised) 2008, 8th impress. 2011

OXF11N (2009), 'Successful Physical Sciences', Oxford University Press, Grade 11, 2nd ed. 2009 (3rd impress. 2009)

OXFC (2011), 'Successful Physical Sciences', Oxford University Press, Grade 10, 2nd ed. 2011 (10th impress. 2013)

OXF11C (2012), 'Successful Physical Sciences', Oxford University Press, Grade 11, 3rd ed. 2012 (7th impress. 2013)

PLATC (2011), 'Platinum Physical Sciences', Maskew Miller Longman, Grade 10, 2011

PLAT11C (2012), 'Platinum Physical Sciences', Maskew Miller Longman, Grade 11, 2012 (6th impression 2013)

S&MN (2005), 'Study & Master Physical Sciences', Cambridge University Press, Grade 10, 2005

S&M11N (2006), 'Study & Master Physical Sciences', Cambridge University Press, Grade 11, 2006 (7th printing 2008)

S&MC (2011), 'Study & Master Physical Sciences', Cambridge University Press, Grade 10, 2011

S&M11C (2012), 'Study & Master Physical Sciences', Cambridge University Press, Grade 11, 2012 (7th print 2013)

SIYAC (undated), Siyavula, 'Physical Sciences', Grade 10, Version 1 CAPS

SIYAN (2010), Siyavula, 'Physical Sciences', Grade 10, Version 0.5, 2010 NCS, available on-line: www.everythingscience.co.za

SIYA11C (undated), Siyavula, 'Physical Sciences', Grade 11, Version 1 CAPS

SIYA11N (undated), Siyavula, 'Physical Sciences', Grade 11, Version 0.9 NCS, available on-line: www.everythingscience.co.za

SPS (1987), 'Senior Physical Science', Maskew Miller Longman, standard 10, 1987 (21st impression, 1996)

SS (1989), 'Successful Science (Physical Science)', Oxford University Press, Standard 10, 2nd ed. 1989 (11th impress. 1996)

APPENDIX B

TABLE **Selected FET textbooks for analysis per curriculum**

NATED TEXTBOOKS			Code name
1	Std 8	"Senior Physical Science", Standard 8, Maskew Miller Longman (Pty) Ltd 1985, 24th impress. 1996	SPS
	Std 9	Standard 9 textbook could not be sourced	
2	Std 10	"Senior Physical Science", Standard 10, Maskew Miller Longman (Pty) Ltd 1987, 21st impress. 1996	
3	Std 8	"Successful Science (Physical Science)", Standard 8, Oxford University Press 1985	SS
4	Std 9	"Successful Science (Physical Science)", Standard 9, Oxford University Press 1986, 3nd ed. 1989, 11th impress. 1996	
5	Std 10	"Successful Science (Physical Science)", Standard 10, Oxford University Press 1986, 2nd ed. 1989, 11th impress. 1996	
6	Std 8	"Physical Science", Standard 8, Juta & Co, Ltd 1985, 12th impress. 1996	BJ
7	Std 9	"Physical Science", Standard 9, Juta & Co, Ltd 1986, 4th impress. 1988	
8	Std 10	"Physical Science", Standard 10, Juta & Co, Ltd 1987, 5th impress. 1991	
NCS TEXTBOOKS			Code name
9	Gr 10	"Oxford Successful Physical Sciences Grade 10 Learner's Book", Oxford University Press Southern Africa (Pty) Ltd 2009, 1st publ. 2005, 2nd impress. (revised) 2008, 8th impress. 2011	OXFN
10	Gr 11	"Oxford Successful Physical Sciences Grade 11 Learner's Book", Oxford University Press Southern Africa (Pty) Ltd 2009, 1st publ. 2006, 2nd ed. 2009, 3rd impress. 2009	
11	Gr 12	"Oxford Successful Physical Sciences Grade 12 Learner's Book", Oxford University Press Southern Africa (Pty) Ltd NB: Details of publication furnished in the book are incorrect (referring to another title)	
12	Gr 10	Siyavula "Grade 10 Physical Science", Version 0.5, 2010 NCS, DoBE	SIYAN (e-book)
13	Gr 11	Siyavula "Grade 11 Physical Science", Version 0.9 NCS, DoBE	(e-book)
14	Gr 12	Siyavula "Grade 12 Physical Science", version 0.9 NCS, DoBE	(Printed)
15	Gr 10	"Study & Master Physical Sciences", Learner's Book, Grade 10, Cambridge University Press 2005	S&M N
16	Gr 11	"Study & Master Physical Sciences", Learner's Book, Grade 11, Cambridge University Press 2006, 7th printing 2008	
17	Gr 12	"Study & Master Physical Sciences", Learner's Book, Grade 12, Cambridge University Press 2007, 11th printing 2010	

