The impact of toys as educative curriculum material on pre-service primary school Natural Sciences teachers’ understandings of energy

By

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ABSTRACT

In this study toys were used as educative curriculum material in an intervention on the topic of energy aimed at Intermediate Phase pre-service science teachers (n= 87) registered for a BEd degree at the Nelson Mandela Metropolitan University, South Africa. The intervention consisted of, amongst other elements, lectures, assignments and toy workshops, with the latter being a key driver in the process. The choice of toys as the educative curriculum material was informed by the fact that there is a huge variety of simple, reasonably priced and easily procured toys that are suitable to demonstrate the concept of energy from both theoretical and practical perspectives. The conclusions that can be drawn from the study are that the use of toys in the preparation of pre-service primary school teachers has the potential to substantially improve their subject content knowledge (SCK), pedagogical content knowledge (PCK), and their confidence related to these two constructs with respect to their understandings of energy. The data generated also suggest that when appropriate educative curriculum materials are integrated into a topic in science-teacher education, there may be a substantial positive impact on pre-service teachers’ confidence in both their understanding of the science content and their perceptions of their ability to teach this content.

An additional finding of the study was that, despite its popularity, status and usefulness over many years, the Science Teacher Efficacy Belief Instrument (STEBI-B) shows low sensitivity to measuring changes in efficacy as a consequence of the so-called ‘ceiling effect’. The ceiling effect is a result of initial high scores which provide little opportunity to show
substantial positive change as a result of an appropriate intervention that is designed to improve efficacy. While this study did not directly address this lacuna in STEBI-B, it made use of an innovative descriptive statistic, ‘percentage gain of potential’, in an attempt to describe and interpret even small changes in efficacy as measured by STEBI-B.
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CHAPTER ONE

INTRODUCTION AND OVERVIEW

1. INTRODUCTION

South Africa’s results in large scale international tests in science have been dismal, as are the results in more regional and national assessments (Department of Education - DoE, 2005; Fleisch, 2008; Howie & Hughes, 1998; Reddy, 2006; van der Berg & Louw, 2007). Despite the progressive nature of the current South African Natural Sciences curriculum since the onset of democracy in 1994 (Department of Education - DoE, 2002), there is little evidence to suggest any significant improvement in the quality of teaching of this subject area (Christie, Butler, & Potterton, 2007). South African researchers claim that this lack of improvement is related to the substance and relevance of teacher training programmes, and as such, are areas of great concern (Arends & Phurutse, 2009), and the national Department of Education considers many programmes to be too theoretical, and not linked closely enough to classroom reality (DoE, 2005).

Many South African research projects have indicated a disappointingly low level of conceptual and pedagogic knowledge amongst teachers. Despite large amounts money being spent on education, South Africa is not succeeding in promoting a strong culture of achievement in many subjects, including the Natural Sciences (Treasury, 2010). This is well illustrated by Webb et al. (as cited in Taylor & Vinjevold, 1999) who found that most teachers
in their study did not score any better on electricity tests than their learners\(^1\). Arends and Phurutse (2009) have suggested that the quality and quantity of instruction is highly compromised where there is teacher incompetence and it follows that any attempt to improve teacher competence requires a relook at teacher training.

The introduction of the Revised National Curriculum Statements in 2002, with their significant changes in the content and methodology for the Natural Sciences, provided a golden opportunity to re-evaluate and redesign the content of method modules used in the training of pre-service primary school teachers. The extent to which teachers move towards effective science teaching can be gauged, amongst others, by measures of self-efficacy, subject content knowledge (SCK), and pedagogical content knowledge (PCK) (De Laat & Watters, 1995; Ingvarson, Meiers, & Beavis, 2005; Murphy, Neil, & Beggs, 2007; Plourde, 2002; Watters & Ginns, 1995). As such, this study focuses on these aspects of pre-service training of teachers.

2. THEORETICAL FRAMEWORK

This study is embedded within the theoretical framework of the notion of teacher development, and particularly teacher learning, that includes ideas of self-efficacy beliefs (SEB), subject content knowledge (SCK) and pedagogical content knowledge (PCK). It is proposed that these concepts can be promoted during pre-service teacher training method courses for the Natural Sciences curriculum by using innovative educative curriculum materials. This study makes use of simple toys (the educative curriculum material) to teach the concept of energy (the subject content knowledge). The approach in this study

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\(^1\) Throughout this text the term for children of school-going age will be ‘learner’. Some of the quotations may refer to children who go to school as ‘students’, ‘children’ ‘pupils’ etc. and, where relevant, the term ‘learner’ has been placed in brackets after these terms.
acknowledges the claim of Verloop, Van Driel and Meijer (2001) that research on teaching, and what contributes to effective teaching, has shifted from the pre-1980s studies of the behaviour characteristics of effective teachers to the study of teachers’ thinking processes and beliefs that underpin their behaviour. It is thus cogent that when one wishes to investigate what makes for effective teacher learning, one should consider factors such as self-efficacy beliefs, subject content knowledge and pedagogical content knowledge. These concepts will be dealt with in detail in Chapter two, but the following thumbnail sketches serve to introduce the terms.

2.1 Teacher learning

According to Fishman and Davis (2006, p. 535), “Teacher learning is an active area for research in education,…” The importance of understanding teacher learning arises because teachers can be viewed as the final “…interpreters of any classroom-based intervention” (Fishman & Davis, 2006, p. 535). Davis and Krajcik (2005, p. 3) have attempted to define teacher learning as involving “…developing and integrating one’s knowledge base about content, teaching, and learning; becoming able to apply that knowledge in real time to make instructional decisions; participating in the discourse of teaching; and becoming enculturated into (and engaging in) a range of teaching practices.” With respect to pre-service teachers, Fishman and Davis (2006, p. 536) claim that as pre-service teachers expand their teaching repertoires (including, amongst other actions, the use of educative curriculum materials) they develop new ideas about teaching, learners and the learning process. If we are able to better understand this process (of teacher learning) then we will be able to inform the design and content of university method programmes (the NMMU Natural Sciences programme for pre-
service teachers in the case of this study) to maximise the learning experience of pre-service teachers.

2.2 Subject content knowledge (SCK)

One of the proposed knowledge areas required of effective teachers is the area of content knowledge (Shulman, 1986b, 1987). This usually refers to discipline specific knowledge and is an important form of knowledge that teachers need to master. Hoban (2007) suggests that primary school science teaching remains problematic in many countries in the world because of the lack of a deep understanding of the science content matter by teachers. This lack of understanding has a ‘knock-on’ effect of reducing teachers’ self-confidence and consequently they try to avoid teaching what they don’t understand and reduce the amount of time devoted to the subject.

The specific SCK that this study addresses is the concept of energy which falls in the domain of the Natural Sciences. Driver and Millar (1986) suggest that there is general agreement that energy is of central importance in any science curriculum, because energy is key to our understanding of the way things happen in the physical, chemical and technological worlds.

2.3 Pedagogical content knowledge (PCK)

The notion of pedagogical content knowledge (Shulman, 1986b, 1987) has been increasingly used in science education literature and its origins, status and usefulness have been subjected to critical scrutiny and question (Summers, Kruger & Mant, 1998). Summers et al. (1998) prefer the term ‘subject-specific teaching knowledge’, with an emphasis on all of the ways in which a teacher helps children acquire understanding of a topic. Van Driel, de Jong
and Verloop (2002) summarise Shulman’s (1986b, 1987) view of pedagogical content knowledge (PCK) as being a form of practical knowledge that is used by teachers to guide their actions in their unique classroom settings. It entails, amongst other things, knowledge of common conceptions, misconceptions, and difficulties that learners encounter when learning particular content as well as a knowledge of specific teaching strategies, analogies and metaphors that can be used to address particular learners’ learning needs in particular classroom situations. In this study the term ‘pedagogical content knowledge’ refers to a form of ‘craft’ knowledge used by teachers in particular classroom situations.

2.4 Self-efficacy beliefs (SEB)

Teacher self-efficacy is seen as teachers’ perceptions of their capabilities and power to positively influence learning (Bergman et al. as cited in Brouwers & Tomic, 2003; Tschannen-Moran & Woolfolk-Hoy, 2001, p. 785). These researchers define teacher self-efficacy as a teacher’s “…judgement of his or her capabilities to bring about desired outcomes of student engagement and learning, even among those students who may be difficult and unmotivated.” In turn, researchers have shown that the teachers’ sense of self-efficacy is a powerful construct related to learner achievement (Ashton, 1984).

2.5 Educative curriculum materials

As noted earlier, educative curriculum materials are materials (including, but not limited to, textbooks, study guides, technology-based materials, activities etc.) designed to support teacher learning (Schneider, Krajcik, & Marx, 2000). Ball and Cohen (1996, p. 6) hint at the importance of curricula materials when they suggest that “The design and spread of curriculum material is one of the oldest strategies for attempting to influence instruction.”
According to Davis, Nelson and Beyer (2008, p. 4), “Educative curriculum materials provide a form of support for teacher learning, knowledge integration, and conceptual change.” While at the same time they “…support the development of this readiness (PCK readiness) and poise teachers for ongoing knowledge development and integration over time.”

Tschannen-Moran and Woolfolk Hoy (2007, p. 944) have touted mastery experiences as the most powerful source of teachers’ self-efficacy and, with this in mind, it appears sensible to introduce and get teachers to experience a variety of ‘classroom-ready’ educative curriculum materials. As such, a variety of different ‘educative curriculum materials’ have been used in an Intermediate Phase (IP) teacher education programme at the Nelson Mandela Metropolitan University (NMMU). This study investigates the effect of a particular educative curriculum material, namely, simple toys in the subject content area of energy on the participating students’ self-efficacy, subject content knowledge and pedagogic content knowledge. While the variety of educative materials used in the course is extensive, this study is limited to investigating the effect of a particular type of educative curriculum material, namely, everyday children’s toys in the content area of energy. The study is embedded within the theoretical framework of the notion of teacher learning (Dietz & Davis, 2009) and is framed around the ideas characteristic of successful pre-service teachers of the Natural Sciences, namely, self-efficacy, subject content knowledge and pedagogical content knowledge.

3. STATEMENT OF THE RESEARCH PROBLEM

As noted earlier, many initiatives have been undertaken in South Africa to improve science and mathematics education, but there has been no noticeable effect on the science and
mathematics education system as a whole (DoE, 2005; Fleisch, 2008; Howie & Hughes, 1998; Reddy, 2006). The literature also indicates a disappointingly low level of conceptual and subject content knowledge (SCK) and pedagogic content knowledge (PCK) amongst South African teachers that is compounded by a teaching force that is in general de-motivated and struggling with a poor self image (Taylor & Vinjevold, 1999). Ramey-Gassert, Shroyer and Staver (1996) found that an important factor that influenced the science teaching self-efficacy of elementary teachers was what they referred to as antecedent factors that included the teachers’ in- and out-of-school experience of science, their teacher preparation and their science teaching experience. As such, this study focuses on teachers’ SCK, PCK and their feelings of confidence and competence, in other words, their self-efficacy beliefs.

4. THE RESEARCH QUESTION

Key factors that have emerged from research (De Laat & Watters, 1995; Harlen, 1997; Jabot, 2002; Meiring, Ilsley & Webb, 2004; Muwanga-Zaki, 2002) are teachers’ lack of subject content knowledge and pedagogical content knowledge and the poor quality of their classroom practice, all of which impact negatively on the teachers’ self-efficacy belief. In the light of the above, the primary question in this study is:

*Can the use of toys as educative curriculum materials meaningfully contribute to the effective preparation of pre-service Natural Sciences primary school teachers in terms of subject content knowledge, pedagogical content knowledge, self-efficacy beliefs and confidence to teach energy in the primary school?*

The subordinate questions that must be answered in order to shed light on the principal research question are:
• *Does this type of approach to pre-service training in the Natural Sciences improve teacher’s subject content knowledge?*

• *Does this type of approach to pre-service training in the Natural Sciences improve teacher’s pedagogical content knowledge?*

• *Does this type of approach to pre-service training in the Natural Sciences improve teacher’s self-efficacy?*

• *Does this type of approach to pre-service training in the Natural Sciences improve teacher’s confidence to teach energy at school?*

5. **METHODOLOGY**

The questions posed by this study are best answered by the use of both quantitative and qualitative measures, in other words a mixed-methods approach. Appendix A provides a schematic outline of identification and the relationship between the various data-generating instruments used in this study.

6. **OUTLINE OF THE STUDY**

In this chapter issues of teacher learning, self-efficacy beliefs, subject content knowledge, pedagogical content knowledge and educative curriculum materials are briefly introduced, after which the problem, namely that there has been little or no positive discernible effect, despite the many initiatives have been undertaken in South Africa to improve science education, is presented. The research question is stated, the research methodology for the study is briefly described and the rationale and significance of the study is sketched.
Chapter two provides a detailed literature review focusing on the theoretical frameworks underpinning teacher learning, self-efficacy beliefs, subject content knowledge, pedagogical content knowledge and educative curriculum materials. Included in the discussion, but not restricted to these, are concepts such as the role of misconceptions-based methodology, a constructivist approach in method courses on teacher self-efficacy beliefs, and the role that these play in classroom practice.

Chapter three outlines the methods used to address the research questions. The theoretical underpinning of the methods, as well as descriptions and justifications of the methods and procedures used for data collection, sampling type, sample size, et cetera are interrogated, as are the data collection techniques. Assumptions that are made in selecting the particular research methods, determined by the type of data required to be collected are justified.

Chapter four focuses on the results and findings, including a description of the procedures and processes used to get from the data collected to the findings. In the case of the quantitative data, both descriptive and inferential statistics are discussed in Chapter four. The methods of data analysis used are explained.

The findings are discussed in Chapter five. These findings are related to the stated theoretical underpinnings and stated assumptions of Chapter two. Chapter six discusses the implications of the findings described in Chapter five for the preparation of Intermediate Phase teachers to teach the Natural Sciences.
CHAPTER TWO

THEORETICAL FRAMEWORK/LITERATURE REVIEW

1. INTRODUCTION

Many researchers (De Laat & Watters, 1995; Harlen, 2009; Murphy et al., 2007; Plourde, 2002) have commented on the lack of confidence and of subject content knowledge with respect to the teaching of the Natural Sciences amongst non-specialist primary school teachers. Confidence, self-efficacy beliefs, subject content knowledge and pedagogical content knowledge are closely intertwined and they are all linked to teacher learning and subsequently to teacher effectiveness (Riese & Reinhold, 2010). This study investigates the effect of educative curriculum materials, in this case toys, in the development of these interconnected aspects of teacher knowledge.

In this chapter the five principle ideas underpinning the study, namely, teacher learning and development, teacher self-efficacy beliefs (SEB), subject content knowledge (SCK) with a focus on the energy concept, pedagogical content knowledge (PCK) and educative curriculum materials (ECM) with a focus on toys as the ECM, are discussed within the context of primary school teachers and the teaching of the Natural Sciences (NS). All five ideas are related to the training of pre-service primary school teachers within the theoretical framework of teacher learning. As is intimated by McDonnough and Matkins (2010) all of the above factors appear to be interlinked:

The assessment of an effective teacher preparation program in science should include measurement of changes in the pre-service teachers’ levels of PCK, which includes
content knowledge, current pedagogical skills, and confidence in the ability to apply content and skills in the future, that is, self-efficacy beliefs. (p. 14)

Riese and Reinhold (2010, p. 79-80) propose a model of “professional action competence” required by teachers to enable them to meet the complex demands of being able to teach in a specific area. Riese and Reinhold’s model (where the concepts relevant to this study have been highlighted by shading in the boxes) is shown in Figure 1.

*Figure 1. Model of competence structure.*

The claim by Riese and Reinhold (2010, p. 79) is that “Up to now it is unclear to which extent needed professional skills and competencies like pedagogical content knowledge are acquired and what their development is like in the university phase of teaching.” They suggest that little has been researched on the interaction between the various components, such as content knowledge and pedagogical content knowledge. This study attempts to investigate the interaction between the highlighted boxes (Figure 1) using a very limited instance, where the subject content knowledge is represented by the concept of energy and the educative curriculum material is represented by children’s toys.

One important underpinning idea in this study is knowledge integration. Davis and Krajcik (2005) and Davis et al., (2008, p. 3) have suggested that because knowledge
integration involves the principle of connecting ideas such as concepts, beliefs and pedagogy, that this could be a “…promising lens through which to view the development of teachers’ PCK.” It will be shown in this chapter how the other ideas mentioned above, namely, self-efficacy, subject content knowledge and education curriculum materials make up the other knowledge concepts in the integrated whole.

2. TEACHER LEARNING AND DEVELOPMENT

In this study teacher learning plays a pivotal role as it is the teachers’ development of various competences that dictates whether they will be effective in the classroom.

2.1 Teacher learning

‘Teacher learning’ is a concept in educational research that has recently come to the fore. A working definition of teacher learning, proposed by Fishman, Best, Foster and Marx (2000, p. 3) is: “…teacher learning: changes in the knowledge, beliefs, and attitudes that teachers possesses that lead to the acquisition of new skills, new concepts, and new processes related to the work of teaching.” It is assumed that these changes that lead to new ways of teaching, will have a positive impact on the learners, that is, the changes will give rise to successful teaching. This can be seen in Adler’s (2000, p. 37) definition of teacher learning which is that teacher learning can be “…usefully understood as a process of increasing participation in the practice of teaching, and through this participation, a process of becoming knowledgeable in and about teaching.”

It would appear that an important contributing factor towards a learner’s success in science (or any subject) is access to qualified, competent and effective teachers of that subject who are able to teach successfully (Arends & Phurutse, 2009; Borko, 2004; Flecknoe, 2000).
According to Arends and Phurutse (2009, p. ix), “…teachers contribute much to learners’ educational achievement and should partly be held accountable for poor learner performance…” and “Teacher competency is increasingly seen as critical if all learners are to derive benefits from the schooling system (Arends & Phurutse, 2009, p. 1).” As such, the teacher training sector should provide opportunities for teachers to improve their knowledge, skills, attitudes and beliefs to such an extent that they will be better equipped to be successful teachers. In order to do this Lowery (2002), believes that educators of pre-service teachers need to know some key ideas if they are to train effective teachers, namely, how teachers learn; what types and levels of knowledge are required by them; and what conditions are best suited for teacher learning.

2.2 Successful teaching

The idea of what constitutes ‘successful teaching’ is problematic (Kleinman, 2006; Powell, 2007; Summers et al., 1998). According to Kleinman (2006, p. 234), “…more than fifty years of research has not contributed much to our knowledge of factors which are associated with good teaching.” This is supported by Powell (2007, p. 112) who also acknowledges that a great deal of research has attempted to define and set up criteria for what constitutes successful teaching, and yet “…the results to date have been meagre and of little help to those who are responsible for training teachers and assessing teaching skill.” Kleinman’s (2006) problem revolves around whether the statement of ‘effectiveness’ involves attributes of the teacher in a particular teaching situation or the outcomes of the teaching situation. The teacher attributes that she raises include the following: intelligence, subject mastery, professional knowledge, experience, cultural background, socio-economic status, gender, marital status and attitude for teaching. She claims that none of these have been
shown with any certainty to impact significantly on the idea of successful teaching (whatever that may be). Verloop et al. (2001) caution that one should be aware of how research on teaching has changed during the past two decades, namely, from the focus of teacher behaviour and attributes towards considering teacher thinking and beliefs that underpin their behaviours, as well as a consideration of teachers’ subject content knowledge and the understanding thereof. Brophy (as cited in Summers et al., 1998, p. 154) identified a new tradition that started to emerge in the late 1980s in studies on teacher effectiveness where teachers’ subject content knowledge and teaching knowledge have been foregrounded as important features. Summers et al. (1998) identified, from previous research on effective teaching, a number of criteria used to assess when teaching has been effective, namely: peer judgment, teacher’s own perception, learner’s perceptions and differential performance of matched groups. Most of these criteria revolve around perceptions or beliefs.

Enochs and Riggs (1990) have long claimed that beliefs can be seen as the foundation on which behaviours are based and that several studies of teacher efficacy beliefs have suggested that it is these beliefs that may account for differences in the effectiveness of individual teachers. In the light of this shift in focus from investigating the purely behavioural characteristics and attributes of perceived effective teachers towards the more encompassing approach that includes knowledge, attitudes and beliefs, this study has as its focus teacher beliefs and the cognitive processes that pre-service teachers employ during their development into initial teachers. This approach gains credence when considering that these components of teacher knowledge (viz. subject content knowledge, beliefs and attitudes) have been shown to have a strong correlation to teachers’ classroom practice (Fishman et al., 2000). It should be noted that Fishman et al. (2000) see knowledge, beliefs and attitudes as
having seven subordinate ideas that include content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), beliefs about self-efficacy as a science teacher, attitudes towards technology and beliefs about system norms and contextual issues.

In the 1980’s Gibson and Dembo (1984) claimed that:

…teachers who believe student learning can be influenced by effective teaching (outcome expectancy beliefs) and who also have confidence in their own teaching abilities (self-efficacy beliefs) should persist longer, provide greater academic focus in the classroom, and exhibit different types of feedback than teachers who have lower expectations concerning their ability to influence student learning. (p. 570)

Garden (1997, p. 250) has succinctly summarised what could constitute effective or successful teaching in science as: “…effective teaching in science depends on teachers having adequate subject-matter knowledge, being well trained in how to maximise student’s learning of the subject, having a positive attitude to the subject,…” According to McDonnough and Matkins (2010), the process of training an effective primary science teacher implies much more than presenting innovative teaching strategies in a method course.

Fishman et al. (2000, p. 4) believe that changes in teachers’ knowledge, beliefs and attitudes can be effected by certain “cognitive mechanism” that they identified as “intelligibility”, “feasibility” and “fruitfulness”. They claim that activities that promote intelligibility could positively affect content knowledge (CK), pedagogical knowledge (PK) and/or pedagogical content knowledge (PCK). Feasibility is an interesting one for non-science specialist teachers, because feasibility includes the feeling that something is not possible, and this feeling of non-feasibility could originate from negative perceptions of self-efficacy and/or a lack of sufficient CK, PK and PCK. Fruitfulness can only be considered to be useful when considering outcomes of the project.
One way of looking at effective teachers is to view them in terms of whether their learners enjoyed science or not. In a case study of Year Six pupils in the United Kingdom, Turner, Ireson and Twidle (2010) identified four categories for why pupils in their study liked or disliked science. These pupils liked science because of the practical work, the teacher, their personal ability in the subject and because it matched their future career aspirations. On the other hand, they disliked science when there was no practical work, their teacher was not liked, and when they found the science boring as well as difficult. One of the main conclusions drawn by Turner, Ireson and Twidle (2010) was the need for teachers to be creative in their delivery of science. Included in the measures that they suggested could be used in order to prevent the alienation of pupils towards science were the use of role-play, stories, different and novel experience and toys.

2.3 Teacher knowledge

Researchers often refer to the concept of teacher knowledge when discussing teacher education and learning (Davis & Krajcik, 2005; Verloop et al., 2001). According to Davis and Krajcik (2005), to be effective, teachers need knowledge and control and understanding of the content or subject matter. In addition to developing pedagogic knowledge (i.e. teaching skills in a general sense) they also need to know the ‘how’ of teaching specific content – referred to as pedagogical content knowledge. All of these forms of knowledge need to be integrated into the body of knowledge that teachers possess. Finally “…teachers must participate in the discourse of teaching and, more generally, become enculturated into a range of teaching practices (Davis & Krajcik, 2005, p. 4).” In a series of seminal works, Shulman (1986a, 1986b, 1987) identified a number of aspects that codified a teacher’s knowledge base into seven domains of knowledge: content knowledge, general pedagogical knowledge,
curriculum knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, knowledge of the philosophical and historical aims of education, and pedagogical content knowledge. He acknowledges that the seven that he arrived at, are at best, a minimum number that could be expanded upon in the future.

According to Shulman (1987), an argument exists that supports the concept of a ‘knowledge base’ for teaching. He considers this knowledge base to be: “...- a codified or codifiable aggregation of knowledge, skill, understanding, and technology, of ethics and disposition, of collective responsibility - as well as a means for representing it and communicating it (Shulman, 1987, p. 4).”

While conceding that a definition of what can be considered to be ‘effective teaching’ is valuable, Shulman (1986a, 1986b, 1987) maintains that effective teaching is not the sole source of evidence on which to base a definition for a knowledge base of teaching. The problem, he suggests, is that the rhetoric surrounding a ‘knowledge base’ based on the concept of effective teaching, does not spell out its character, nor does it identify the sources of this knowledge (Shulman, 1987).

Barnett and Hodson (2001, p. 427), asked and attempted to answer the question: “In what kind of knowledge base is science teaching located?” What prompted this question was that their research indicated that successful science teachers did not all have the same characteristics, and yet no matter how their personalities may have differed, they were able to inspire children to learn science. On the other hand, their research also indicated that less successful science teachers were not successful despite the fact that they may have used the same, or similar teaching techniques and strategies, as the successful science teachers. This
could support Verloop et al.’s (2001) assertion that research into what makes a successful science teacher has shifted in focus over the past two decades from a set of attributes or characteristics to a more cognitive/beliefs based approach which includes the idea of self-efficacy.

3. SUBJECT CONTENT KNOWLEDGE (SCK)

A term that is often used in some of the literature on science education is ‘subject matter knowledge’ or ‘SMK’ (Nilsson, 2008; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). While different researchers may have differing views on a definition of SMK, this study accepts the description of SMK as adopted by Nilsson (2008, p. 1284) where she describes SMK as having aspects of concepts and constructs in a given field, but that it also includes, for science teaching, the concepts of scientific literacy, ideas of the scientific discourse and an understanding of the structure of the discipline of science. To complicate matters, some authors have used the term ‘subject content knowledge’ to include science curriculum resources that complement the substantive and syntactic content knowledge of the subject (Mulholland & Wallace, 2005). While SMK as described by Nilsson (2008) and SCK as described by Mulholland and Wallace (2005) may be useful in many contexts, these descriptions are not the focus of this study. This study is concerned with the first part of Nilsson’s description of SMK that deals with concepts and constructs only, and, which in this study, will be referred to as subject content knowledge (SCK). While the importance of subject matter knowledge is acknowledged, in this study a discussion of only the substantive and syntactical aspects of subject matter knowledge will be used.
3.1 SCK in general

Subject content knowledge is important for teachers because “…the teacher has special responsibilities in relation to content knowledge, serving as the primary source of student understanding of subject matter (Shulman, 1987, p. 9).” Preece, Postlewaite, Skinner and Skinner (2004, p. 818), are more brutal in their comment on the importance of subject content knowledge when they claim that in the act of teaching, a teacher’s subject knowledge is on “public display to the pupils.” A strong motivation in support of a thorough subject content knowledge base comes from a number of researchers over the years (Belfort & Guimarães, 2002; Grossman, Wilson, & Shulman, 1989; Leinhardt, Putnam, Stein, & Baxter, 1991). This can be summarised by Belfort and Guimarães (2004, p. 504) who claim that: “There are several indicators from research that a solid subject content knowledge may be essential for a successful teacher.”

Tambyah (2008, p. 47) foregrounds the difference between secondary and primary teachers with respect to subject matter knowledge. The secondary teacher teaches the discipline of the subject, that is, they need to be steeped in subject content knowledge and, while it is important that primary teachers also have this to some extent, and for science this would imply an understanding of the nature of science and scientific literacy, these primary teachers end up teaching ‘topics’ associated with science.

Historically learners in South African schools have had limited opportunities to formally develop their understanding of science. Many were taught science by underqualified teachers and teachers whose understanding of science was limited (Rollnick et al., 2008). Rollnick et al. (2008, p. 1366) claim that for this reason “It is not difficult to see why SMK
draws serious attention in any investigation into the nature of PCK in the South African context.” This issue is not unique to South Africa as numerous international studies have found that pre-service teaching students often do not have a robust enough understanding of concepts that they are required to teach and that their subject content knowledge is often fragmented and disjointed, often as a consequence of ineffective teaching while they were at school (Loughran, Mulhall, & Berry, 2008).

According to Nilsson (2008), for student teachers to challenge learners’ concepts (or alternative conceptions) they need to have a robust understanding of the subject content. Shulman (as cited in an interview transcript in Berry, Loughran, & van Driel, 2008, p. 1273) referred to primary school teachers as being “…sinfully under-prepared for the content they teach,…a teacher who does not both understand and have a real affection for a subject will never be able to teach it well…”.

While it is agreed that a thorough knowledge and understanding of subject content knowledge is essential for the successful teaching of science, Khwaja (2006) suggests that the picture of what makes for effective teaching is complex and does not rest only on the level of subject content knowledge of the teacher. In fact Khwaja (2006, p. 9) says “Its’ (teacher knowledge) role is, to say the least, more uncertain than suggested by the official reports.” Some of the complexity noted above is generated by, in addition to subject content knowledge, the teachers’ attitude towards the subject, the ability to select appropriate learning experiences for the learners, teaching style et cetera, in other words, subject content knowledge plus pedagogical content knowledge, plus confidence/attitude, plus pedagogical knowledge are all needed to be effective teachers (Khwaja, 2006). Khwaja (2006) suggests
that these factors all interact in a complex fashion to lead towards effective or less effective teaching of science.

3.2 Subject content and science teaching

According to Easley (1990, p. 61), many teachers (in the United States) are “...anxious about science and quite unintentionally transfer their anxiety to their pupils either by science avoidance or by authoritarian presentations of science terminology and generalisation.” This has serious consequences for science teaching. One possible origin of this anxiety can be found in teachers’ subject content knowledge. Low levels of confidence in teaching science characterise the practice of poorly or underqualified teachers. Teachers who do not have an adequate command of content tend to adhere to a more transmission mode of teaching (Carr, Barker, Bell, Biddulph, Jones, Kirkwood et al., 1994; Shulman, 1987). Additional support for this common assumption comes, not from the observation of underqualified teachers, but from studies that illustrate increased confidence with increased knowledge and understanding of science (Ritchie, 1994). A more serious consequence of the lack of content knowledge is highlighted by Brophy and Good (as cited in de Freiter, Vonk, & van den Akker, 1995, p. 30) who reports that “...teachers with limited backgrounds in certain subject matter areas may teach incorrect content or fail to recognise their students’ distorted understandings.” This is reason enough to concentrate on content knowledge. It is clear that content knowledge needs to be given a priority to ensure that attempts at influencing the other areas of teachers’ knowledge base stand a chance of success.

Borko (2004, p. 6) encapsulates the role of subject content knowledge when she claims that “A key reason for deepening teachers’ knowledge of subject matter … is to improve
classroom teaching.” Alonzo’s (2002) research examined teachers’ content knowledge from two perspectives: content knowledge and the use of content knowledge in instruction. Alonzo’s (2002) expectations were that the students were not expected to directly teach the content that they had learnt in the course, but that they were to use their experiences to guide the activities that they were doing in their own classrooms with their own learners.

Appleton and Kindt (2002) have suggested that many of the difficulties experienced by primary school teachers are caused primarily because of their insufficient science content knowledge. They do, however, concede that in addition to this lacuna in subject content knowledge teachers difficulties can also be found in other areas, such as, lack of resources, lack of experience, and alternative conceptions.

In a review of the literature on alternative frameworks (misconceptions) Trumper, Raviolo and Shnersch (2000, p. 697) came to the conclusion that: “One of the most interesting recent results of research in cognitive science and science education is the realisation that students and teachers hold strong misconceptions or alternative frameworks about many different science concepts.”

Subject content knowledge has been found to be of great concern to the non-expert primary teacher (Summers et al., 1998). Newton and Newton (2001, p. 369), claim that most elementary school teachers end up having to teach subjects that they were not good at in their own education – causing the concomitant lack of confidence in these learning areas. The views of primary school teachers were found to be in contradiction to those held by ‘expert’ secondary school teachers, who in a study by Illes (2002), hardly acknowledge that their own
subject content knowledge played any part in their efforts to cause conceptual change in their learners.

Harlen (1999) claimed, in an extensive report on a review of the research on the effective teaching of science, that: “There can be little room for doubt that in order to be effective in all aspects of teaching science, a sound understanding of the subject is necessary.” She continued by adding a condition; that this knowledge has to be integrated into the other knowledge that the science teacher may have.

A recent study conducted amongst beginner South African teachers and their immediate managers (subject heads and principals) found that most of these managers were satisfied with beginner teachers’ subject content knowledge, but that these teachers’ pedagogical content knowledge was an area of concern (Arends & Phurutse, 2009, p. x). These manager’s claims about SCK are disputed by Webb et al. (as cited in Taylor & Vinjevold, 1999), who found that most teachers in their study in the Eastern Cape did not score any better on electricity tests than their learners.

During an extensive literature review, McDonnough and Matkins (2010, p. 13), found that “The quality and quantity of science taught to elementary school children is strongly influenced by their teachers’ confidence, attitudes, and knowledge level.” As Ryan (1995, p. 11) succinctly claims, “Content knowledge improves the chances of teaching very good lessons, but does not eliminate poor lessons.” For this reason, to concentrate solely on content knowledge, would defeat the object of improving teaching effectiveness. Bleicher and Lindgren (2005, p. 206) found that “…increasing the quantity of science content courses that pre-service elementary teachers are required to take may not be sufficient to overcome their
reluctance to teach science if some of their learning does not take place in a constructivist environment.”

The crucial link, or defining of the relationship between SCK and PCK could be the concept of misconceptions/alternative or pre-scientific conceptions as proposed by Good (1991) and van Dijk and Kattmann (2007). Understanding misconceptions could be construed as content knowledge, while the origins and ways to remediate them could be categorised as PCK. Van Dijk and Kattmann, (2007) prefer the term pre-scientific conception to alternative or misconceptions as they believe that this term best describes the understanding on continuum of scientific understanding. Numerous researchers have stressed the idea that an understanding and thorough knowledge of subject matter, is a prerequisite for the development of PCK (Van Driel et al., 2002; Van Driel, Verloop, & De Vos, 1998). These researchers also make the point that PCK develops in the actual teaching practice of teachers which van Dijk and Kattmann (2007) suggest implies that beginning teachers usually have very little, if any, PCK.

Pre-service and in-service teachers often cite a need to improve their content knowledge as a reason for attending university/or college. McDermott (2006) found that when science content is taught in a traditional university-type course, even when there is a large hands-on component, efforts at developing robust understanding are largely unsuccessful. The term ‘failure of further learning’ as conceptualised by Preece et al., (2004, p. 806) means the strong tendency of learners to “continue to recall schema formed when information was first encountered, including errors and omissions, despite additional presentations of the material being learnt.” This ‘failure of further learning’ effect means that different strategies from the traditional ones should be attempted to improve teachers’ content knowledge.
Morrell and Carroll (2003) found that teacher training that focused only on subject content matter was not sufficient to produce an increase in science teaching self-efficacy. They did, however, albeit cautiously, suggest that teachers with relatively low science teaching self-efficacy could find that their self-efficacy was improved by science content classes. On the other hand, Bleicher and Lindgren (2002) claim that conceptual understanding is an essential foundation that must be in place before one can develop teaching confidence. They also link teaching confidence directly to self-efficacy. Enochs and Riggs (1990) reported that teachers whose content knowledge was weak also tended to have a significantly lower self-efficacy than teachers with strong content backgrounds.

According to their definition of self-efficacy, Bleicher and Lindgren (2002) suggest content knowledge and the development of conceptual understanding are crucial and foundational to the development of teaching confidence. They also suggest that conceptual understanding is a robust understanding that is durable and long lasting. Staver (2007, p. 11) claims that teachers require a “deep” understanding of science and that “Deep understanding in science goes well beyond memorisation of isolated facts and concepts. Deep scientific understanding includes a coherent system of facts, concepts, scientific inquiry, and strong problem-solving ability.”

3.3 Energy

Energy is a concept that is included in most school science curricula, for example South Africa (DoE, 2002; DoE, 2003), Australia (Department of Education and Training Western Australia, 2007), New Zealand (Ministry of Education, 1993), England (Qualifications and Curriculum Authority, 2007), United States of America (Centre for Science, Mathematics and
Although the list is not exhaustive, energy is an important concept in science and it is almost certain that it would be included in the curriculum of most countries. In fact, 30 years ago, Watts (1983, p. 213) claimed that “It would certainly be difficult to find any course in science where energy does not play some part.” In South Africa, energy in the General Education and Training (GET) Natural Sciences curriculum can be found in the core knowledge area *Energy and Change* where the focus is on “…how energy is transferred in physical and biological systems and on the consequences that human needs and wants have for energy resources (DoE, 2002, p. 6).” The centrality of energy in the curriculum, coupled with its complexity, makes the energy concept a crucial area of teacher understanding.