CAPS TEXTBOOKS			Code name
18	Gr 10	"Platinum Physical Sciences", Learner's Book, Grade 10, Maskew Miller Longman (Pty) Ltd, 2011	PLATC
19	Gr 11	"Platinum Physical Sciences", Learner's Book, Grade 11, Maskew Miller Longman (Pty) Ltd, 2012, 6th impression 2013	
	Gr 12	Grade 12 textbook was not approved by DoBE	
20	Gr 10	"Oxford Successful Physical Sciences Grade 10 Learner's Book", Oxford University Press Southern Africa (Pty) Ltd 2011, 1st publ. 2007, 2nd ed. 2011, 10th impress. 2013	OXFC
21	Gr 11	"Oxford Successful Physical Sciences Grade 11 Learner's Book", Oxford University Press Southern Africa (Pty) Ltd 2012, 1st publ. 2006, 3rd ed. 2012, 7th impress. 2013	
22	Gr 12	"Oxford Successful Physical Sciences Grade 12 Learner's Book", Oxford University Press Southern Africa (Pty) Ltd 2013, 1st publ. 2007, 2nd ed. 2013	
23	Gr 10	Siyavula "Grade 10 Physical Sciences", Version 1 CAPS, DoBE	SIYAC (Printed)
24	Gr 11	Siyavula "Grade 11 Physical Sciences", Version 1 CAPS, DoBE	(Printed)
25	Gr 12	Siyavula "Grade 12 Physical Sciences", Version 1 CAPS, DoBE	(e-book)
26	Gr 10	"Study & Master Physical Sciences", Learner's Book Grade 10, Cambridge University Press 2011	S&MC
27	Gr 11	"Study & Master Physical Sciences", Learner's Book Grade 11, Cambridge University Press 2012, 7th printing 2013	
28	Gr 12	"Study & Master Physical Sciences", Learner's Book Grade 12, Cambridge University Press 2013, 4th printing 2014	

APPENDIX C

TABLE 7.1 On "Models in science" (from Matter & Materials) in CAPS textbooks

CAPS book	On Models
PLATC (2011)	p.17: A **model** is a representation of an object or system. Models that are often used in science are ideas or conceptual models. These show and explain scientific ideas or theories. In the previous chapter, an example of a conceptual model was the kinetic molecular model of matter. In this chapter, we look at the development of models used to describe the structure of the atom. Since a model represents the current scientific understanding, as ideas change, the model changes as well. p.15: In order to explain these (macro) observations, we need to understand what is happening to the atomic or molecular structure of the substance. This is the microscopic level. At the **microscopic** level, you cannot see the atoms or molecules under a microscope, but you can imagine what the atoms and molecules look like by referring to the diagrams in Chapter 1… p.15: (in margin) KEY WORDS: **macroscopic** – big or bulk properties that are visible and measurable **microscopic** – very small, even too small to be seen with the aid of an ordinary microscope
SIYAC (undated)	p.62: Nowadays, we know that atoms are made up of a **positively charged nucleus** in the centre surrounded by **negatively charged electrons**. However, in the past, before the structure of the atom was properly understood, scientists came up with lots of different **models** or **pictures** to describe what atoms look like. Definition: Model - A model is a representation of a system in the real world. Models help us to understand systems and their properties. For example, an *atomic model* represents what the structure of an atom *could* look like, based on what we know about how atoms behave. It is not necessarily a true picture of the exact structure of the atom. Models are often simplified. The small toy cars that you may have played with as a child are models. They give you a good idea of what areal car looks like, but they are much smaller and much simpler. A model cannot be absolutely accurate and it is important that we realise this, so that we do not build up an incorrect idea about something.
S&MC (2011)	p.20: When scientists are trying to understand or explain a difficult concept or phenomenon, they often make use of models. A **model** is a real or mental picture of the concept in terms of what we know. We use models to explain certain observations and measurements. An example is the wave model of light. We cannot see light waves, but we can see water waves. We assume that light is made of waves because experiments show that light often behaves in the same way that water waves do. Models are not stagnant; we can modify and develop them as new information becomes available. When a model corresponds closely to the results from many experiments over a wide range of circumstances, we call it a theory. We can also refer to the wave theory of light in the example above. Models and theories are helpful, but we must remember that they are only a picture of what happens and not the real phenomenon.