### 3.3.1 Energy concept issues

As noted earlier, the concept of energy has been identified as problematic, because of its abstract nature to both teachers and learners. According to Faiq (2008), one of the most important challenges is translating abstract concepts into understandable ideas, for example energy cannot be seen and only the effects of the energy transfer are noticeable, making energy an extremely abstract construct that is difficult for learners to understand.

While numerous researchers have emphasised the importance of the concept of energy in all branches of science, they have also stressed the complexity of the scientific concept of energy itself (Millar, 2005; Summers & Kruger, 1992; Yuenyong & Yuenyong, 2007). Boyes and Stanisstreet (1990, p. 513) succinctly state what other researchers are saying: “Energy, one of the most important themes in science education, is one of the most difficult.” The reason for this is twofold, namely that energy, in its scientific context, is an abstract,
mathematical idea, and secondly, there is often a mismatch between the everyday and the scientific understandings of the word energy (Millar, 2005, p. 3). It should be noted, however, that it is not surprising that the teaching of the concept of energy might appear daunting for primary school science teachers, who, apart from limited school science experience, tend to have little or no in-depth post-school experience of the formal disciplines of science. On the other hand, teachers with a background in physics, chemistry, or life sciences often believe that they understand the concept of energy well enough and thus should find it relatively easy to teach. Their belief may, however, be ill founded because of the high degree of abstractness of the concept and the mismatch between the everyday understanding of the topic as opposed to the scientific understanding, which is often counterintuitive (Department for Children, Schools and Families - DCSF, 2003, 2009). The teaching of difficult concepts such as energy is always going to be influenced by the preconceptions that learners bring to the class, and the problems surrounding the teaching of conceptual ideas such as energy, are compounded when they are being ‘taught’ by teachers who themselves hold ideas that are at variance with the accepted scientific ideas (Trumper et al., 2000, p. 700).

The DCSF (2009), in their study guide dealing with strengthening the teaching and learning of energy to facilitate learners’ thinking about energy, identified three threads of progression. These threads of progression appear to resonate with what is required in the South African Natural Sciences curriculum statement. The first thread concerns the idea of energy transfers being used to explain observable phenomena. This thread appropriately links up with the use of simple everyday toys that are used to teach energy transfer. Their second thread deals with the measurement of energy to illustrate the concept of energy conservation. While the use of numerical values might not be the focus of the primary school energy
curriculum, the concept of energy conservation is crucial for a thorough understanding of energy. The final thread concerns the management of energy resources and this is closely aligned with the human needs and wants aspect that is included in the South African document (DCSF, 2009, p. 3; DoE, 2002).

The concept of energy is fraught with possible misconceptions/alternative conceptions that could be held by learners and teachers alike. Over the years various researchers have compiled lists of possible misconceptions associated with energy (Gilbert & Watts, 1983; Watts, 1983). The three main non-scientific beliefs held by students with respect to energy were identified by Gilbert and Watts (1983) and can be summarised as (i) energy has to do with living and moving things (ii) energy makes things work and (iii) and energy changes from one form to another. Trumper (1997, p. 158) and Trumper et al. (2000, p. 699) compiled a comprehensive list of the most popular and persistent misconceptions with respect to the concept of energy:

- **Anthropocentric and anthropomorphic:** energy is associated with human beings, or as Watts (1983) originally called it, ‘human-centred’ energy. In this framework the energy is associated with human beings or the learners may treat objects as if they have human attributes. This view or framework links energy to living things.

- ** Depository:** Watts, (1983) says that in this framework or model learners see some objects as having energy (and being rechargeable) while other objects simply expend it. In this model there are also neutral objects whose actions are normal. Energy is a casual agent in this model. The energy causes motion or actions.
- **Ingredient**: energy is a dormant ingredient within objects, released by a trigger. Here energy is not seen as the cause agent.

- **Activity**: energy is an obvious activity. Many learners will see activity (movement) as the only means of identifying energy. The problem, suggests Watts (1983), is that the activity itself is seen as ‘energy’ or that this energy is often equated with a verb.

- **Product**: According to Watts (1983) energy is seen as a by-product of a situation, that is, it is not an ingredient or a process.

- **Functional**: energy is seen as a very general kind of fuel associated with making life comfortable.

- **Flow-transfer**: energy is seen as a type of ‘fluid’ transferred in certain processes.

- **Identity**: failure to differentiate between energy and other physical terms for example force (Watts & Gilbert, 1983; Duit, 1984).

- **Conservation**: energy ‘lost’ (accounting model).

Trumper (1997, p. 157 & 169), in his study of pre-service elementary school teachers ideas of the energy concept, found that they held the following ideas concerning the energy concept:

- energy is a concrete entity

- few accepted the idea of energy conservation

- mostly they did not accept the idea of energy degradation
- many were ambiguous in their recognition of different types of energy
- widespread confusion of the concepts of energy and force

In his doctoral thesis, Illes (2002) asked three important questions of lower secondary school teachers:

- What do pupils really think energy is?
- What do teachers really think energy is?
- What is the best way to model energy for science teaching, that is: Do pupils acquire the concept of energy best through a ‘transformation’ or a ‘transfer’ approach? (p. 4)

As noted earlier in the PCK section, there are two models that could be referred to in the teaching of the energy concept, namely the transfer model and the transform model (Millar, 2005; DCSF, 2009). While the transfer model tends to be the most accepted one at present in many school curricula, the transform model still appears, usually alongside the transfer model, in other curricula (Illes, 2002; Herrmann-Abell & DeBoer, 2009).

In his study of lower secondary school teachers’ perspectives of the energy concept, Illes (2002) found that teachers explicitly fore-grounded ‘transforming energy’ despite curriculum recommendations to focus on ‘energy transfer’. They did not explicitly focus on energy dissipation and often muddled scientific language with everyday language when dealing with energy conservation. This last finding supports what Solomon (1983) found when she investigated the teaching of the energy concept at schools. She claimed that many
primary school teachers used the energy concept (mainly in its ‘everyday’ usage) on a regular basis.

The transform idea is often seen as energy changing from one form to another or “…it is a view that sees energy travelling through machines and wires and changing its appearance at different points – that is what (Duit, 1987) calls a quasi-material conception (Trumper, 1997, p. 158).” In the 1980s and 1990s many texts focused on two aspects of energy, namely, the various forms of energy and the ways in which this energy can be transformed and the law of conservation of energy. This approach was neatly summarised by Duit and Haeussler (1994) and called the ‘energy quadriga’:

- Energy transformation
- Energy transport
- Energy conservation
- Energy degradation

The use of specific terminology is often a clear indicator of the preferred model of the authors of academic articles and school textbooks (DCSF, 2009). Reference to many different forms or types of energy is usually a clear indicator of a preference for the transformation model. For example, Herrmann-Abell and DeBoer (2009, p. 1) refer to some of the key ideas in the energy concept as being “…motion energy, thermal energy, gravitational energy and elastic energy” and “…any object that is moving has motion energy (kinetic energy)” and “…the motion energy of an object that is not moving is zero” (Herrmann-Abell & DeBoer, 2009, p. 3). They are referring to many specific different forms or types of energy. It is the extensive use of this terminology that illustrates a preference for the transformation model by
many teachers. It is noteworthy that it is the transfer, rather than the transform, model that is promoted in the South African curriculum.

3.3.2 The energy concept in primary school curricula

The energy concept can be found in the South African General Education and Training (GET) Curriculum Statements in the section on Energy and Change. This section of the curriculum “…focuses on how energy is transferred in physical and biological systems…” (DoE, 2002, p. 6).” The following phrases, extracted from the curriculum statements, illustrate how energy is viewed in this phase of schooling in the South African.

- “…save energy by switching lights off…(p. 41)”
- “…energy transfers by conduction and convection…(p. 45)”
- “…describes how the heart, lungs and stomach work together to provide a human with energy…(p. 53)”
- “…identifies which processes of energy transfer were involved as a hot car engine cooled down…(p. 56)”
- “…green plants use energy from the sun…(p. 64)”
- “…feel tired and lack energy…(p. 66)”
- “…wasted energy…(p. 68)”
- “…lose energy as heat…(p. 73)”

The energy concept is found in many primary school curricula throughout the world, for example, Australia uses terms such as: “Objects can be grouped as sources or receivers of energy”; “Energy sources can be classified as renewable and non-renewable”; “Ways to use energy more efficiently”; “…exploring ways to save energy”; “Energy can occur in different
forms”; “Energy can be changed from one form to another (transformed)” and “Energy can be transferred” (Department of Education and Training: Western Australia, 2007, p. 1-3), while New Zealand uses similar terms: “…scientific concept of energy and investigate ways in which energy changes can be put to use”; “…identify the energy transformations occurring”; “…understanding of the applications of energy and its transfer and transformation…” (Ministry of Education, 1993, p. 70-82). The English (Qualifications and Curriculum Authority, 2007, p. 210-217) and some parts of the United States of America (Centre for Science, Mathematics, and Engineering Education, 1996, p. 110-112) curricula address energy as follows: “…renewable energy resources…”; “…energy can be transferred usefully…”; “…transfer of energy by light, sound or electricity”; “…transfer of energy…”; “Conservation of energy…”; “One form of energy is converted to another form…”

According Straver (2007), a deep understanding in science goes well beyond the memorization of isolated facts and concepts. Deep scientific understanding includes a coherent system of facts, concepts, scientific inquiry, and strong problem-solving ability. Learners need to be able to solve-problems, mentally, in terms of trying to conceptualise these abstract concepts in science, that is, energy transfers. Straver continues by saying that the use of concrete, manipulative materials and familiar events help students to directly experience scientific phenomena and encourage their active construction of abstract concepts (Straver, 2007). By using educative curriculum materials such as toys in science, understandings of abstract concepts may be made more accessible.
4. PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

Abel (2008, p. 1410) has been bold enough to suggest that pedagogical content knowledge (PCK) is approaching the status of what Kuhn (1962) might describe as a paradigm (of teacher knowledge research) because it “…is shared among the research community and guides our thinking about teacher learning.” A number of researchers, however, caution that despite its prominence in teacher education there is no universally accepted definition or conceptualisation of the idea of PCK (Mulholland & Wallace, 2005; Nilsson, 2008; Smith, 1999; Van Dijk, 2009).

4.1 PCK in general

In 1987, Shulman, in his seminal work – Knowledge and teaching: Foundations of the new reform - started to redefine what constituted the knowledge base for teachers. One of the consequences for this was that teacher educators started to re-evaluate their views on the knowledge base for teachers and this impacted on how they viewed the training of teachers (Bullough Jr, 2001). The driving force in the USA was the political goal of professionalising teaching and Shulman (1986a, 1987) attempted to address this, by amongst other concepts, introducing the concept of Pedagogical Content Knowledge (PCK) (Van Dijk & Kattmann, 2007).

According to Veal and MaKinster (1999), content knowledge was initially viewed as the focus in teacher training but subsequently the focus shifted more towards pedagogy, with content often taking a back seat. It was left to Shulman to combine these two knowledge bases into PCK. It should be noted that PCK is seen as a radical shift away from the idea that pedagogy is a content-free skill (Rollnick et al., 2008). Tambyah (2008, p. 44), notes that
“The capacity to conceptualise and teach subject matter by making it accessible to learners is critical to teachers’ work” and Van Dijk and Kattmann (2007, p. 887) have described PCK as where “…curriculum and instruction intersect, that is, mainly at the classroom level.”

Alonzo (2002) sees pedagogical knowledge as the bridge between content knowledge and pedagogy. Content knowledge and general pedagogical knowledge, the first couple of Shulman’s sources of the teachers’ knowledge base, do not, according to Shulman (1987, p. 15), distinguish a teacher from non-teaching peers, or the veteran from the novice. de Freiter et al. (1995, p. 67) claim that it is “something else” that gives rise to the distinction. This “something else” could be referred to as pedagogical content knowledge. De Freiter et al. (1995, p. 65) have interpreted Shulman’s concept of pedagogical content knowledge as, “…how a teacher’s understanding of subject matter is transformed to make it ‘teachable’.” PCK falls into the general category that Shulman (1987, p. 11) refers to as “the wisdom of practice”. In a review of the literature surrounding PCK over a period of 20 years, Abel (2008, p. 1407), identified four important characteristics of PCK:

- PCK includes discrete categories of knowledge that are applied synergistically to problems of practice
- PCK is dynamic, not static
- Content is central to PCK
- PCK involves the transformation of other types of knowledge

According to Bullough (2001, p. 656), PCK is “Grounded in the wisdom of practice,…” while Shulman (1987, p. 13) sees it as teachers “…becoming able to elucidate subject matter in new ways, reorganise and partition it, clothe it in activities and emotions, in metaphor and
exercises, and in examples and demonstrations, so that it can be grasped by students.” Verloop et al. (2001) see PCK as a specific form of teacher knowledge. It is ‘specific’ in that it is different from content knowledge “…because of the focus on communication between the teacher and student,” and its direct relationship to subject matter differentiates it from general pedagogical knowledge (Verloop et al., 2001, p. 449). On the other hand, Shulman (1986a, p. 8) claims that PCK could be construed as the “…amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding.” Van Dijk and Kattmann (2007) support this by proposing that there is general agreement amongst educational researchers that PCK is a unique knowledge domain.

Van Driel et al. (2002) summarise Shulman’s (1986, 1987) view that pedagogical content knowledge (PCK) is a form of practical knowledge that is used by teachers to guide their actions in highly contextualized classrooms. It entails, amongst other things, knowledge of common conceptions, misconceptions, and difficulties that learners encounter when learning particular content as well as a knowledge of specific teaching strategies, analogies and metaphors that can be used to address particular learners’ learning needs in particular classroom situations. Rollnick et al. (2008, p. 1367), have succinctly summarised all the different views and ideas surrounding PCK by describing it as “…how teachers teach their subject by accessing what they know about the subject, the learners they are teaching, the curriculum with which they are working, and what they believe counts as good teaching in their context.”

Abel (2008, p. 1406), reflected on the impact that Shulman’s framework for teachers’ knowledge had on her teaching: “Shulman’s teacher knowledge framework helped me understand my students, allowed me to identify appropriate learning goals for them, and
challenged me to generate viable instructional strategies in my method courses.” This sums up the effect of Shulman’s ideas and in particular his idea of PCK.

Interestingly Barnett and Hodson (2001) identified four categories of PCK: firstly, knowledge of learners’ existing knowledge (the constructivist perspective), secondly, knowledge of effective teaching and learning strategies, and they closely linked to this the third category, different ways of presenting the subject matter. In the fourth category they introduced the term ‘curricular saliency’, that is what enables “…a good teacher to judge matters such as depth of treatment and contextualisation (p. 433).” Appleton (2003) suggests that only including more content knowledge for pre-service will not necessarily result in more or better PCK.

A number of researchers (Halim & Meerah, 2002; Van Driel et al., 1998) have used Shulman’s (1986a, 1986b, 1987) two key elements of PCK, namely: an understanding of learners’ specific learning difficulties in specific content/contexts/topics, thus making it contextually bound, and secondly, an understanding of how to help learners to overcome these learning/understanding difficulties. Van Dijk and Kattmann (2007, p. 890) have suggested a third essential element which they refer to as “subject content knowledge for teaching”, an idea that they have adopted from Ball and Bass (2000).

Van Driel, et al. (2002) suggest that there is a general consensus that PCK is developed through an interactive process which finds it roots in classroom practice and therefore it is not sufficient to merely instruct teachers on what PCK is, or possible to ‘give’ them all the PCK that they may need to teach. While it is accepted that PCK is developed or improved with teaching experience (Bullough Jr, 2001; Davis et al., 2008) teachers can be instructed in PCK during
their formative pre-service training, that is, they can develop what Smithey (2008) refers to as ‘PCK-Readiness.’

Two key elements of PCK have been identified by Van Driel et al. (1998) on this issue, namely: teachers’ knowledge of content specific learning difficulties (misconceptions) linked to specific content and, secondly, teachers’ knowledge of specific teaching strategies with respect to the teaching (remediation, fixing, changing) of these misconceptions. Many researchers (Aydin, Demirdögen, Tarkin, & Uzuntiryaki, 2010; Van Dijk, 2009) are in agreement with Van Driel et al. on this issue.

Schmelzing, Wuesten, Sandman and Neuhaus (2010, p. 72) speak of ‘PCK-in-action’, that is, the implicit procedural knowledge and skills involved in the ‘knowing how…’, and the ‘knowing that…’ which is the reflective, explicit and declarative components of PCK. According to Aydin et al. (2010), practicing teachers develop their PCK during their teaching, while pre-service teachers base much of their initial PCK on their experiences during their educational life as student and during teaching practice. While much research on PCK has focused on the practical use or identification of PCK in the classroom, this so-called ‘process-product’ paradigm as suggested by Abel (2008) has now been supplemented by an approach that suggests that the classroom is not the only place to identify and possibly measure PCK, in that it can also be identified by investigation of teachers’ characteristics (Schmelzing et al., 2010).

4.2 PCK and science

The notion of pedagogical content knowledge (Shulman 1986b, 1987) is increasingly used in science education literature, and its origins, status and usefulness have been subjected
to critical scrutiny and question (Summers et al., 1998). The suitability of the term ‘pedagogical content knowledge’ has been questioned by some researchers. Summers et al. (1998) prefer the term ‘subject-specific teaching knowledge’, with an emphasis on all of the ways in which a teacher helps children acquire understanding of a topic. Davis et al. (2008) also claim that PCK is subject and even topic specific. Summers et al. (1998, p. 155) claim that PCK suggests that one can “...select from content and make it more teachable.” They propose that while this may be true, it does not include the whole picture of what is required in helping children to learn. Summers et al. claim that:

...teaching a student with major misconceptions is not simply a matter of using aspects of one’s own content knowledge - it involves identifying, analysing and understanding that student’s knowledge (misconceptions) as well. This clearly takes one beyond one’s own content knowledge. (p.169)

There is now a growing consensus among those concerned with primary science teacher education that “…developing teachers’ subject knowledge is not of itself enough to improve pupils’ learning, a key issue is how teachers can make this knowledge accessible to pupils (Summers et al., 1998, p. 154).” These statements suggest that a closer look is required into notions of PCK (both generally and specifically), and issues of PCK in terms of energy, which is the focus of this study.

It is PCK that separates the science teacher from the scientist (Veal & MaKinster, 1999). This study uses the term and concept ‘pedagogical content knowledge’ as a form of ‘craft’ knowledge, used by teachers in particular classroom situations.

McDonnough and Matkins (2010, p. 14), suggest that “A teacher’s PCK is in a constant state of flux as she progresses along the continuum from pre-service experience into practice
and beyond.” Nilsson (2008, p. 1284) has captured the essence of what many researchers have stressed about PCK in that they all claim that “…the development of PCK is determined by the content to be taught, the context in which the content is taught, and the way the teacher reflects on his/her teaching experience.” In the light of this one should consider that when one is attempting to develop pre-service students PCK, then it should be focused within a context and encompass particular content, which is the case in science.

There are many different ways in which the simplified scientific ideas that are often presented during teacher training are interpreted and internalised by teachers (Summers et al., 1998). For some teachers these simplified ideas quite rightly constitute teaching knowledge, which they understand is derived and extracted from a much deeper understanding of the topic. However, for many others this knowledge constitutes the sum total of their understanding of the subject (Summers et al., 1998). Verloop et al., (2001, p. 454) note that “…knowledge and beliefs function as filters for interpreting new experiences…” they further claim that it makes sense to consider these filters or lenses when preparing to initiate innovative materials/ideas/concepts. It is this lack of deeper understanding that has been a matter of concern to teacher educators in South Africa (Taylor & Vinjevold, 1999) and which results in a lacunae in science teachers’ PCK; a serious shortcoming in their teaching arsenal. This is illustrated in a study by Meiring et al., (2004) that showed a poor understanding by teachers of electricity-based questions that tested a ‘robust’ understanding of a concept, that is, the ability to transfer knowledge into unfamiliar contexts.
4.3 PCK and the teaching of energy

Veal and MaKinster (1999) developed what they referred to as the General Taxonomy of PCK. The taxonomy ‘drilled’ downwards from General PCK to Domain Specific PCK to Topic Specific PCK. This research focuses on one topic, namely energy in the topic specific PCK area of the taxonomy.

According to Millar (2005, p. 3) “It is not an overstatement to say that the teaching of energy is a mess.” In fact, Trumper (1997) in his 1990 and 1993 study of pupils and his 1997 study of pre-service primary school teachers, found that both groups held similar associations with respect to energy. The Department for Children, Schools and Families (DCSF): Introductory Section (2009, p. 10) introduced the idea of “learning demand” that “…focuses on the differences between everyday ways of talking and thinking about phenomena and the scientific ways of doing so.” The claim is made that the energy concept has one of the highest “learning demands” of all school science topics.

The abstractness of the energy concept is always problematic, and as Millar (2005, p. 4) suggests “It (energy) does not help us understand how or why they (things) happen.” Millar (2005, p. 5) summarises one of the main issues that impact on the teaching of energy as “We all become used to talking about energy in ways that are not completely scientific – and, as a result, can come to think of energy in ways that are not in line with the scientific idea. This then poses problems for how we teach energy,…” It is as a result of these issues that the concept of a topic specific PCK, in this case, energy, needs to be addressed in pre-service science teacher training.
4.3.1 Transfer or transform?

Two models are commonly used for the teaching of energy, namely the energy transfer model and the energy transformation model (DCSF, 2003 and 2009; Millar, 2005). While both models have been, and are still being used in schools, the preferred model in the South African context is the transfer model (DoE, 2002). The modules presented to students in this study adopt the contemporary model of energy transfer and, while the transformation model is considered at times (particularly from the perspective of PCK), it is the transfer model that is fore grounded.

The particular model being used by a specific teacher is easily identified by listening to the language used. A teacher using the energy transfer model, apart from the easily identified term ‘transfer’, will talk about the energy being transferred ‘from’ something ‘to’ something ‘by’ something (e.g. Energy from the sun is transferred to the leaf cells by light). A teacher using the energy transformation model will identify different types of energy (e.g. Light energy from the Sun is changed into chemical energy in the leaf).

According to Millar (2005, p. 7), this second approach, the transformational model, has been the subject of much debate. Concerns have been raised that this approach makes energy appear to be something (stuff) that can be stored in different places and take on different forms. The transform model is a particular view that could be seen as envisaging “…energy as travelling through machines and wires and changing appearance at different points - … (Millar, 1995, p. 6).” The criticism is that learners simply learn a set of ‘energy’ labels that add little to their understanding. Another criticism that Millar (2005, p. 8) highlights is that this approach focuses attention in the wrong place, because when dealing with the concept of
energy the focus should be on the processes involved, whereas the ‘forms of energy’ approach causes the focus to be on the ‘form’ of energy at a particular place.

4.3.2 Conservation of energy

Conservation of energy is an aspect of the energy concept that often creates confusion for teachers. Two useful methods have been suggested for teaching this idea. The first model is the accounting system model where money or wealth is being transferred (preferably using online banking – where no physical cash is involved). The DCSF, (2009, p.1) proposes this banking model because “Energy does not make things happen – it merely makes things possible. In the same way, money does not actually cause things to happen, it merely makes them possible.” This model has two advantages in that it reinforces the scientifically correct idea that energy is not ‘stuff’ and therefore does not actually ‘flow’, while at the same time enabling the idea that energy can be transferred.

The second model uses Sankey diagrams and, while this is essentially an accounting model, it does approach it from a different perspective (see Figure 2).

![Sankey energy diagram](image)

*Figure 2. Sankey energy diagram.*
With reference to Figure 2 the thickness of the arrows shows how much energy is involved, while the length of the arrows is irrelevant. Useful energy transfers are represented from left to right and wasteful energy transfers are represented by downward arrows.

The DCSF (2009, p. 9) claim that in reality teachers actually hold, what they claim to be relatively ‘few misconceptions’, about energy. They suggest that the main misconceptions held are as follows:

- energy is used up or created
- energy is a kind of stuff
- fuels are energy
- heat and temperature are the same thing
- energy makes things happen. (p. 9)

Although they may appear few in number, they are significant misconceptions.

Illes (2002), in an extensive study of how teachers approached the teaching of the energy concept, arrived at a number of suggestions that can be construed as PCK for the energy concept. Firstly, he found that while teachers stressed the importance of terminology when they taught science in general, when it came to dealing with the energy concept they spontaneously mixed scientific and everyday uses of terms. Illes identified the following issues:

- energy dissipation (energy was said to be ‘lost’)
- energy conservation (energy was said to be ‘produced’ or ‘made’)
- energy efficiency (‘quick and convenient’ meant ‘energy efficient’)
- the storage of energy (energy resides in objects)
- the nature of energy (energy causes events) (p. 13)

Illes (2002) identified six clear recommendations for the conceptualisation and teaching of energy: Firstly, energy comprises distinct superordinate concepts (Duit, 1984; Duit & Haeussler, 1994), secondly, energy is transferred not transformed (Duit, 1984; Ellse, 1988; Chrisholm, 1992), thirdly, the number of energy forms are limited (Chrisholm, 1992; Ellse, 1988), fourthly, energy dissipation is important per se, and as a means to introduce the topic (Duit, 1984; Ogborn, 1986), fifthly, energy is an abstract concept (Duit & Haeussler, 1994; Osborne & Freeman, 1989) and lastly, stores of energy are le-localised into food/fuel-oxygen systems (Ogborn, 1986).

The commonly used approach of emphasising the energy concept by using the concept of work was found to be, at best problematic, and at worst creating the wrong understanding of energy. Illes (2002) supported recommendations that de-emphasise the ‘work’ concept (Duit & Haeussler, 1994; Ogborn, 1986; Warren & Richmond, 1983). He also suggested that teachers should abandon the term ‘heat’ as noun (Warren, 1976) and to only use it as a verb (Ellse, 1988) and in this way retain a technical definition of heat as energy transfer (Mak & Young, 1987).

To summarise, one can use the ideas of Millar (2005) and Yuenyong & Yuenyong (2007) who suggest that it could be expected of a primary school science teacher to have a reasonable understanding of the following ideas with respect to energy:

- Scientific idea of energy: Abstractness.
• Scientific idea of energy: Conservation of energy.

• Scientific idea of energy: Integrating framework that energy gives us.

• Scientific idea of energy: Energy is transferred.

• Everyday idea of energy: Consumption and degradation.

• Everyday idea of energy: Fuels and sources.

4.3.3 Curriculum guidance with the teaching of energy

A source of guidance when it comes to teaching would naturally be the curriculum. This guidance may be sought in curriculum statements, syllabi, teaching guidelines, schemes of work and to some extent textbooks or study guides. In the United Kingdom (UK) the idea of energy is formally introduced in Year Seven where it is suggested that it be taught explicitly using the energy transfer model with the focus on energy resources (DCSF, 2009, p. 12). A similar approach is adopted in South Africa where the only difference being that energy is first introduced in Grade Four, albeit at a basic level (DoE, 2002).

5. TEACHER SELF-EFFICACY BELIEFS

The concept of self-efficacy originated between 40 and 50 years ago, but has in the past two decades been particularly influential in the training of pre-service teachers (El-Deghaidy, 2006). The importance of teacher efficacy for teaching and learning is illustrated by Gencer and Cakiroglu (2007, p. 664) who claim that “Teacher efficacy has emerged as one of the few teacher characteristics that consistently relates to teaching and learning over the past 25 years.”
Bleicher (2004) provides a compelling reason for the study of self-efficacy by teacher educators. He states that:

The aim of studies on self-efficacy is to better inform teacher educators. This research-based information enables them to provide an opportunity for pre-service elementary teachers to develop increased self-efficacy and outcome expectancy beliefs. Upon this foundation, the goal is to build capacity for pre-service elementary teachers to translate increased pre-service self-efficacy and outcome expectancy beliefs into increased teaching confidence in their future careers. (p. 389)

Bandura (1994, p. 71) defines self-efficacy as “Peoples’ beliefs about their capabilities to produce results,” while teacher self-efficacy is defined by Tschannen-Moran and Woolfolk-Hoy (2001, p. 783) as “…a teacher’s judgment of his or her capabilities to bring about desired outcomes of student engagement and learning, even among those students who may be difficult or unmotivated.” The idea of teacher self-efficacy originated in the simple idea that teacher’s perceptions of their own capability are important, and that this has significant ramifications for teaching (Tschannen-Moran & Woolfolk-Hoy, 2001, p. 784). El-Deghaidy (2006) identified a number of possible types of impact and classroom behaviours linked to teacher self-efficacy beliefs of primary school science teachers, for example, the amount of time spent on teaching science, the type of teaching approach (inquiry, didactical, constructivist etc.), learner achievement in science and learner attitude towards the teaching and learning of science.

Another significant idea is that self-efficacy is a motivational construct and that it is not linked to competence, because it is defined by a person’s self-perceptions of competence (Tschannen-Moran, Woolfolk-Hoy, & Hoy, 1998; Tschannen-Moran & Woolfolk Hoy, 2007). According to Jabot (2002), self-efficacy theory provides us with one of the strongest
indicators of classroom behaviour. A number of researchers (Ashton, 1984; Ashton & Webb, 1986; Bandura, 1977; Jabot, 2002; McDonnough & Matkins, 2010; Morrel & Carroll, 2003; Tschannen-Moran & Woolfolk Hoy, 2007) have shown an apparent link between teachers’ self-efficacy, teacher performance and learner achievement. This is succinctly summarised by Tschannen-Moran and Woolfolk Hoy (2007) when they suggest that:

Compelling evidence has been accumulating over the past three decades revealing the relationship of teachers’ beliefs about their capability to impact students’ motivation and achievement to important processes and outcomes in school. Teachers’ self-efficacy has been related to their behaviour in the classroom and to student outcomes such as students’ self-efficacy beliefs, motivation, and achievement. (p. 944)

The findings of research on science teacher attitudes, efficacy beliefs and science instruction are summed up by Bursal’s (2008, p. 100) statement: “These findings lead to the conclusion that some elementary teachers’ negative attitudes towards science negatively affect their science teaching efficacy beliefs, which eventually leads to ineffective science instruction.”

The importance of self-efficacy in science teaching research is highlighted by the fact that more than 20 research papers on teacher self-efficacy were presented at 2010 Annual International Conference of the National Association of Research in Science Teaching (NARST, 2010).

Ashton (1984) asserts that:

…no other teacher characteristic has demonstrated such a consistent relationship to student achievement. A teacher education programme that has as its aim the development of teacher efficacy and which includes the essential components of a motivational change program should develop teachers who possess the motivation essential for effective classroom performance. (p. 28)
Enochs and Riggs (1990, p. 704) suggested that the assessment of the science teaching efficacy of pre-service teachers is relevant and useful because “Early detection of low efficacy in science teaching can be valuable in providing specific activities for pre-service students.”

5.1 Origins of the notion of self-efficacy

The concept of teacher efficacy has its origins in the 1960s and 1970s with two broad-based theories based in a psychological framework that can be seen as underpinning the study of teacher efficacy (Tschannen-Moran et al., 1998). The two theories in which the concept of teacher efficacy is grounded are Rotter’s social learning theory and Bandura’s social cognitive theory (Tschannen-Moran & Woolfolk-Hoy, 2001). According to Tschannen-Moran et al. (1998, p. 202) these two separate, but intertwined approaches, have led to a degree of confusion and lack of clarity over the concept of teacher efficacy, which in turn has led to substantial “…disagreement over the conceptualisation of teacher efficacy (Tschannen-Moran & Woolfolk-Hoy, 2001, p. 784).”

The Rand Corporation initiated research on teacher self-efficacy and originally their measure consisted of only two questions (Tschannen-Moran & Woolfolk-Hoy, 2001). These two questions attempted to relate teacher efficacy to a teacher’s belief in where the control over the reinforcement of their actions is situated, either internal or external control. It was this Rand measure that served as the basis of Rotter’s theory of locus of control, where control is perceived as being either internal or external. When the teacher has control over the reinforcement of their actions it is referred to as an internal locus of control, but when external factors (difficult and unmotivated learners, the nature of the subject, equipment etc.) overwhelm their ability to control the reinforcement of their actions, then the locus of control
is considered to be external. These external factors have been labelled as general teaching efficacy (GTE), while the internal factors can be aligned to self efficacy (Ashton, 1984).

It was Bandura who, in 1977, introduced the concept of self-efficacy. He claimed that there are two factors that impact on this concept, firstly, self-efficacy (internal locus of control) and secondly outcome expectancy. According to (Woolfolk-Hoy, 2000, p. 2), self efficacy “…has proved to be a powerful force in learning and motivation.” Bandura’s (1977) approach to self-efficacy is based on social cognitive theory that posits that we are motivated to do something well if we are confident that we can perform the action successfully (self-efficacy expectation) and that our actions will have a favourable result (outcome expectancy) (Bleicher & Lindgren, 2002). Self-efficacy was fairly easily linked to internal locus of control, but the suggested linkage of outcome expectancy to external locus of control became problematic, so while self-efficacy tends not to be problematic with researchers, it is the second factor, outcome expectancy, which has been only tentatively linked to Rotters’ external locus of control, that has caused problems.

Four areas were identified by Bandura (1977; 1997) as sources of efficacy expectation, namely mastery experiences, physiological and emotional states, vicarious experiences, and social or verbal persuasion. Mastery experiences, or indicators of capability, have been identified as the most powerful of these four sources. Of course mastery experience exhibits a two-face Janus effect in that if the performance has been successful then efficacy belief is enhanced and vice versa. Tschannen-Moran et al. (1998, p. 219) explained: “Mastery or enactive experiences are the most powerful source of efficacy information. The perception that a performance has been successful raises efficacy beliefs, contributing to the expectation of proficient performance in the future.” On the other hand, when the experience has been a
failure, or perceived failure, then efficacy beliefs decline and there is a negative expectation of future performance (Woolfolk-Hoy, 2000). It is this mastery source that prompts teacher education programmes to model good teaching. While it might be considered wishful thinking, it is this that prompts El-Deghaidy (2006, p. 3) to claim that “…successful models of teaching can contribute to the expectation that pre-service teacher performance will be similar to the competent teacher.” While it is accepted that mastery experience is accepted as the dominant source of self-efficacy, Tschannen-Moran and Woolfolk Hoy (2007) suggest that if this source is in any way significantly deficient then one or more of the other three sources of self-efficacy may come to the fore.

The second source of efficacy expectation, namely physiological and emotional states, rests on feelings about experiences. If the experiences are attributed to effort and ability then a positive self-efficacy is promoted, but if the feeling is that the success is attributed to others, or luck, then self-efficacy may not be enhanced (El-Deghaidy, 2006; Mulholland & Wallace, 2001; Pintrich & Schunk, 1996; Woolfolk-Hoy, 2000).

Woolfolk-Hoy (2000, p. 3) identifies a vicarious experience as one in which the skill in question is modelled by someone else. If the person closely identifies with the model then the stronger will be its effect on efficacy. As with mastery experiences, there could be both a positive and a negative aspect to the effects of these vicarious experiences on efficacy. If the model does a good job then efficacy is enhanced, but when the model performs poorly, the opposite is true.

The fourth, and last source of efficacy expectation or source of information on efficacy, social or verbal persuasion, the ‘pep talk’, has not been identified as a powerful or enduring
source because of its limited impact. Often it is only seen as having the effect of getting a person to start something new, or attempt a new strategy or try harder to succeed (Woolfolk-Hoy, 2000). On the other hand, Mulholland and Wallace (2001, p. 257) found that social persuasion was seen as a major influence on science teaching efficacy belief, however, it should be noted that their study was based on a single case study of a teacher moving through her final year pre-service study and into her first year of teaching.

Tschannen-Moran and Woolfolk-Hoy (2001, p. 787) describe self-efficacy as a ‘future-orientated’ belief which they base on an extract from Bandura who defined perceived self-efficacy as “…belief in one’s capabilities to organise and execute the courses of action required to produce given attainments.” Self-efficacy is also linked to context (Bandura, 1977; Bursal, 2008; El-Deghaidy, 2006). Bandura (1977) linked teacher efficacy to a specific context, claiming that a teacher could have a high efficacy in one area but a low efficacy in another area and thus reinforcing the role of context specificity.

5.2 Issues with respect to the self-efficacy concept

While acknowledging that international education-research literature tends to use the terms teacher efficacy and teacher self-efficacy interchangeably, Dellinger, Bobbett, Olivier and Ellett (2008, p. 751) claim that these terms are not synonymous and that they are two distinctly different constructs. In this study the perceived differences between these two terms, while acknowledged as worthy of some consideration, are not considered relevant enough to differentiate between the two terms and thus the internationally accepted norm that they are synonymous is used.
Tschannen-Moran et al. (1998) highlight some of the issues that plague researchers working in the area of teacher efficacy. Examples of questions that need to be asked are:

- Is teacher efficacy a trait that can be captured by a teacher-efficacy instrument or is it specific to a given context?
- Are the traditional assessments of teacher efficacy adequate to the task?
- Does the concept need to be refined or expanded to capture more aspects of teachers’ self-efficacy?
- What is the best interpretation of the two factors that consistently emerge on quantitative measures of efficacy?
- What contributes to a strong, positive teacher efficacy?
- How malleable is a sense of efficacy once it is established?
- In what ways does a teacher’s sense of efficacy influence teaching behaviour?
- How do teachers’ efficacy beliefs influence student beliefs and achievements?