OXFC (2011)

p.9: A model is a representation of something. A model car is a scaled down version of the real thing. It is recognisable as a car but some detail has been lost.
(BOX) In Science, a model is a simplified description of a system or phenomenon that contains the essential aspects of the system.

The purpose of scientific models: The purpose of a scientific model is to explain and help us understand the physical world. To do this it needs to:

- Simplify a complex situation. When we think of the particle kinetic model of matter we think of small ball-like particles interacting with each other. Yet the atoms and molecules the model represents are very complex objects.
- Agree with experimental observations. When a gas is heated its behaviour is explained by the increased kinetic energy of its particles.
- Predict what will happen if circumstances change. Equations based on the model can predict changes in quantities.

The limitations of scientific models: Just because a model is a simplification, it does not mean that phenomena always have a simple explanation. There may be more than one factor involved.

How to recognise a scientific model: The words "model" – *atomic model* – and "theory" – *kinetic molecular theory* – are clues that you are using a scientific model. Another clue is that the situation has been simplified. For example, the periodic table arranges the elements in a simplified form that agrees with experimental observations and theoretical knowledge.

How models change with new information: As scientists make new discoveries they adapt the model to explain the new evidence. If the model cannot explain a new discovery scientists may have to discard it and create a new one.

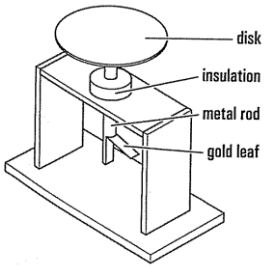
APPENDIX D

Table a OXFN and S&MN texts on the "electroscope"

OXFN (2008), p.61-62

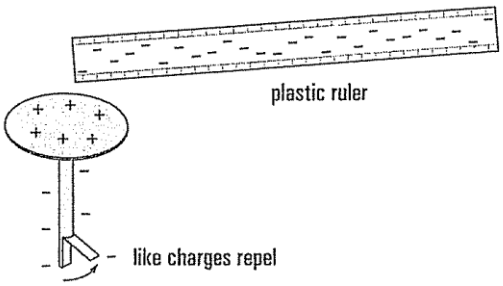
Detecting charge – The electroscope: Figure 5 shows an **electroscope**. The metal disc is connected to a rod that has a piece of gold leaf attached so that the gold hangs loose next to the rod. The disc rod and gold leaf are all conductors of electricity. This means that electrons can move freely from atom to atom.

Charge a plastic ruler by friction and bring it close to the disc as shown in Figure 6.1. Electrons are repelled from the disc and move down the rod. This gives both the rod and the gold leaf a negative charge and the leaf lifts. However, when the piece of plastic is moved away, the leaf drops. You can use an electroscope in this way to detect if an electroscope is charged.

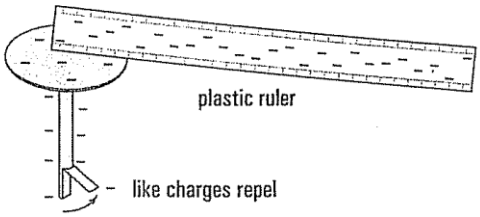


▲ **Fig 5** The gold leaf is raised in a charged electroscope, but falls back against the rod when uncharged.

To charge an electroscope so that it remains charged, touch the disc with a charged object and some charge will transfer between the two. When the charged object is removed the gold leaf remains raised.