Science Teacher Outcomes Expectancy (STOE) was conceived as a measure of the degree to which it is believed that the teacher can affect the learner’s achievement in science, but as noted by Bursal (2008), inconsistencies in interpretation have arisen owing to the fact that STOE was initially based on a teacher-centred classroom while in ‘real’ or present-day classrooms we find that there are evolving roles of teachers with a concomitant movement from teacher-centred to learner-centred approaches.
However, “The development of teacher efficacy beliefs among prospective teachers has generated a great deal of research interest because once efficacy beliefs are established they appear to be somewhat resistant to change Woolfolk-Hoy (2000, p. 5).” But, while self-efficacy may be difficult to change it can, however, be changed at any time, with early learning appearing to be the time in which it is most susceptible to change (Tschannen-Moran & Woolfolk Hoy, 2007; Woolfolk-Hoy, 2000).

The implication of this is that it may be more difficult to impact on self-efficacy in the later stages of teachers’ careers and that prospective teachers will be more vulnerable to attempts to change their self-efficacy than teachers in the middle to later stages of their careers. Hoy and Woolfolk (1990) found some evidence that self-efficacy can change during pre-service education, but that it was much more difficult to change in-service teachers’ self-efficacy. Henson (as cited in Morrell & Carroll, 2003) provided a plausible answer to this by suggesting that the impact on teaching self-efficacy is a construct which develops with time and experience and consequently impacting on it is problematic. Tschannen-Moran et al. (1998) found that a number of intervention strategies were able to raise the efficacy level for in-service teachers. After an extensive literature review, Aydin and Boz (2010, p. 697) concluded that “…there is no consensus on the effect of teacher education programmes on pre-service teachers’ self-efficacy.”

5.3 Self-efficacy belief studies and teaching

As noted earlier, research has shown that a high degree of self-efficacy has a positive effect on teacher’s actions in the classroom (Ashton, 1984; Ashton & Webb, 1986; Bandura, 1977; Finson, Riggs, & Jesunathadas, 2000; Jabot, 2002; Morrel & Carroll, 2003; Tschannen-
Moran & Woolfolk Hoy, 2007). In this study the concept of self-efficacy is discussed with respect to its relationship to confidence, with particular reference to the teaching of science. The influence of subject content knowledge and pedagogical content knowledge on self-efficacy is interrogated the relationship between self-efficacy and teachers’ impact in the classroom is discussed as is the relationship between self-efficacy and science teaching.

5.3.1 Confidence

Bleicher and Lindgren (2002) claim that self-efficacy and teaching confidence are synonymous terms, while Jabot (2002) believe that a lack of confidence towards science content exhibited by pre-service teachers suggests that there might be a link to self-efficacy. According to Bleicher and Lindgren (2002), the construct of self-efficacy captures the connection of attitudes and beliefs to practice. Their reason for linking confidence to self-efficacy is that students and teachers will commonly refer to teaching confidence when they are referring to self-efficacy. The definition of self-efficacy used by Bleicher and Lindgren (2002, p. 2) is “…an attitude, based on a belief that a person has the ability to get the job done, answer the right question, or come up with the best plan.” This definition resonates well with Bandura’s (1994) definition of self-efficacy, but there is still a difference in interpretation of the link between confidence and self-efficacy. Pajares (1996) and Bandura (1977) do not see a clear link between confidence and self-efficacy. Pajares (1996) warned against the use of general instruments that attempt to measure ‘confidence’ in a general sense and suggested that these ‘confidence’ instruments do not relate closely enough to the specific performance that they wish to predict. It was Watters and Ginns (1995) who introduced the term ‘science anxiety’ in an attempt to highlight the impact of the negative and limited experiences of science on pre-service teachers’ confidence to teach the subject. They claim
that positive experiences during their pre-service training may improve these students’ self-efficacy belief to teach science.

According to Summers and Kruger (1992), there is a link between concept knowledge and confidence. In their research into English primary school teachers’ understanding of the energy concept, Summers and Kruger (1992) found that many teachers who retained many of the misconceptions found in school learners, were not confident to teach science. Appleton (1995) claims that the origin of teachers’ lack of confidence to teach science can be traced back to their poor science background knowledge. Preece et al. (2004) found this in their concept of the ‘failure of further learning’ effect which is linked to a lack of confidence.

Khwaja (2006, p. 17) found that “…many primary teachers cite their lack of science knowledge and understanding as an important factor in determining their confidence to teach primary science.” Harlen and Holroyd (1997) caution that despite a common sense expectation that there should be a positive correlation between confidence to teach something and an understanding of that concept, there are other influences that impact on teachers’ confidence. While they did find that for the majority of the teachers that they investigated, confidence and understanding did correlate, there were a significant number of instances where this was not the case. They found that factors such as gender, age groups taught, the teacher’s own school and personal experience et cetera all impacted on confidence. Preece et al. (2004) found a weakly positive relationship between students’ confidence in their knowledge and the actual knowledge that they exhibited in content-knowledge tests.

A number of researchers have suggested that teachers of science (particularly primary school teachers of science) need to have a positive attitude towards the teaching of science
and sufficient confidence in their ability to teach it (i.e. personal science teaching efficacy belief) otherwise they will severely compromise both the quality and quantity of the science taught to children (Bleicher, 2004; Mulholland & Wallace, 2001). Whitby (as cited in Khwaja, 2006, p. 9) found that “…teachers’ confidence to teach science was determined by their own science subject knowledge and understanding, and that this in turn influenced their teaching style.”

In contrast to similar studies of the beginning teacher, Arends and Phurutse (2009, p. x), found that in South Africa “Beginner teachers were confident that they were more than adequately competent in lesson preparation, content knowledge, making key concepts explicit to learners, relating content knowledge to everyday experiences, helping learners engage with texts, and creating a stimulating classroom environment.” This contradiction could be explained, according to Arends and Phurutse (2009), by the possibility that these beginner teachers are not capable of accurate self-reflection at this early stage of their careers. Khwaja (2006, p. 11), in her review of the literature, found that many primary school teachers rated their ability to teach science rather higher than the reality in the classroom and that “experience led to increased confidence.”

5.3.2 Subject content knowledge

This study is undertaken in the belief that it would be useful to pursue teaching strategies per se, as opposed to simply conveying subject content knowledge, because, as Morrel and Carroll (2003) discovered, teacher training that focused only on content area training was not sufficient to produce an increase in science teaching self-efficacy. They did, albeit cautiously, suggest that teachers with relatively low science teaching self-efficacy
beliefs could find that their self-efficacy was improved by science-content classes. On the other hand, Bleicher and Lindgren (2002) claim that conceptual understanding is an essential foundation that must be in place before one can develop teaching confidence and they link teaching confidence directly to self-efficacy. Riggs and Enoch’s (1990) reported that teachers whose content knowledge was weak also tended to have a significantly lower self-efficacy than teachers with strong content backgrounds. Bleicher and Lindgren (2002) argue that content knowledge of itself, is not sufficient to improve confidence, and that the development of conceptual understanding is crucial and foundational to the development of teaching confidence and, according to their definitions of self-efficacy and confidence, to self-efficacy as well.

5.3.3 The teacher and classroom

Morrell and Carroll (2003) claim that self-efficacy has been shown to correlate with teaching behaviour and a number of researchers (Ashton, 1984; Bandura, 1994) have shown an apparent link between teacher self-efficacy, teacher performance and learner achievement. Finson et al., (2000) support this claim by saying that the mode of teaching that can be linked to teachers who have a low self-efficacy, tends to be authoritative, teacher-centred and not demonstrating an understanding of the various developmental levels of learners, thus indicating a link between teacher self-efficacy and their actions in the classroom. Jabot (2002) further claims that self-efficacy theory provides us with one of the strongest indicators of classroom behaviours. While he does not reject claims such as those made by Jabot, Bandura (as cited in Pajares, 1996) cautions that to make valid predictions based on self-efficacy assessments, researchers need to follow the theoretical guidelines with regard to the specificity of the self-efficacy assessment and the correspondence with critical tasks. The
Science Teaching Efficacy Belief Instrument (STEBI) developed by Riggs and Enoch (1990) focuses specifically on the teacher of science.

In general, Woolfolk-Hoy (2000) claims that self-efficacy plays a vital role in learning and that it is a better predictor of achievement than self-concept or self-esteem. According to Tschannen-Moran and Woolfolk Hoy (2007), a teacher’s efficacy beliefs are raised if they think that their teaching performance has been a success, this then contributes to their expectation that their future efforts will also be successful. They sum up the impact of efficacy by claiming that “Efficacy affects the effort they (teachers) invest in teaching, the goals they set, and their level of aspiration (Tschannen-Moran & Woolfolk-Hoy, 2001, p. 783).”

For continuing professional development (CPD), or in-service training (INSET), to have an effective impact on classroom instruction one needs three pieces of teacher knowledge, namely; subject content knowledge, pedagogical content knowledge and pedagogic knowledge (Alonzo, 2002). Apart from a change in name of one of the factors (educational knowledge instead of pedagogic knowledge) Reed, Davis and Nyabanyaba (2002) identified the same three pillars of teacher knowledge in in-service mathematics training. It could be reasonably expected that while their research involved in-service teachers, that these same three factors, to a greater or lesser extent, could also apply to pre-service teachers. The present study will attempt to determine the relationship, if any, between the above three ideas and teacher self-efficacy.

What teachers say, and what they actually do in classrooms, may appear to be two very different stories, but in the case of self-efficacy, this discrepancy is not fatal to comments on
teachers’ efficacy, because efficacy is about what the teachers believe, which may not necessarily translate into real action in the classroom (Taylor & Vinjevold, 1999). According to Tschannen-Moran et al. (1998), one of the big issues in determining the measurement of teacher efficacy is the level of specificity and context. If the instrument is too subject or topic specific and too contextual in nature then the measures may reduce their level of predictive value and generalisability. This apparent lack of generalisability may appear anomalous to other researchers who are saying that while there is a need for a high degree of specificity in the assessment of self-efficacy, it does not necessarily have to be excessively specific and context bound so as to make it useless for any generalisability (Bandura, 1994; Riggs & Enochs, 1990). This supports the approach taken in this study.

5.3.4 Self-efficacy and science education

A number of researchers have reported that pre-service primary school teachers struggle with the content of science and have low self-efficacy beliefs (confidence) towards teaching the subject (Jabot, 2002; Watters & Ginns, 1995). Hawkins (1990) suggested that science teaching is caught up in a cycle of history in which science teachers often teach the way in which they were taught, which is often badly or ineffectively. Preece et al., (2004, p. 819) suggests that although the “failure of further learning” effect (i.e. the persistence of alternative ideas as a result of poor initial learning experiences) can be overcome, at least in part, in well-designed courses. Ramey-Gassert et al., (1996) investigated elementary teachers and what factors influenced their science teaching self efficacy. They found three categories of factors, namely, antecedent experience, and internal and external factors. The antecedent experiences included their school experience, their teacher preparation experiences coupled with their science teaching experiences.
Duit (2006) presents a model for science education research that he suggests would be relevant for improving school practice and teacher education programmes. This ‘Model of Educational Reconstruction’ postulates that science subject matter issues and students’ learning needs must be given equal attention in the area of research. Much of the research that has been done in the past has focused on science content – mainly through the study of science misconceptions - and it is now necessary to give some attention to the second area of research proposed in the Educational Reconstruction model. One area of research that could be linked to students’ learning needs is self-efficacy. It is self-efficacy that has caught the attention of science education researchers in recent times (Jabot, 2002; Morrel & Carroll, 2003). In a number of studies that he and his co researchers carried out, Bleicher (2004, p. 384), found that all their studies supported “…the development of self-efficacy and conceptual understanding as a first principle in an elementary science teaching method course.” It should not, however, be interpreted that subject content knowledge is less important than self-efficacy, because Jarrett (1999) found that an increase in science content knowledge as a result of some form of intervention (especially hands-on activity) had the effect of increasing science teacher efficacy, as measured by STEBI-B. Tschannen-Moran et al. (1998, p. 225) found, as a result of a specific intervention designed at classroom practice, that “Teachers who successfully implemented the new programme exhibited marked gains in self-efficacy while teachers who learnt about the new method but were unsuccessful in their attempts to implement it saw their level of self-efficacy decline.”

5.4 Measurement of self-efficacy

The measurement of self-efficacy has always been problematic and researchers have struggled to develop effective instruments to measure it (Tschannen-Moran & Woolfolk-Hoy,
Despite these difficulties, that include: issues of validity and reliability; confusion and debate over the meaning of the two factors that have been identified; disagreements over the conceptualisation of teacher efficacy and questions with respect to the context in which teacher efficacy is measured, studies of teacher efficacy have borne much fruit (Tschannen-Moran & Woolfolk-Hoy, 2001, p. 784).

Many questions have been asked about the validity and reliability of some of the measures of self-efficacy. Factor analysis of some of the measures have revealed a two-factor structure that have consistently been detected during this factor analysis, namely, a person’s belief in their ability to teach effectively, and secondly, their belief that effective teaching will have a positive effect on student learning. In the restricted context of science teaching these two factors have been identified as: Personal Science Teaching Efficacy Beliefs (PSTEB), that is, a teacher’s belief in his or her ability to teach science effectively and Science Teaching Outcomes Expectancy (STOE), that is, the belief that effective teaching will have a positive effect on student science learning (Bursal, 2008). Despite these potential pitfalls, Woolfolk-Hoy (2008) has identified at least 12 instruments that have been developed to access efficacy in various situations, including teachers belief in their ability to make a difference.

Pajares (1996) and Woolfolk-Hoy (2000) claim that measurement of self-efficacy, because it makes most sense in perceived abilities, should be restricted to narrowly defined activities. In this present study the measurement of self-efficacy is restricted only to science. However, Bandura (as cited in Woolfolk-Hoy, 2000) highlights the danger of too specific measures as they lose their predictive power for anything but the specific circumstance. Another issue that needs to be considered is how closely the self-efficacy construct might be constrained by context (Tschannen-Moran & Woolfolk-Hoy, 2001). As such, this study uses
an instrument, Science Teacher Efficacy Belief Instrument (STEBI-B), that has been shown to be a valid and reliable measurement of science teacher efficacy (Riggs & Enochs, 1990).

5.4.1 Science teacher efficacy belief instrument (STEBI)

Researchers have attempted, and struggled, to develop effective measuring instruments that clearly capture teacher efficacy. Significant disagreements and debates have centred on the conceptualisation of teacher efficacy and the validity and reliability of the instruments have often been questioned. The issues of context and transferability of the instruments to other contexts, as well as the now all too familiar two-factor analysis, coupled with the subsequent disagreements over the meanings of these two factors, continues to fuel the debate around teacher-efficacy measurement (Tschannen-Moran & Woolfolk-Hoy, 2001).

Riggs and Enochs (1990) developed the Science Teaching Efficacy Belief Instrument (STEBI) based on an initial approach used by Gibson and Dembo (1984). Initially Riggs and Enochs (1990) started out with an instrument designed to measure self-efficacy and outcome expectancy beliefs for teaching behaviours in general. They then modified and tested the items for the teaching of science. The Personal Science Teaching Efficacy Belief (PSTEB) scale and the Science Teaching Outcome Expectancy (STOE) scale were combined to produce the Science Teaching Efficacy Belief Instrument (STEBI). Initially STEBI was designed for in-service science teachers and when it was adapted to accommodate pre-service teachers it was renamed STEBI-A for in-service and STEBI-B for pre-service teachers (Enochs & Riggs, 1990). During the adaptation process the number of items was reduced from 25 to 23, and where appropriate, items were rephrased from the present tense (e.g. ‘I do not teach…) to a future tense (e.g. ‘I will not teach…”).
One of the strengths of the STEBI instruments is their theoretical base (Yilmaz-Tuzun & Topcu, 2008) as seen in that STEBI-B is a science-specific measure for science self-efficacy, and as such, acknowledges Bandura’s (1997) claim that self-efficacy is a context or situation specific construct.

STEBI-B has a number of statements that can be grouped into two broad categories, that is, it has two subscales embedded within it, namely Personal Science Teaching Efficacy belief (PSTEB) and Science Teaching Outcome Expectancy (STOE). Loosely illustrative of the two factor structure that was exhibited when factor analysis was carried out on most efficacy measures (Bleicher & Lindgren, 2002). The one subgroup is based on Rotter’s (as cited in Wenner, 2001) Locus of Control (LOC), while the other sits closer to Bandura’s social cognitive theory (Tschannen-Moran & Woolfolk-Hoy, 2001). McDonnough and Matkins (2010) note that although the usefulness of STOE as a predictor of teacher effectiveness and self-efficacy has been questioned, this construct sits easily with external locus of control beliefs, and is still useful in the overall picture of self-efficacy beliefs.

Morrell and Carroll (2003) found that intervention programmes with pre-service teachers had a significant impact on PSTEB, but the impact of STOE, that is, the impact that teachers feel that they can have on students’ learning was low and typically not changed by what is done in teacher preparation programmes.

6. EDUCATIVE CURRICULUM MATERIALS

Pre-service teachers are often disappointed with teacher education programmes complaining that they are presented with large amounts of theory and not enough practical knowledge (Loughran, Mulhall, & Berry, 2008). A useful approach might be to shift the
focus from one that has been dominated by theoretical perspectives, towards a more practical approach, by having as a goal, the integrating of the concepts of SCK with PCK in teacher training method classes (Loughran et al., 2008). This study proposes the use of a particular category of educative curriculum materials to achieve this goal. Educative curriculum materials are described by Davis et al., (2008) as those materials:

…designed with the intention of supporting teacher learning in addition to student learning, can promote the knowledge integration process of identifying weaknesses with ideas, adding ideas to one’s repertoire, and making links between ideas; at the same time these materials support conceptual change processes such as promoting dissatisfaction with some ideas and the intelligence, plausibility, and fruitfulness of others. (p. 1)

The concept of educative curriculum materials has been proposed by a number of authors (Ball & Cohen, 1996; Davis & Krajcik, 2005; Dietz & Davis, 2009). According to Davis and Krajcik (2005, p. 3), “Curriculum materials that are intended to promote teacher learning in addition to student learning have come to be called educative curriculum materials.” It should be noted that Davis and Krajcik (2005) stress that the word educative (in educative curriculum materials), when used in the context of teacher learning, refers to being educative for the teacher, that is, they see the teacher as a learner in the context of the use of the materials. As such it can be seen that educative curriculum materials are designed to promote teacher learning and could therefore be profitably included in pre-service teacher training. The importance of educative curriculum materials is stressed by (Davis et al., 2008, p. 4) when they claim that these materials “…provide a form of support for teacher learning, knowledge integration, and conceptual change.” In addition to this, educative curriculum materials are grounded in actual practice and can be used as important cognitive tools for
teachers (Davis & Krajcik, 2005). Educative curriculum materials have, for this reason proved to be particularly useful form of support for teachers (Davis et al., 2008).

It has been suggested by Davis and Krajcik (2005) that it is in the areas of subject content knowledge and pedagogical content knowledge that educative curriculum materials come into their own. A number of researchers (Davis & Krajcik, 2005; Ball & Cohen, 1996) have suggested a number of positive effects on teacher learning of educative curriculum materials. The first positive effect could be linked to constructivism and misconceptions, in that, educative curriculum materials assist teachers in predicting and being able to interpret learners’ responses. It should be noted that the above suggests that these types of materials will assist in the development of the prospective teachers’ PCK. The second positive influence of educative curriculum materials is that in the process of working with these materials the teachers will improve their content knowledge. The third plus is related to the way that the materials might assist teachers in integrating different aspects of work that they will be doing during the year when they teach. The fourth role of educative curriculum materials is to assist the teacher in seeing what pedagogical ideas the developers used to underpin their materials, for example, the underlying principle behind a particular material might be a constructivist approach to learning and as such be the teacher might be able to develop their pedagogic knowledge. The last role recommended by Davis and Krajcik (2005) is that educative curriculum materials assist in developing the teacher’s pedagogical design capacity (i.e. it allows them to entertain the possibilities of adapting and developing their own educative curriculum materials). According to Davis et al., (2008, p. 5), “Educative curriculum materials can help teachers identify a weakness with their current ideas, or, in other words, can create some dissatisfaction with ideas.” It is this that makes educative
curriculum materials ideally suitable for use in a programme of modules that focus on misconceptions and a constructivist approach to learning, as is the case of the teacher training programme in which this study is embedded.

The limitations of educative curriculum materials have been highlighted by Davis and Krajcik (2005, p. 8) who claim that while it is relatively easy to used educative curriculum materials that will be used by teachers (i.e. new ideas and ‘things’ to use in the classroom) it is far more difficult to develop the connections between the different ideas that the materials may be linked to. The final limitation of educative curriculum materials is that one cannot assume that they will automatically develop the teacher into an effective classroom practitioner. As Davis and Krajcik (2005) succinctly point out, one cannot claim to be an expert when one is not able to know when and how to make adjustments to educative curriculum materials so as to make them effective in new situations.

McKenney, Voogt, Bustraan and Smits (2009) see curriculum materials as being a catalyst that promotes the complex relationship between teacher knowledge, beliefs and contexts during the implementation of a curriculum. Davis et al. (2008) lay a claim for the inclusion of educative curriculum materials in teacher training programmes:

Specific features of educative curriculum materials can support specific aspects of teacher learning, such as identifying weaknesses or creating dissatisfaction with a current idea, adding new ideas about specific instructional strategies to teachers’ repertoires of ideas, adding new general principles of practice to their repertoires...determining the plausibility and fruitfulness of new ideas, and making connections between ideas. Educative features facilitate these processes and work in concert to promote the development of PCK. (p. 3)
Some of the educative curriculum materials used in this research could be considered innovative, certainly in the context of what currently takes place in the majority of primary school class rooms in South Africa (Taylor & Vinjevold, 1999). Verloop et al. (2001, p. 453), drawing on the work of Trigwell, Posser and Taylor, claim that “There is growing consensus that educational innovations are doomed to fail if the emphasis remains on developing specific skills, without taking into account the teachers’ cognitions, including their beliefs, intentions and attitudes.”

6.1 Educative curriculum materials and conceptual change

To be effective educative curriculum materials need to bring about conceptual change. The idea of conceptual change approaches in the teaching of science originates in the constructivist theoretical framework (Trumper et al., 2000). A word of caution comes from Illes (2002, p. 13), based on his study of lower secondary school science teachers, he found that despite “…elaborate and sometimes extensive teaching strategies…” that were designed to teach the energy concept, if the precise method of attempting to bring about conceptual learning and conceptual change were not made explicit, then one could not expect the learners to simply acquire the concept.

Harlen (1994) stresses that all curriculum materials are designed to help learners learn, but if one is evaluating them, then one needs to be very clear on their way in which they are designed to bring about this learning. It is this that makes it difficult to evaluate curriculum materials in the traditional empirical manner. For example, some innovative materials may focus on attitudes and values that will always be difficult to assess, and thus we end up with issues of validity.
Stofflett and Stoddart (1994, p. 46) claim that the best way to enable teachers to change their instructional approach is to get them to experience from a learner’s viewpoint this instructional approach. This approach enables teachers to reconstruct their personal understanding of the concept. The alternative approach of modelling “being told about and observing a demonstration of an innovative instructional approach” is not as effective as the teacher experiencing the innovative method first hand. Asoko (1996) claims, that teachers’ interest is captured when they are encouraged to consider their learners’ ideas. The assumption is that many of the teachers would have similar conceptions, but by stressing that these are learner ideas, the situation is detached as it were, from the teachers’ feelings of inadequacy. Support for this comes from Asoko (1996, p. 37) who says “Consideration of why students might respond as they do not only provide opportunities to consider children’s learning but also prompts teachers to reflect on their own understandings and whether these are scientifically acceptable.”

A pre-service module on science methodology is not about simply giving pre-service teachers an array of different activities, using educative curriculum materials, that they can store and use with learners when they start teaching, but it is about getting them to experience the learning for themselves. In all cases the underlying science ideas as well as possible learners’ ideas and different means of teaching concepts should be addressed. These science modules should not only be about developing the pre-service teachers’ content knowledge but also about the development of their pedagogical content knowledge. This is done because of the awareness of Asoko’s (1996) claim. “Teachers also need to find ways to make appropriate ideas of science accessible to young children and support pupils in relating these ideas to experience (p. 36).”
6.2 Toys as examples of educative curriculum material

To make any curriculum material ‘educative’ one needs to add the educative element – always bearing in mind that the ‘educative part’ means the promotion of the teacher’s knowledge base and practice (Davis & Krajcik, 2005). A number of different educative curriculum materials are used in the science modules in which this study is situated. Examples of educative curriculum materials used in the BEd Intermediate Phase programme at the Nelson Mandela Metropolitan University are: Science UpD8 worksheets (Science UpD8, 2010) Concept Cartoons (Kabapinar, 2005; Keogh & Naylor, 1999), Research Projects, hands-on investigations (Huber & Moore, 2001), analogies (Asoko & de Boo, 2001) et cetera. These different educative curriculum materials have been included in the modules to support Davis and Krajcik’s contention (2005, p. 4) that “…teacher learning will best be promoted by a set of complementary approaches, not by a single one.”

As suggested by Davis and Krajcik (2005) effective educative curriculum materials should include three components, namely, the instructional approach – what actually needs to be done, the rationale for this particular approach and finally the recommendations for effective for use (i.e. the outline of the PCK that can be learnt from the materials).

According to Davis and Krajcik (2005), the effectiveness of educative curriculum materials is influenced by the following factors:

- The curriculum materials must be of high quality in terms of content and pedagogy
- Their effectiveness is limited (or enhanced) by teacher characteristics – knowledge, beliefs, self-efficacy etc.
- Educative curriculum materials need to be used in conjunction with other forms of support. (p. 8-9)

Tytler (2002) claims that

Most toys by their nature exhibit scientific principles in one form or another. They can be used to enliven and extend the range of science activities in the classroom, or to form the basis of interesting and enjoyable discussions between children and adults in any situation. Through their intrinsic interest and by the associations they generate, toys provide an impetus to investigation and learning through play. (p. 1)

By accepting Tytler’s (2002) advice that students must be active participants (hence the workshop-format included in this study), and in order to improve conceptual understanding and self-efficacy, one needs to allow students to engage with their own ideas in attempting to understand the underlying energy concepts involved in the functioning of the toys.

The educative curriculum materials used in this study are pitched at pre-service teachers, and if one assumes that PCK is heavily dependent on teaching experience (Van Driel et al., 1998), which these students lack, then the materials are required to be more explicit in the area of PCK and hence they really need to be ‘educative’ in nature.

An anecdotal story by Jacobsen (2005) suggests a suitable motivation for using toys as the educative curriculum material for teaching the energy concept to pre-service primary school teachers, many of whom have limited (and often) poor experiences of science during their school years.

My twin brother and I sat by the swimming pool in the Phoenix heat, feet splashing in the water. Our entertainment: a new pump water rocket. We filled the lime-green plastic rocket to the mark with pool water, snapped it on to the hand-held pump, and underwent a flurry of pumping. Pressed the release, and let it rip. We experimented. How high
would it go? What if you put in less water? How many times could you ask Dad to retrieve it from the roof before he blew his stack? In our youth, little did we know that we had a piece of science in our hands. To us, it was just a toy, an afternoon diversion. But a diversion such as this provides a perfect way to catch a student’s interest. It’s a toy, its fun – but wait, it’s also science, it’s also chemistry. (p. 1443)

Although the focus of this study was on the energy concept in the mechanical sense, support comes for the use of toys to teach chemistry. Sarquis and Sarquis (2005, p. 1450) claim that toys are a very good teaching resource (educative curriculum material) based on the suggestion that they are non-threatening to all children (and students), and that they present chemistry (or any science for that matter) in a more friendly manner than the traditional educative curriculum materials, for example, textbooks, test tubes and air tracks et cetera. Many people would agree with Sobey and Sobey (2008, p. xi) when they claim that “Some toys command interest and inspire wonder. They do the unexpected, or seemingly impossible. They make us think about how they work and how they relate to the scientific concepts we’ve learnt.”

7. CHAPTER SUMMARY

This chapter provides an overview of the literature that is relevant to this study. The factors that are relevant, namely, subject content knowledge, pedagogical content knowledge and science teacher self-efficacy are each explained in general terms, as well as in terms of teacher learning and teacher knowledge. This last factor mentioned, self-efficacy, is linked through the literature to the idea of teacher confidence. These factors are then focused onto a very specific topic, namely, the concept of energy, a requirement of an Intermediate Phase Natural Sciences teacher’s knowledge and understanding. The chapter concludes with a general discussion of educative curriculum materials, followed by the introduction of the
educative curriculum material that becomes the focus of this study, namely, simple children’s toys.
CHAPTER THREE

METHODOLOGY

1. INTRODUCTION

The chapter starts by describing, discussing and justifying the research methodology and design employed in this study. A number of data collection methods and instruments are used in the study and each of these is explained in terms of their structure and purpose in the data collection process. This section also reviews each of the different data collection instruments and includes a description of these instruments, their degrees of validity and reliability, as well as possible advantages and disadvantages of the respective instruments in the context of this study. Where questionnaires were used, these were all administered via an electronic learning management platform (Moodle®) and the motivation for doing this, together the merits and disadvantages of such a method of administering a questionnaire are discussed. The rationale for the development of the science content knowledge questionnaire dealing with energy, as well as the development of the questionnaire that attempts to assess the state of the students’ pedagogical content knowledge (PCK) with respect to the teaching of energy at primary school level, are discussed. A brief outline of one type of educative curriculum materials, namely, toys, and how these toys are used in the intervention described. The demographics of the respondents are introduced and the sample type and size are discussed and justified. Additional demographic data, in terms of students’ school experiences with respect to science, are included so as to assist in developing an understanding of the students’ initial attitudes towards science. Finally, the data analysis, as
well as reference to the ethical considerations taken during the research, is discussed. The chapter concludes with a summary of the methodological limitations of the study.

2. FRAMEWORKS, PARADIGMS AND METHODOLOGIES

According to Hall and Howard (2008, p. 253), a research framework requires a number of conceptual ideas, namely, a philosophical position (i.e. the epistemology or “How do we know what we know?”); a methodology which is the design framework, and finally the methods, which are the instruments and tools used in the research. Nudzor (2009, p. 115) describes methodologies as “…the strategies, plans of action, processes or designs lying behind the choice and use of particular methods, whereas methods concern the techniques or procedures used to gather and analyse data.” Analysis of the data is the final aspect that should be considered when working within a research framework. The methodologies that may be employed by researchers consist of three elements and the content of these three elements flow out of the research questions in the study. The first element emerges from the fact that the nature of the research questions should determine the route that the study will follow, that is, the research questions will determine the knowledge claims or the philosophy that underpins the study. The second element is determined by the researcher’s choice of the first element, and are the strategies of the inquiry, this is followed by the final element, namely, the methods of the inquiry.

Traditionally two philosophies have prevailed in the methodologies of research, namely, the positivist-dominated quantitative approach and the non-positivist or interpretivist approach of the qualitative research methodologies. A number of researchers have, however, identified a third ‘movement’, namely, the mixed-methods approach (Creswell & Plano Clark,
Following on from these researchers, Teddlie and Tashakkori (2009) identify three methodological movements in social and behavioural science research, namely, researchers who work in the post-positivist/positivist paradigm and focus on numerical data and its analysis (the QUANs), the QUALs who function in the constructivist/interpretivist paradigm and deal with narrative data and its analysis, and finally the mixed-methods methodologists who function in a pragmatist environment and deal with both quantitative and qualitative data. In some studies this ‘mixed-methods’ strategy is referred to variously as the ‘combined-methods’ approach, ‘multiple-research’ strategy, ‘multi-method’ approach, or ‘integrated-research’ approach (Nudzor, 2009). In this type of pragmatic approach the focus shifts from both the positivist view of a single reality and the constructivist approach of a constructed reality to one in which the emphasis is on ‘what works’ with respect to truth and reality (Creswell, 2003). Doyle et al., (2009, p. 183) have attempted to circumscribe the essence of pragmatism with respect to research methodologies by claiming that “…the practicality inherent in pragmatism is concerned with finding the most appropriate method to answer a research question or set of research questions.”

When considering various methodologies, Creswell (2003), claims that the two ‘traditional’ research practices, namely, the quantitative and the qualitative methodologies lie on a continuum, and that much social sciences research lies somewhere on the continuum between the two. “The best that can be said is that studies tend to be more quantitative or more qualitative in nature (Creswell, 2003, p. 4).” Table 1 shows how Creswell (2003, p. 6-20) identified and categorised the above mentioned elements of inquiry for three of the dominant research practices.
Table 1

*Creswell’s Categories of Research Practice*

<table>
<thead>
<tr>
<th>Knowledge claims (epistemology/ontology)</th>
<th>Strategies</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positivist/post positivist</td>
<td>Experimental design</td>
<td>Pre-determined</td>
</tr>
<tr>
<td>Deterministic</td>
<td></td>
<td>Instrument-based</td>
</tr>
<tr>
<td>Reductionist</td>
<td></td>
<td>Statistical analysis</td>
</tr>
<tr>
<td>External reality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualitative*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constructivist</td>
<td>Narratives/text</td>
<td>Emerging methods</td>
</tr>
<tr>
<td>Interpretivism</td>
<td>Case Studies</td>
<td>Open-ended questions</td>
</tr>
<tr>
<td>Multiple-participatory meanings</td>
<td></td>
<td>Interview data</td>
</tr>
<tr>
<td>Constructed reality</td>
<td></td>
<td>Text and image analysis</td>
</tr>
<tr>
<td>Mixed Methods</td>
<td>‘What works’ Approach</td>
<td>Both emerging and pre-determined methods</td>
</tr>
<tr>
<td>Pragmatist</td>
<td></td>
<td>Both open and closed questions</td>
</tr>
<tr>
<td>Pluralistic</td>
<td></td>
<td>Multiple forms of data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Statistical and text analysis</td>
</tr>
</tbody>
</table>

Note. *Creswell does divide this into two, namely, a qualitative approach that subscribes to a constructivist approach and one that follows the emancipatory approach – where appropriate, the approach followed in this study is the constructivist one.

As can be seen from Table 1, the adherents of the positivist quantitative approach and those representing the interpretivist qualitative approach would approach an inquiry in entirely different ways and as such, could be construed as totally incompatible. On the other
hand, if one were to adopt the pragmatic third methodological approach, where there is an
opportunity to adopt the approaches of both of the traditional approaches, then there is scope
for “…balancing out any of the potential weaknesses of each perspective (Gray, 2009, p. 33).”

Every methodology has its strengths and weaknesses and when working in the school or
pre-service teaching environment one needs to be cognisant of the fact that “It is now widely
recognised that we cannot pin down cause and effect using an experimental design as in
science; there are just too many differences between pupils for this to work…(Harlen, 1994,
p. 2).” According to Bell (1999):

No approach depends solely on one method anymore than it would exclude a method
merely because it is labelled ‘quantitative’, ‘qualitative’, ‘case study’, ‘action research’,
or whatever…Methods are selected because they will provide the data you require to
produce a complete piece of research. Decisions have to be made about which methods
are best for particular purposes and then data-colllecting instruments must be designed to
do the job. (p. 101)

Lankshear and Knobel (2004) believe that once one moves into the realm of
methodologies that offer an alternative to the experimental science model, one is able to raise
a number of challenges to the traditional approaches that have been used to measure the
quality of research.

More specifically, they (qualitative researchers) are arguing that strict concerns for
replicability and consistency methods, conditions and outcomes in establishing the
reliability of a study’s findings often generate problems many qualitative researchers are
keen to avoid. Such concerns, it is alleged, ignore subtleties and contradictions in the
data, tend to construct simplified readings of the complex phenomenon under study and
usually overlook the effects of the researcher on data and interpretations. (p. 363)

The typology (or different types) of mixed-methods research has been discussed by a
number of authors (Creswell & Plano Clark, 2007; Doyle et al., 2009; Hall & Howard, 2008)
and this boils down to three decisions, namely, a weighting decision, a mixing decision and a timing decision. It is these decisions that will be guided by the mixed-method typology that has been adopted. The typology itself will be dictated by the actual research questions.