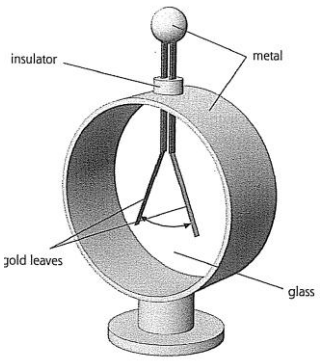
▲ **Fig 6.1** A nearby negative charge repels electrons down the rod, leaving an excess of positive charge on the disc.



▲ **Fig 6.2** Charge transfers to the electroscope when the ruler touches it.

S&MN, (2005), p.93-94

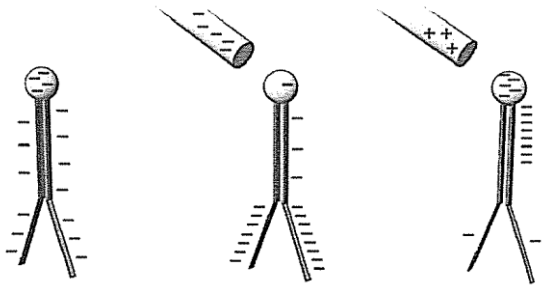
THE ELECTROSCOPE: An electroscope is an instrument for detecting electrical charges. Inside a case there are two moveable leaves, often made of gold. The leaves are connected by a conductor to a small metal ball on the outside of the case.



When the gold leaves in an electroscope are uncharged, they hang straight down. If you touch the ball with a positively charged Perspex rod, they pick up the positive charge and swing away from each other. Both the leaves now have a positive charge and they repel one another. When you take the rod away, they maintain their position, because both are still positively charged.

If you bring a negatively charged PVC rod close to the metal ball, the leaves loose some of their charge and move closer together. If you touch the metal ball with the PVC rod, the leaves pick up its negative charge and move away from each other again.

An uncharged electroscope can be used to test if an object carries a charge, but it cannot determine the type of charge.



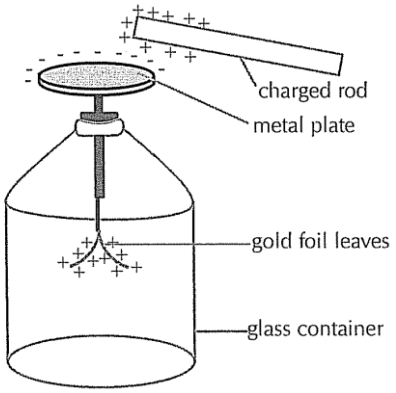
To test if the charge is positive or negative, you first have to charge the electroscope with a known charge. If the electroscope is carrying a negative charge, negatively charged objects near it will cause the leaves to move further apart, as in illustration (b) below. In (c), positively charged objects will cause the leaves to move closer together.

Caption: A previously charged electroscope can be used to determine the sign of a given charge

Table b SIYAN and SIYAC text on the "electroscope"

SIYAC (undated), p.267-269 and SIYAN (2010), p.310-311

***INVESTIGATION*: The electroscope**

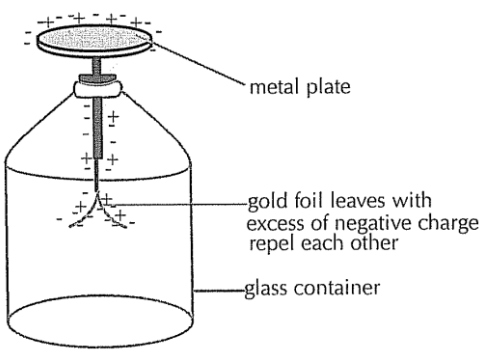


The electroscope is a very sensitive instrument which can be used to detect electric charge. A diagram of a gold leaf electroscope is shown the figure below. The electroscope consists of a glass container with a metal rod inside which has 2 thin pieces of gold foil attached. The other end of the metal rod has a metal plate attached to it outside the glass container.

The electroscope detects charge in the following way: A charged object like the positively charged rod in the picture, is brought close to (but not touching) the neutral metal plate of the electroscope. This causes negative charge in the gold foil, metal rod, and metal plate, to be attracted to the positive rod. Because the metal (gold is a metal too!) is a conductor, the charge can move freely from the foil up the metal rod and onto the metal plate. There is now more negative charge on the plate and more positive charge on the gold foil leaves. This is called *inducing* a charge on the metal plate. It is important to remember that the electroscope is still neutral (the total positive and negative charges are the same), the charges have been induced to *move* to different parts of the instrument! The induced positive charge on the gold leaves forces them apart since like charges repel! This is how we can tell that the rod is charged. If the rod is now moved away from the metal plate, the charge in the electroscope will spread itself out evenly again and the leaves will fall down because there will no longer be an induced charge on them.