Lankshear and Knobel’s (2004, p. 363) idea of communicative validity is “…to present readers with carefully argued interpretations and claims, and adequate evidence to support them.” This take on the process of validation revolves around the interpretive argument and, importantly, the evidence that is called upon to support the argument. Three of the more relevant strategies that are used to provide for communicative validity are: the use of multiple sources of evidence, participant checks and outsider audits. While it might be convenient to claim that the first strategy, multiple sources of evidence, is similar to triangulation, Lankshear and Knobel (2004, p. 364) claim that, while there are definite similarities between triangulation and the use of multiple sources, these two concepts are not synonymous. Participant checks involve the researcher, the participants and the interpreted data in that the draft reports or interpretations are sent to key participants for perusal and comment and outsider audits involve people not directly associated with the study to assess the report.

A second important aspect of an interpretive study is trustworthiness. This requires the researchers to demonstrate that they have collected sufficient data to adequately respond to the research question (Lankshear & Knobel, 2004). The two conditions required to enhance trustworthiness are sufficiency of solid relevant data and coherence of the methodology and design of the study.

Nudzor (2009) sums up the underlying principles that should determine the choice of an appropriate methodology for a particular inquiry:
...the definition of a good or appropriate research methodology is not based on the primacy of which research traditions are utilised, the skill base of the researcher nor who has control over the research outcomes, but rather how a particular approach might be purposeful for answering the research question posed. (p. 124)

One of the reasons for the adoption of a mixed-methods approach in this study is that its use should produce a more complete picture as it combines information from complementary data sources (Denscombe, 2008).

3. RESEARCH DESIGN

The importance of a good research design cannot be overestimated as it is able to bring about high quality research (Lankshear & Knobel, 2004). According to Abel (2008, p. 1408), “In high quality research, the researcher establishes a strong link between theoretical framework and research questions.” The current study is placed within a theoretical framework of science teacher self-efficacy and PCK. One of the characteristics of PCK, as identified by Abel (2008), is that it involves discrete packages of knowledge, in this study the focus is on science teacher self-efficacy beliefs and on one particular aspect of science, the teaching of energy in the primary school. Secondly, the idea that PCK is not static is illustrated in the design of the research in that students’ PCK (with respect to teaching the energy concept) is measured at two points in time, before and after instruction.

In potentially complex social settings, such as the one in which this study was carried out, it is often possible to adopt a quasi-experimental design (Brown & Dowling, 1998; Lanksheir & Knobel, 2004, Cohen, Manion, & Morrison, 2007) or an approach similar to what Mouton (2001, p. 158) refers to as “Evaluation Research: Implementation (process) evaluation.” The respondents (students) in this study, while all being registered for a pre-
service programme did not all take exactly the same number of science courses at exactly the same time while at school. Some of the students\(^2\) had already completed one or more of the science-based courses in the BEd programme, but this study had as its focus a specific topic (viz. energy) and a specific intervention that consisted of lectures, assignments, assessments and toys workshops.

This study fulfils the criteria for a quasi-experimental design as categorised by Lankshear and Knobel (2004), namely, the participants were already in existing groups, there was no random assignment to the treatment conditions, the study is used to evaluate some sort of intervention, and the data were gathered using pre- and post-intervention instruments. According to Lankshear and Knobel (2004), quasi-experimental designs are extremely useful for teacher researchers when they want to evaluate intervention programmes or treatments. In turn, using a mixed-method approach usually produces both qualitative and quantitative data (Creswell, 2003; Creswell & Plano Clark, 2007; Creswell & Garrett, 2008) as was the case in this study. Table 2 shows the various data collection instruments that were designed to generate qualitative and quantitative data.

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\(^2\) From now on in this report the respondents in the study will be referred to as students because all the respondents were students completing a particular module in the same pre-service BEd programme.
Table 2

*Allocation of Data Collection Instruments to Quantitative and Qualitative Methodologies*

<table>
<thead>
<tr>
<th>Data Collection Instrument</th>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant writing</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Science Teacher Efficacy Beliefs (STEBI-B)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Subject content knowledge (SCK) questionnaire: energy concept (SCK-EC)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Pedagogical content knowledge (PCK) questionnaire: energy concept (PCK-EC)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Toys workshop worksheet</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Post-intervention written assignment</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Post-intervention web-based assessment</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Post-intervention written test</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

4. **VALIDITY AND RELIABILITY OF DATA COLLECTION INSTRUMENTS**

In all research, whether qualitative or quantitative, attention needs to be applied to the constructs of validity and reliability. Morse, Barrett, Mayan, Olson and Spiers (2002, p. 14) have linked validity and reliability to what they refer to as “rigour” in research, claiming that “Without rigour, research is worthless, becomes fiction, and loses its utility.” According to Cohen et al. (2007, p. 133), “Threats to validity and reliability can never be erased completely; rather the effects of these threats can be attenuated by attention to validity and reliability throughout the piece of research.” This study, which uses a mixed-methods
approach, consisted of both qualitative and quantitative data-collection instruments, which, by a variety of means, such as accessing similar information at different times, using different instruments, tried to: “…minimise invalidity and maximise validity (Cohen et al., p. 133)” as well as maintaining a focus on reliability. In quantitative research validity and reliability can be found in “…the certainty of hard numbers and p values (Morse et al., 2002, p. 14)”, however, because this cannot be the case in qualitative research, different criteria for what constitutes validity and reliability have been proposed for qualitative research (Lincoln & Guba, 1985). This alternative criterion for rigour in qualitative research has been identified by Lincoln and Guba (1985) as the concept of ‘trustworthiness’ that comprises of the four aspects of credibility, transferability, dependability and confirmability.

4.1 Validity

Cohen et al., (2007, p. 133) suggest that “…reliability is a necessary but insufficient condition for validity in research; reliability is a necessary precondition of validity, and validity may be sufficient but not a necessary condition for reliability.” In this mixed-methods study, validity is a requirement of both the qualitative and quantitative data and as such, the original version of validity (i.e. does the instrument actually measure what it claims to measure) may be inappropriate or insufficient to determine the validity of this study. According to Cohen et al., (2007, p.133), a more suitable interpretations of validity can be discerned for qualitative and quantitative data. They suggest that for qualitative data validity “…might be addressed through the honesty, depth, richness and scope of the data achieved, the participants approach, the extent of triangulation and the disinterestedness or objectivity of the researcher” while in quantitative research the validity of the data could be improved
through “…careful sampling, appropriate instrumentation and appropriate statistical treatment of data.”

4.2 Reliability

In this study it is accepted that the suitability of reliability may be different for the quantitative and qualitative data. It is acknowledged that reliability finds a vital status in quantitative data in that “Reliability in quantitative research is essentially a synonym for dependability, consistency, and replicability over time (Cohen et al., 2007, p. 146),” while its suitability in qualitative research is contested, as can be seen by Le Compte and Preissle (as cited in Cohen et al., 2007, p. 148) who suggest that: “…the canons of reliability for quantitative research may simply be unworkable for qualitative research.” It is for this reason, however, that the idea of ‘trustworthiness’ has been introduced into the qualitative lexicon.

On the other hand Morse et al., (2002, p. 17) have introduced the concept of verification in qualitative research, that is, “Verification is the process of checking, confirming, making sure, and being certain.” They maintain that “Whether quantitative or qualitative methods are used, rigour is a desired goal that is met through specific verification strategies (Morse et al., 2002, p. 19).” The different data collected via the various methods in this study all interact with each other to promote rigour in the study.

5. DATA COLLECTION PROCEDURES AND INSTRUMENTS

Lankshear and Knobel (2004, p. 187) introduced the principle of “elegance and economy” that is, “…concerned with getting the greatest amount of high-quality data from the minimum use of resources, and with the least possible complexity in operation.” With this in
mind, much data in this study were collected asynchronously using a web-based platform via a learning management tool, namely Moodle® (referred to as LEARN).

A variety of data collection instruments were used in this study, namely, participant writings, questionnaires and assignments and web-based online and written assessments.

5.1 Participant writing

“Participant journals collect data written from the point of view of the participant, and can offer helpful insights into his or her thoughts,…(Lankshear & Knobel, 2004, p. 255).” While the student participant writings in this study cannot be considered to be participant journal as such, because they were not maintained for the duration of the module, the participant writing that was used as a research product in this study could be considered similar to a participant journal, in that the documents that were created were done at the request of the researcher and were to a large extent anecdotal and reflective on the part of the respondent (Lankshear & Knobel, 2004).

Bransky, Hadass and Lubezky (as cited in Trumper, 1997) claim that, as a result of their previous failures in science, pre-service primary school teachers are usually not that keen on science and develop negative attitudes towards the subject. One of the antecedent factors identified by El-Deghaidy (2006) that impact on science teaching self-efficacy, is the students in and out of school science experience. The constructivist nature of the pre-service programme followed by the students in this study dictate that one should be aware of the antecedent factors that influence their attitudes towards science. The method adopted in this programme comes in the form of participant writing.
The participant writings were in the form of an assignment or task that the students had to complete at the start of their first science module in the IP programme. The assignment was a short (500-800 word) reflection on their school science experience. This assignment is normally a highly personal (and in some cases emotional) report, where words such as ‘hated’, ‘loved’, ‘brilliant’, ‘useless’, ‘pointless’, et cetera are frequently used by the students. The analyses of these assignments are used to sketch a picture of the diverse science experiences that have been experienced by students who complete this pre-service primary school teacher training.

The circumstances under which the participant writings were collected, that is, via an assignment (for assessment) does raise an unavoidable limitation of this data collection instrument, namely, that this data may not necessarily represent the respondent’s actual feelings and reflection as they may have written about what they thought the lecturer would like to hear (Lankshear & Knobel, 2004). However, experience of reading these assignments over the years has shown remarkably similar themes and ideas being raised by students with respect to their school science experience.

A total of 89 assignments were analysed with the view to identifying themes or key ideas that might be considered to be common threads that run through the school science experiences of the students in the Intermediate Phase pre-service programme. The data from this source were not used to compare specific students’ personal reflections and their own particular self-efficacy and confidence, but to sketch a general picture of the typical student enrolled in these particular Intermediate Phase Natural Sciences courses.

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3 The respondents were in their second-year of the programme when they participated in this study, but the assignment referred to in the participant writing, was completed at the start of their first-year of study.
5.2 Web-based electronic surveys or questionnaires

Gaiser and Schreiner (2009, p. 17) claim that “The reason we develop research instruments is so that we can collect data that will help us develop a new understanding.” Taking cognisance of this, there is no reason why new approaches to various instruments should not be explored. The increasing use of the Internet has opened the way for an alternate to paper-and-pencil instruments (PAPI) to conduct questionnaires (Couper, 2000). While Sadler (1998) claims that paper and pencil tests are cheap and relatively easy to administer and score, Archer (2008) suggests that these advantages are enhanced even further with the use of Web-based questionnaires, and the advantages of time saving, cost and data entry, has resulted in an explosion in the use of this technology (web-based questionnaires) in the last ten years. The advent of electronic questionnaire instruments such as Survey Monkey®, and electronic Learning Management Systems (LMS) such as Blackboard®, WebCT®, Sharepoint® and Moodle® (Modular, Object Orientated, Dynamic, Learning, Environment) have created another opportunity or method to gather data that might normally be garnered using ‘traditional’ paper and pencil assessments. The LMS used in this study was a freeware package called Moodle® and renamed at the NMMU as LEARN.

While the format of web-based questionnaires do not appear to have many unique advantages over PAPI instruments the potential exists for asynchronous taking of the questionnaire with the added advantage of data being collected at any and all times, namely, 24/7/365, without restricting respondents to a particular geographic location. The idea that the whole process is also entirely in an electronic format has some compelling advantages, namely, reduced data entry time arising from the fact that responses can be directly downloaded into Microsoft Excel® format, thus saving time and money as well as reducing
the chance of human error during data entry and coding (Fleming & Bowden, 2009). The paperless nature of the questionnaires can be seen as being environmentally friendly (Yun & Trumbo, 2000).

On face value the above enhanced advantages might be very appealing, but there are significant dangers attached to this form of data collection. With the advent of more and faster technologies in the computer field one needs to investigate the effect of mode (e.g. computer versus paper-and-pencil) on testing and assessing. In their study on the effectiveness of web-based questionnaires, Clariana and Wallace (2002, p. 594) could not determine from the literature any definite trend because different studies produced differing results, but what they did find was succinctly summarised in their analogy, “...though the kind of truck used to deliver groceries cannot impact the nutrition of the groceries, if the learner has never driven a truck, the groceries may not be delivered at all.” The implication of this is that if respondents are not au-faux with working on computers and doing online assessments and questionnaires then this could seriously impact on the data collected. A cautionary note is also sounded by Hayslett and Wildemuth (2004, p. 73) who suggested that “…the medium in which a researcher gathers data may affect the data gathered.” In other words, what they referred to as mode effects. Having said this, they did find that in the majority of the studies that they considered, no significant mode effects for web-based questionnaires were noted.

As noted earlier, the use of web-based instruments for conducting questionnaires has a number of advantages, especially in environments where the access to the internet is high, as was the case in this study. Hayslett and Wildemuth (2004) suggest that the validity of web-based questionnaires may be lower than their PAPI alternatives as a result of serious issues
with the respondent’s demographics. In this study, however, the problems of sampling and coverage were of a minimal nature as whole cohorts of students from a specific programme were targeted. There was no mismatch between the target populations, that is, the set of people that were to be studied, and the frame population which is delimited by the means of access, in this case email addresses. In this case there is in fact no sampling frame. The sample used in this study is one where all the respondents have access to email, albeit, with some restricted access due to the lack of easy availability of computers. In this study all the students had completed at least one or two online courses that used the same or similar approaches as was used in the web-based questionnaires and had access to the NMMU computer laboratories and other computer venues. Ganassali (2008) suggests that web-based questionnaires are particularly suitable for internal questionnaires such as staff/student evaluations, as was the case in this study.

A possible disadvantage of web-based questionnaires carried out asynchronously, over a standard paper and pencil instrument (PAPI), is that there is no place to jot down notes on questions or ask questions of the questionnaire administrator - thus no chance of unexpected information. Addition text boxes for comment included in the web-based questionnaires (usually at the end of the questionnaire) also have their limitations. Hayslett and Wildemuth (2004, p. 13) say “..., even this accommodation (text boxes) is not sufficient to allow people to circle portions of questions, draw in arrows, and make other non-textual annotations that may be useful in interpreting their responses.”

A major headache of any questionnaire, namely, non-responsiveness can have serious implications for the questionnaire analysis. A low response rate can cause unintentional bias (Brown & Dowling, 1998) and as such, a great deal of time and effort was spent on ensuring a
high response rate. The response rate of any questionnaire has been closely related to three factors, namely, who the person or organisation is who is promoting the questionnaire, the topic and how long it takes to complete (Fan & Yan, 2010). Methods to increase responsiveness in traditional questionnaire methods may not work in the web-based environment especially in cases where questionnaires are completed in the respondent’s own time, that is, an asynchronous environment. Technical difficulties, namely, access to computers, slow internet speeds et cetera, can also contribute to non-responsiveness. The researcher can, however, continuously monitor the numbers taking the questionnaires and respond to low response by following up using electronic means, for example, emails and chat room messages.

According to Ganassali, (2008), the ideal questionnaire should contain between 15 and 30 items, because anything longer than this can cause response wariness. On the other hand, they acknowledge that research thus far has failed to show a strong correlation between questionnaire length and drop-out rate, and that the ‘ideal’ time to complete the questionnaire should be approximately 13 minutes. The questionnaires in this study consisted of between 30 and 50 items, but in many cases every second item was not a new idea but merely an item that requested the student to express a level of confidence in their response to the previous question.

Response rates can be improved by personalised email invitations, follow-up reminders, pre-notification to the questionnaire and simpler formats (Archer, 2008). A disadvantage, as was the case in this study, is that one gets to the point where people are so bombarded by questionnaires that simply ‘tune out’ (Couper, 2000). According to (Couper, 2000) the major
sources of error in web-based questionnaires involve sampling, coverage, non-response, and measurement error.

According to Couper (2000, p. 475), “Measurement error simply stated is the deviation of the answers of respondents from their true values on the measure.” The issue arises in that self-administered instruments lack the clarity and motivational aspects that are brought to the instrument during an interviewer administered instrument. Fan and Yan (2010) identified poorly worded questions as a major contributor to measurement error as these questions are often misunderstood, resulting in an inaccurate answer, and in the case of web-based questionnaires there is no one present to clarify items.

It is accepted that a slightly different approach or attitude towards the ethical issues of confidentiality may need to be considered when dealing with online questionnaires. These issues are considered in Section Eight of this chapter under the heading of ‘Ethical Consideration’ and include the use of passwords, anonymity/confidentiality, storage of data et cetera.

This study used three questionnaires, namely, Science Teacher Efficacy Beliefs for pre-service primary school teachers (STEBI-B), subject content knowledge for the energy concept (SCK-EC) and pedagogical content knowledge for the energy concept (PCK-EC).

5.2.1 Format of the questionnaires

All the questionnaires in this study were web-based and consisted of a combination of a number of different styles of items, for example, Likert-style scales, multiple-choice (MC) type items (including a number of different MC styles) and open-ended response items. According to Haladyna (1994), a number of factors impact on the choice of item style, such
as, the ease of item and test construction, administration, scoring, analysis and evaluation of test items, the role of guessing, reliability and validity. Many of the items utilised in the questionnaires in this study, required a response (either by directly-linked responses within the item or as separate follow-up items) that would give some indication of the respondent’s confidence in the response (see Section 5.3).

*Likert-style items*

All Likert-style items in the web-based questionnaires used ‘radio buttons’ (i.e. blank circles next to each item option that requires the respondent to click with the computer cursor in the circle next to the option of their choice), thus forcing the choice of only one option. It should be remembered that all that can be inferred from a Likert Scale is rank order and that nothing can be said about the degree, or amount, of difference between the numbers (Bell & Opie, 2002, p. 202.). All the Likert-style items were coded, so for example, when the five options offered for selection were: Strongly Agree, Agree, Neither Agree nor Disagree, Disagree and Strongly Disagree, they were coded 5, 4, 3, 2, and 1 respectively.

*Multiple-choice items*

A number of different formats for multiple-choice items exist. The most common type used in this study was the distractor-driven type item. Sadler (1998, p. 265) claims that “Distractor-driven multiple-choice combines the richness of qualitative research with the power of quantitative assessment measuring conceptual change along a single uniform dimension.” The choice of the multiple-choice format in this study was motivated by; firstly the ability of MC items to identify students’ knowledge, misconceptions, beliefs or attitudes and secondly, as a result of standardised answers, the ease with which responses can be
compared and scored (Sadler, 1998). It should be noted, however, that when using multiple-choice techniques, guessing is always going to be a problem (e.g. a four-option multiple-choice item has a 25% chance of guessing). In an attempt to identify where guessing might have occurred many items in the questionnaires contained follow-up items dealing with the student’s confidence in their choice of option in the previous MC item. The option, ‘just guessed’, in the follow-up confidence item is important because it is a valid option in the types of items included in the questionnaires used in this study.