Grounding

If you were to bring the charged rod close to the uncharged electroscope, and then you touched the metal plate with your finger at the same time, this would cause charge to flow up from the ground (the earth), through your body onto the metal plate. Connecting to the earth so charge flows is called **grounding**. The charge flowing onto the plate is opposite to the charge on the rod, since it is attracted to the charge on the rod. Therefore, for our picture, the charge flowing onto the plate would be negative. Now the charge has been added to the electroscope, it is no longer neutral, but has an excess of negative charge. Now if we move the rod away, the leaves remain apart because they have an excess of negative charge and they repel each other. If we ground the electroscope again (this time without the charged rod nearby), the excess charge will flow back into the earth, leaving it neutral.



APPENDIX E

Table E1 Findings on overall perceptions of Electrostatics and its purpose communicated in the textbooks (CT1 and CT2)

Communicated ideas and aspects of concern
1. The key players of electrostatics are "static charge" and "action-at-a-distance" interactions. Electric field is not seen as a fundamental physical entity of Electrostatics. (Section 5.2.2.7, pp.116-118) 2. The purpose of Electrostatics is to learn how to calculate forces. (pp.116-118) 3. The emphasis in electrostatics phenomena is placed on the "staticness" of charge. Static charge is not presented as *excess* charge on objects or as *net* charge. There is no mention to charge *imbalance* in objects or similar. (Section 5.2.2.3, pp.112-113) 4. Electrostatics and current electricity are presented implicitly or explicitly as two disparate and opposing fields of study, since: (pp.112-114) - Electrostatics concerns static charge unlike current electricity which concerns moving charge (Section 5.2.2.3, pp.112-113 & section 5.2.2.4, p.113) Other possible ideas communicated implicitly: - Electrostatics concerns insulators unlike current electricity which concerns conductors (Section 5.2.2.5, p.114) - Electrostatics is not of much use unlike current electricity (Sect. 5.2.2.4, p.113-114) 5. Static electricity is a special type of charge originating in rubbing or friction (a 17th century idea). (Section 5.2.2.2, pp.111-112) 6. Careless, irrational narratives encourage superficial/mindless reading. The lack of rationality does not favour intellectual satisfaction and may alienate learners, especially diligent learners from science. (Section 5.2.2.6, pp.114-116)

Table E2 Findings on "Introduction to atomic model" (CT3)

Communicated ideas and aspects of concern
1. No links to previous knowledge on the structure of the atom. NCS and CAPS authors seem unaware of what is being covered under Matter and Materials or previous grades. (Section 5.3.2.1, p.125-126)
2. Half the texts mention the atom, very casually. No reference to the atom as a model. (Section 5.3.2.1, p.126)
3. Texts do not make clear whether the 'charges' or the protons /electrons referred to as constituents of matter, originate in the atom or whether they are extras in the materials (even when these references are preceded by a reference to the atom). (Section 5.3.2.1, throughout)
4. The concept *charge* as a fundamental, inherent property of matter is missing. (Section 5.3.2.1, pp.126-127)
5. In NCS and CAPS texts, e*lementary charge* and c*harge quantisation* are presented, if at all, in isolation towards the end of the chapter Electrostatics, where they serve no purpose. In NATED 550, these precede Coulomb's law and electric field respectively. (Section 5.3.2.1, pp.126-128)
6. The *elementary charge* is presented as the 'electron charge', not as a physical constant, the atomic *unit* of charge. The proton is usually disregarded in these. (Section 5.3.3.1, pp.129-130)
7. Hence, most texts do not mention that the charge of protons and electrons is numerically equal, even though most refer to neutral objects as having equal numbers of protons and electrons. (Section 5.3.2.1, pp.126-128)
8. The rare historical accounts disregard contradictions, are inaccurate and do not reflect how science is done. They endorse a "rhetoric of conclusions" approach. (Section

5.3.3.2, pp131-132)

9. Erroneous expressions in CAPS curriculum are maintained resulting in irrational reasoning and a source of confusion for learners. (Section 5.3.3.1, pp.129-130)
10. Few incidents of confusion between inductive and deductive inferences were found, due to lack of understanding of the nature and role of science models. (Section 5.3.3.2, pp.131-133)

Table E3 Findings on "Charged and uncharged objects" (CT4)

Communicated ideas and aspects of concern
1. No mention to change in behaviour of objects upon been charged. (Section 5.4.1.1, p.140)
2. The concept "charge" as a fundamental physical quantity is disregarded. The notion "charge of an object", in the sense of *excess* or *net charge* is missing. The term n*et charge* is only associated with neutral objects. (Section 5.4.1.1, pp.141-144)
3. Multiple meanings and representations of *charge* are incorporated but left to learners to figure out. No distinction between the concepts *charge*, *net charge* and *charged particle*. (Section 5.4.2.2, pp.146-152)
4. Disregard for ions as possible charge carriers. (Section 5.4.1.1, pp.143-144 & Section 5.4.2.2, pp.146-152)
5. Deployments of questionable inscriptions, not communicating with the verbal text, encourage multiple and inconsistent messages conflicting with other knowledge. (Section 5.4.2.2, pp.146-152 & Section 5.4.2.3, pp.152-157 & Section 5.4.3.1 pp.158-159)
6. The word "electrons" is often evaded in favour of 'charges' or 'negative charges' resulting in erroneous messages. (Section 5.4.3.2, p.160)
7. Protons and electrons are not referred to in their context within the atom. Hence the origin of charge lies in protons and electrons rather than within the atom. (Section 5.4.2.3, pp.155-157 & Section 5.4.3.2, p.160)
8. Introduction of an alternative micro-cosmos with no assumptions or internal consistency at odds with science: - The "quasi-modo" model of matter, of objects consisting of positive and negative charges, a hybrid between macro and micro (Section 5.4.3.4, pp.162-163) - The "electron-proton" model of matter, a quasi-micro model, were objects are made of protons and electrons, conflicting with knowledge gained in Matter and Materials.

(Section 5.4.3.5, pp.164-165)

- In the textbooks, the micro-cosmos is considered real, complex and unfamiliar and must be ‘explained’, as one of the goals of teaching and learning science. (Sections 5.4.3.6 & 5.4.3.7, pp.165-169)
- The notion of science education of proceeding through the familiar to the unfamiliar or through the known to the unknown is misunderstood. (Section 5.4.3.7, pp.167-169)

Table E4 Findings on "Distinction between conductors and insulators" (CT5)

Communicated ideas and aspects of concern
1. No links to previous knowledge on classification of materials. (Section 5.5.2.1, pp.176-179)
2. That materials can be classed based on their electric properties is left to learners to infer. (Section 5.5.2.1, pp.176-179)
3. Mobile electrons are associated with all conductors (no distinction between ionic and metallic conductors). (Section 5.5.2.1, pp.176-179)
4. No mention of the human body as a conductor, though often used in examples. (Section 5.5.2.1, pp.176-179)
5. Features given for conductors / insulators are haphazard, uncorrelated and statement-like. (Section 5.5.2.2, pp.180-181)
6. Confusion between macro and micro domains. (Section 5.5.2.2, pp.182-184)
7. Use of simplistic reasoning (reduced causal) in the scarce attempts to 'explanations'. (Section 5.5.2.2, pp.182-184)
8. Use of contingent instead of efficient causes for distinction between conductors-insulators. Dominant distinctions are in terms of: - spreading or distribution of charge (macro statement) (Section 5.5.2.2, pp.185-188) - ability to allow charge/electricity/electrons to flow through (macro statement) (Section 5.5.2.2, pp.188-189) - (in CAPS texts) ability to become charged by rubbing (misconception) (Section 5.5.2.2, pp.189-190)
9. No effort to address counterintuitive claims and no evidence of research. (Section 5.5.3, pp.191-200)
10. Promotion of misconceptions (the 'empty pipe' conductor) instigating local and sequential reasoning with consequences in DC circuitry. (Section 5.5.3, pp.191-200)

11. Concept of *electrostatic equilibrium* is missing promoting reasoning in terms of 'repelling forces' (see "pushing charges" model below). (Section 5.5.3.1, pp.191-193)
12. Established, relevant theoretical models from Mater and Materials, which learners are already familiar with (e.g. metallic bond model), are not linked to electrostatics. Instead, alternative models with no internal consistency are employed:
    - The "pushing charges" model for the spreading of charge. Encourages notions of forces at odds with Coulomb forces and disregards "superposition of forces". (Section 5.5.3.1, pp.191-193)
    - The "distinct particle" model for the 'leaking' and transfer of charge. Presumes distinct *particles* /electrons. It cannot be used for positively charged metallic conductors. (Section 5.5.3.2, pp.194-199) Hence,
13. Avoidance of examples with positively charged conductors (only left to learners). (Section 5.5.3.2, p.195)
14. Ignore the need for contact between two objects for charge to transfer. (Section 5.5.3.2, pp.196-199)
15. Do not perceive air as a material and fail to address its role in the discharging action of sharp points of conductors. (Section 5.5.3.2, pp.196-199)
16. The alternative models above instigate misconceptions on the transfer of charge between conductors. (Section 5.5.3 in general & Section 5.5.3.2, p.200)

Table E5 Findings on "Triboelectric charging" (CT7)

Communicated ideas and aspects of concern
1. The meaning of 'charging by contact' is elusive in both curricula and textbooks, sending the message that charge transfers via the same mechanism in all scenarios. (Section 5.6.1, pp.202-206 & Section 5.6.2, pp.212-217)
2. The general requirement for charge to transfer, "need for contact", is disregarded. (Section 5.6.3.1, p.212)
3. Both conditions for triboelectric charging to occur, i.e. "contact followed by separation" and "dissimilar materials" are disregarded. (Section 5.6.3.1, pp.212-214)
4. No links to electronegativity or other knowledge. Accounts of triboelectric charging are at odds with the scientific understanding of the process. (Section 5.6.3.1, pp.214-217)
5. No reference to formation of ions on the surface of insulators upon triboelectric charging. (Section 5.6.3.1, pp.214-217)
6. Convey the idea that *mobile electrons* move between insulators *during contact*, hovering on the surface they end up, thus, conflicting with the notion of "insulator". (Section 5.6.3.1, pp.214-218)
7. The role of the nucleus is disregarded. The nucleus is mentioned in only two texts as playing no role in the charging process because protons are far from the rubbing action and cannot be rubbed off. (Section 5.6.4, generally)
8. Communicated wrong ideas found in several texts: - WI-1: Rubbing charges one object (physical systems of single objects) (Section 5.6.4.1, pp.218-219) - WI-2: The cause of charging is the rubbing or friction (Section 5.6.4.2, pp.220-222) - WI-3: Use of empirical instead of inferential causes (unsuccessful causal reasoning) (Section 5.6.4.3, pp.222-226)

- WI-4: Charge is ‘produced’ and charge is ‘created’ (Section 5.6.4.4, pp.227-228)
- WI-5: Charges /electrons jump off and are picked up (Section 5.6.4.5, pp.229-230)
- WI-6: Contact is not always necessary (Section 5.6.4.6, p.231)

9. Confusion between “transfer of charge” and “transfer of matter” (charged particles). Negative charge is considered synonymous to electrons, and electrons are considered the only mobile charged particles in matter, hence the following erroneous messages are promoted: (Section 5.6.5, pp.232-245)
   - An object can only gain or lose negative charge (Section 5.6.5, pp.235-245)
   - Positive charge does not transfer, only negative charge transfers (Section 5.6.5, pp.235-245)
10. Consequently, positive charge is not presented as equivalent to negative charge, but as something deficient of negative charge and hence subservient to negative charge. (Section 5.6.5, pp.235-245)
11. Notions of charge transfer resemble the old notion of the single-fluid model of electricity, where the electric fluid is made of electrons. (Section 5.6.5, pp.235-245)

Table E6 Findings on "Polarisation of materials" (CT8)

Comments, communicated ideas and aspects of concern (NCS and CAPS texts)
Only one CAPS text addresses polarisation of conductors. Another series addresses "charge induction" in conductors as the alternative to polarisation of insulators. 1. The representation of conductors indicates that the level of complexity and cognitive demand in Electrostatics is considerably lower than in Matter and Materials, the latter considered as chemistry and this background is disregarded in Electrostatics. (Section 5.7.3.1, pp.255-258) 2. There is need for systematic research on the level of complexity of Electrostatics Grade 10 as compared to that of chemistry Grade 10 and as compared to the level of Electrostatics Grade 8 (i.e. of the lower secondary). (Section 5.7.3.1, pp.255-258) 3. Diagrammatic representations of polarised and charged objects are confusing, and they are either in discord with the written text, or in conflict with other relevant representations in the texts or all of the above. (Section 5.7.3.1, pp.255-258; Section 5.7.3.2, pp.261-263; p.288 & throughout Section 5.7.3) 4. The above indicate that written texts and diagrams are not produced in conjunction and are not drawn by the authors themselves, to the detriment of meaning making. (Section 5.7.3.2, pp.261-263; p.288 & throughout Section 5.7.3) 5. Regarding polarisation of insulators, all texts refer to atoms or molecules, but none refers to the actual cause of the polarisation in terms of forces. In the case of polar molecules, texts clearly give the impression that the molecules 'know' and rotate. (Section 5.7.3.2, pp.261-264) 6. More than half the texts mix macro and micro descriptions which conflict and confuse the reader. The account of polarisation in one of the series is quite unacceptable. (Section 5.7.3.1, pp.267-271) 7. The cause of attraction between charged and uncharged objects is wrong in all but one series.

This is because explanations are based on ‘unlike charges attract’ resulting in the erroneous understanding that only the side of the polarised object nearest to the external charge interacts with the external charge, thus disregarding the interaction of the entire object. (Section 5.7.3.2, pp.264-267)

8. Unscientific notions and stumbling blocks in the understanding of the interaction between charged and uncharged objects due to entrenched ideas held by students, as identified in the literature, are not only overlooked by the texts but encouraged (e.g. in diagrams and confusing texts) and in many cases communicated by the texts themselves (e.g. in explanations). (Throughout Section 5.7.3, pp.255-287)

Table E7 Findings on the presentations of the "Leaf electroscope"

In NATED texts the electroscope is presented descriptively as a revision from Std 7. NCS and CAPS have omitted the electroscope, yet in all Gr 10 NCS and one CAPS texts, it is included prominently. The following concern these NCS and CAPS texts.

1. Although the purpose of using an *uncharged* electroscope in the texts is relatively clear, the purpose of using a *charged* electroscope is not. Texts concentrate on the process of charging it, neglecting the purpose of charging it.
2. Hence on one hand NCS authors feel strongly about the inclusion of the electroscope, but on the other hand, and without guidance from a curriculum, they are not clear/sure as to why they should include it or what to do with it.
3. The above suggests that the 'author conviction' for the necessity of the inclusion of the electroscope might have been for habitual rather than conceptual reasons.
4. Two NCS texts present feeble-accounts-sound-straightforward of the behaviour of the leaves of the electroscope, expecting learners to invent and apply characteristics of conductors with no suitable background, not even on conductors.
5. The third NCS text and its identical CAPS counterpart are in a different league, by introducing the notions of *charge induction* and *grounding* to address the "charging" and "discharging" of the electroscope. However,
   - *Induction* and *grounding* are in need of careful introduction themselves, and this is not done. Hence texts, though long, are too brief and condensed for meaning making.
   - The two accompanying diagrams are utterly insufficient, are not linked clearly to the text, and are a source of conflict and confusion; one representing charge, the other charged particles with same symbols and not explained.
   - Crucial information of the behaviour of the leaves is missing from the narrative.
   - There is confusion between the transfer of charge and the transfer of charged particles, a distinction which is important for interpreting the behaviour of the leaves.
   - Counterintuitive claims are not addressed.
   - Justification of charge transfers rely on 'like repel, unlike attract'. This is erroneous and results in conflict between the grounding during *charging* and the grounding during the *discharging* of the electroscope.
   - Considering the complexity of the interpretation of the electroscope, the account should have revolved around carefully designed diagrams rather than relying on verbal text.