Haladyna (1994, p. 28) claims that “A common and long-standing misconception used by critics of multiple-choice is that this format is restricted to trivial learning, such as the recall of useless facts.” Badger (as cited in Haladyna, 1994, p. 28) cautions that “Even though it can be shown that an essay and equivalent multiple-choice test are highly correlated and that the multiple-choice test is more reliable, the responses to essay items in mathematics and science can reveal the nature of learning difficulty more certainly than choosing a wrong multiple-choice option.” This should not affect the questionnaires because the options are to a large extent based on misconceptions that have been well documented in the literature.

Haladyna (1994, p. 29) suggested that “If multiple-choice and essay scores based on the same content knowledge are highly correlated, which they invariably are, why not use the more efficient and reliable method?” and “Thus, the implication that essay format is best for measuring higher level thinking and that multiple-choice is best for measuring recall is simply not supported by current and past research experience, and current technology.” Martinez (as cited in Haladyna, 1994, p. 29) noted that when he used items with identical stems but that required different response options (multiple-choice or open-ended) that he “...detected student misunderstandings of the items from the essay test, information which is not normally
available from multiple-choice formats. Thus it would seem that some forms of essay testing provide insights into common student misunderstandings and failure to learn.” It is for this reason that a number of items in the questionnaires consisted of an open-ended or free-response style.

Open-ended response

Each questionnaire had a number of open-ended response items. The inclusion of this style of item was to allow for students to comment and provide ideas and suggestions that might not have been accessed in the Likert and multiple-choice items. Where appropriate these responses were coded, but in other cases the responses were used to support or provide credibility to the responses of some of the other item responses.

5.2.2 Piloting of the questionnaires

In this study, cognisance is taken of the statement that “All research instruments need to be piloted, no matter how small the investigation” (Bell & Opie, 2002, p. 55 & p. 192). If a questionnaire is to attempt to construct a semblance of construct validity then pilots of the questionnaires are essential, not optional. Haladyna (1994) noted that even with expert item development, as much as 40% of all new items could fail to perform as intended when first tried. This is an important point to consider when considering the merits of piloting. “Therefore, one should never overlook the opportunity to improve each item by subjecting it to review (Haladyna, 1994, p. 63).” After writing an item it must be reviewed (piloted) with the purpose of improving it. Haladyna (1994, p. 127) claims that “Both research and experience have shown that multiple-choice items are flawed in some way, so these reviews are much needed.” He also cautions that some researchers have noted that if an item already
works, then editorial changes can disturb its performance, while other researchers found that if style is edited there were no significant differences. We are also cautioned about the reordering of options, as this may also have an effect (Haladyna, 1994). There are two types of editing, that is, content editing versus statistical editing. Content editing means that content changes are needed because information in the item needs to be improved or corrected, while statistical alterations are as a result of statistics suggesting that a distractor is not doing what it was intended to do and is therefore removed or revised. “The two kinds of alterations may lead to different performances of the same item” and items that have been statistically altered could be regarded as new ones (Haladyna, 1994, p. 63).

The STEBI-B questionnaire has gained such a prominent place for itself in the science education literature (Aydin & Boz, 2010; Bleicher, 2004; Bleicher & Lindgren, 2005; Bursal, 2008; De Laat & Watters, 1995; Enochs & Riggs, 1990; Morrel & Carroll, 2003; Watters & Ginns, 1995) that it was deemed not to require a pilot study of its items. It is acknowledged, however, that all of the above researchers used a paper-and-pencil questionnaire and not a web-based approach. For reasons noted above, this difference is not considered substantial enough to have required web-based piloting of the questionnaire. On the other hand, the other two questionnaires, namely, the subject content knowledge and the pedagogical content knowledge questionnaires, despite including a number of items used previously by other researchers and ideas gleamed from the relevant literature, were trialled using two methods. Firstly the draft questionnaires were sent to five science lecturers within the department to scrutinise and evaluate and return with suggestions and recommendations to the researcher. This study also took note of Munby’s (1997, p. 338) reservation of this “panel of judges” approach that “…relies on a tenuous assumption: that the meanings test items have for judges
are in some way equivalent to those held by the students who are to take the test.” He says while this technique should not be rejected, it is insufficient to use for construct validation. The method of questionnaire construction for SCK and PCK followed what is referred to by Rohaan, Taconis and Wim (2007) as the “rational or content-orientated method.”

This method is classified as ‘intuitive’ and focuses on optimizing content validity. Rather than empirical data, judgments of experts are of particular importance for the specification and construction of items. This method is found to be especially useful if the central concept is conceptualized insufficiently and if empirical data are scarce. Both of these features apply to PCK…(p. 62)

Secondly, a small sample of second-year students (from the final sample) completed the questionnaire online and their responses were considered before the questionnaires were given to the whole cohort of students. Haladyna (1994, p. 138) cautioned that even when pilot studies were carried out, that “It is surprising how flaws are discovered by the test taker even after the items passed through all other reviews.”

According to Bell and Opie (2002), all questionnaires need to be piloted, but before the students were invited to complete the pilot-questionnaire, it was given to a panel of five science lecturers, all of whom were involved to varying degrees in pre- and in-service science teaching programmes at the NMMU. This was to ensure agreement on item relevance, that is, content validation in terms of integrity, validity and reliability. These lecturers were also asked to comment on the ability of the items in the questionnaire to determine the level of science knowledge and confidence in this knowledge, of pre-service primary school science teachers. Apart from a small number of editorial changes (e.g. spelling and grammar mistakes and formatting) the only disagreement was on the inclusion or exclusion of one item in the SCK questionnaire (viz. Item #5: Write down the first three things that you associate with the
term "energy". You may also like to expand on your associations in a sentence). The issue here involved the interpretation and usefulness of the item. It was finally agreed that while the item might be difficult to use statistically, it might provide some insight into the students’ ideas concerning energy. Once the questionnaire had passed the above ‘panel of judges’ phase (Munby, 1997; Rohaan, Taconis, & Wim, 2007) it was ready to be piloted.

Three months before the energy module was due to start, the questionnaires were completed by a small number (less than 10% of the total potential number of students). This small pilot group were self-selecting in that all the students registered for the course were invited, via email, to attempt the questionnaire. They were told in the email that it was a pilot questionnaire and that participation was voluntary. Once between five and 10 students had completed each questionnaire, online access was stopped. This pilot study resulted in a number of minor editorial changes and the removal of items that, while not being duplicates of other items in the questionnaire, were found to be so similar, that they did not add any new information or data.

5.2.3 Student choice

Each and every electronic web-based questionnaire began by briefly outlining the purpose of the study and the purpose of that particular questionnaire. Students were told that the questionnaires were primarily for research purposes but that they might help the student to gauge their own understandings of the energy concept. All students were given the option of not taking part in the questionnaire and some availed themselves of this option. After opening the questionnaire online, a number of students indicated that they did not wish to take part, but despite this, they still completed the questionnaire. On the other hand, some students
simply opened and then closed the questionnaire without responding to any items. Finally, a number of students simply did not go online to see what the questionnaires were all about. However, the response-rate, that is students who completed the questionnaires, was greater than 95% in all questionnaires.

5.3 Measuring confidence

Teacher self-efficacy, subject content knowledge and pedagogical content knowledge have, to greater or lesser extents, been linked to teacher confidence in teaching certain topics (Bleicher & Lindgren, 2002; Harlen & Holroyd, 1997; Jabot, 2002; Khwaja, 2006; Summers & Kruger, 1992).

Preece et al. (2004), in their study involving an audit of pre-service teachers’ content knowledge, did a correlation between content knowledge and confidence in the answers. They employed this correlation with respect to each item individually and then with their questionnaire as a whole. Their focus was on knowledge, so their four-point scale was labelled: Level 0 = no knowledge; Level 1 = some knowledge, insecure; Level 2 = basic knowledge, needs refreshing and Level 3 = secure knowledge. They argued that because they used specific knowledge statements in each question, they could use the above responses to determine a confidence score. While Preece et al. (2004) provided the initial idea for an item structure that would be capable of accessing confidence, it was decided that the possibility did exist in this study for the development of another item structure that might be better at accessing students’ confidence in their responses.

A first attempt at developing such a questionnaire item with the ability to access respondents’ confidence was developed. A Likert-type scale was tried in this first attempt,
but it became clear that the inherent problem with all Likert-type scales soon surfaced, that is, the consideration that it is not a continuous scale, in that the difference between numbers 1 and 2 and numbers 4 and 5 may, or may not, be perceived as the same. The second attempt at a confidence-item structure was the result of ideas generated by the researcher and student colleagues. This second attempt (see Figure 3) described the meaning of each number in more detail and thus avoiding the impression of a continuum that is often created by the Likert numbers.

**Choosing 1 means:** You have no idea at all about the answer and the only reason why you picked an option is because you were instructed to answer all the questions.

**Choosing 2 means:** You remember dealing with the topic (at school, university etc.), but you never understood it very well. This is not a wild guess, but you are unsure of your answer, AND/OR you recognise the correct answer because you learnt it off by heart at some stage, AND/OR you think your choice looks (sounds) correct because the words or terms used in it appear as if they could be correct.

**Choosing 3 means:** You are easily able to eliminate some options that you know are definitely wrong. You can narrow it down to two or three options that could be correct. You then decide which one is correct based on knowledge that you are a little unsure of.

**Choosing 4 means:** You very easily narrow the options down to two that could be correct. You then pick one based on knowledge that you are fairly sure of. You do, however, think that there is a small chance that you could still be wrong.

**Choosing 5 means:** You are able to eliminate options that are wrong and there is no doubt in your mind that you have chosen the correct answer.

*Figure 3.* The structure of the confidence items that was piloted using a number of student colleagues.
While the confidence-item version appearing Figure 3 may appear to be better from the point of view of describing the ‘values’ of the various numbers, it was found to be too cumbersome for people to work with in a long questionnaire. In all the piloting it became clear that each descriptor had to clearly indicate what made it different to the other descriptors in the series.

Ultimately two formats (or structures) for accessing confidence level were developed by the researcher for use in the SCK and PCK questionnaires in this study. The first of these formats is illustrated in Figure 4, where confidence was measured within the item itself. Students were presented with a statement and asked to select one option from the options given.

<table>
<thead>
<tr>
<th>For the next 27 items you will be given a statement and then asked to respond as to whether the statement is TRUE or FALSE. You have levels at which you may respond. These options are defined as:</th>
</tr>
</thead>
<tbody>
<tr>
<td>I know this is TRUE (You have absolute confidence you know the statement is true).</td>
</tr>
<tr>
<td>I think this is TRUE (You somehow think the statement is true, but you are not 100% confident it is true).</td>
</tr>
<tr>
<td>I have no idea (Choose this option if you understand the statement and context, but you really do not know the answer, or the best you could do, would be to take a wild guess at the correct answer).</td>
</tr>
<tr>
<td>I think this is FALSE (You somehow think that the statement is false, but you are not 100% confident it is false).</td>
</tr>
<tr>
<td>I know this is FALSE (You have absolute confidence you know the statement is false).</td>
</tr>
</tbody>
</table>

*Figure 4. Confidence levels within a question.*

While there appear to be five choices, there are in reality only three levels of confidence. The first and last options ‘I know this is TRUE’ and ‘I know this is FALSE’ are
essentially the same highest level of confidence. ‘I think this is TRUE’ and ‘I think this is FALSE’ can be considered to be a second level of confidence. While the ‘I have no idea’ is indicative of no confidence in the response. To summarise, Figure 4 is an attempt to ascertain the respondents’ level of confidence on three levels, namely, absolutely sure (I know this is TRUE and I know this is FALSE), reasonably sure (I think this is TRUE and I think this is FALSE) and not confident or just guessing (I have no idea).

The second confidence-type measure is a second item placed immediately after the relevant item in the questionnaire (see Figure 5).

<table>
<thead>
<tr>
<th>How confident are you that your response to the above question is correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Very confident</td>
</tr>
<tr>
<td>• Confident</td>
</tr>
<tr>
<td>• Not Confident</td>
</tr>
<tr>
<td>• Just guessing</td>
</tr>
</tbody>
</table>

*Figure 5. Confidence level measured by a follow-up item.*

For the recording of data, the confidence levels illustrated in Figure 5 were reduced from four possible levels down to three levels. This was done by collapsing the last two levels into a ‘no confidence’ level.

### 5.4 Questionnaires

#### 5.4.1 Science teacher self-efficacy belief instrument B (STEBI-B)

Riggs and Enoch (1990) developed an instrument to measure elementary teachers’ science teaching efficacy. The questionnaire that they developed was called the Science
Teaching Efficacy Belief Instrument (STEBI). Two versions of the questionnaire were
developed, namely STEBI-A for in-service teachers and STEBI-B for pre-service teachers of
science. The questionnaire used in this study was the STEBI-B version that consisted of 23
statements. An analysis of the responses to the various statements is able to provide two sub-
scores – one of the sub-scores yields a measure for the Personal Science Teaching Efficacy
Belief (PSTE B) subscale, while the other yields scores for Science Teaching Outcome
Expectancy (STOE). The two scales, PSTEB and STOE, which were identified by Enochs
and Riggs (1990) were found to be homogeneous and distinct. Of the 23 statements, 13
statements are specifically designed to give a score for PSTEB while the remaining ten
statements provide a score for STOE. Respondents use a five-point Likert-type scale to
respond to each of the 23 statements. The following response options were provided: strongly
agree (5), agree (4), uncertain (3), disagree (2) or strongly disagree (1). Some statements are
positively worded while others are negatively constructed. Where the statement was
positively constructed then the scoring is five points for ‘strongly’ agree and decreasing in
points to an allocation of one point for ‘strongly disagree.’ The negatively worded statements
are scored by reversing the numerical values. The possible range of scores is 13 to 65 for
PSTEB and 10 to 50 for the STOE subscale. These two scores cannot be added together or
aggregated because they measure two different aspects of science teaching self-efficacy.
High scores on PSTEB indicate a strong belief in one’s ability to teach science, while high
scores on the STOE indicate high expectations with regard to the outcomes of science
teaching on learner’s achievement – that is, the teacher’s belief that student learning can be
influenced by their effective teaching. The specific items allocated to the two subscales and
the scoring is indicated in Appendix E1.
The STEBI-B instrument has been shown to be a robust instrument for measuring self-efficacy. Over the past two decades the validity and reliability of the STEBI questionnaires have been assessed on numerous occasions (Enochs & Riggs, 1990) and revisited by Bleicher (2004) and others. The internal reliability, Cronbach’s alpha of the self-efficacy scale and for the outcome expectancy scale was determined by Riggs and Enochs (1990) to be 0.89 and 0.76 respectively. The instrument’s robustness can also be seen in the sense that, while it was originally designed for English speakers, it has proven successful when translated into other languages (Aydin & Boz, 2010; El-Deghaidy, 2006; Yilmaz-Tuzun & Topcu, 2008). Despite the fact that English is the language of teaching and learning of the students in this study, the majority of students were not English home language speakers. It is for this reason that small language adaptations were made to the STEBI-B instrument. See Appendix E1 for an indication of the specific words that were changed. The two types of adaptations involved, firstly the changing of specific words into the South African equivalent, for example, replacing of the word ‘student’ with ‘learner’ and ‘grades’ with marks et cetera, and secondly, replacing words such as ‘monitoring’ with ‘managing’ and ‘inadequacy’ with ‘shortcomings.’

Two issues need to be taken into account when using the STEBI instrument, namely, the ‘ceiling effect’ and the time within the study that the instrument is administered.

In this study the STEBI-B instrument was administered just before the start of the intervention (i.e. the lectures and toy workshops on energy) but after the students had previously completed two science courses or modules. Aydin and Boz (2010) suggest that before one plans activities designed to enhance self-efficacy, one should have sufficient evidence to determine whether the respondents’ self-efficacy is high or low. They suggest
that the best time to administer self-efficacy measuring instruments is before the students have undertaken any science (i.e. in their first-year of study). This was not the case in this study and this could have lead to the second issue, namely, the ‘ceiling’ effect.

According to Roberts, Henson, Tharp and Moreno (2001), there is a suggestion that self-efficacy instruments may suffer from a ceiling effect, that is, the instrument may be limited in providing enough range for respondents who initially scored high on the instrument, to be able to demonstrate that there is improvement after intervention.

5.4.2 Subject content knowledge (SCK) questionnaire on energy

This section deals with the development of the Subject Content Knowledge: Energy Concept questionnaire (SCK-EC). The purpose of this questionnaire is to ascertain the levels of understanding of energy by Intermediate Phase (IP) student teachers prior to, and after, a specific intervention, namely, the teaching of energy using simple toys via two energy-toy workshops. All students would have at various points in their lives come into contact with the energy concept, and as such, should have some ideas, albeit incorrect or muddled, pertaining to the energy concept. As a consequence of this, the SCK-EC questionnaire, in addition to accessing the IP students’ understanding of energy, also tries to determine the student’s confidence in the accuracy or correctness of this understanding.

Children’s understanding of the energy concept has been investigated intensively over the last few decades (Driver & Millar, 1986; Duit, 1984; Duit & Haeussler, 1994; Millar, 2005; Finegold & Trumper, 1989; Trumper, 1997; Trumper, 1998; Trumper et al., 2000). The results of these studies have produced numerous lists of learner (and student teacher and
teacher) misconceptions with respect to energy. It is these fundamental misconceptions that underpin the items included in the SCK-EC questionnaire.

A starting point in the development of the SCK-EC questionnaire was a scouring of the Natural Sciences curriculum for the primary school (DoE, 2002) in search of references to energy. On completion of this analysis a comparison was carried out between this ‘curriculum list’ and a ‘list of common misconceptions (or alternative conceptions)’ gleaned from the research literature referred to above. This process produced a list of fundamental ideas relevant to the teaching of energy in the primary schools and as such produced a number of focus ideas on which to base the SCK-EC questionnaire’s items.

With this list of focus ideas in mind, a literature search sourced a number of items that have been used in the past to determine understandings of the energy concept (DoE, 2005; DCSF, 2003; DCSF, 2009; Finegold & Trumper, 1989; TIMSS & PIRLS, 2009; Trumper, 1998; Trumper, 1997; Trumper et al., 2000). Using this range of literature enhanced the level of content validity, that is, the questions were representative of the content related to energy concepts as found in the literature.

The items used in this study were sourced from three main sources, namely, Trends in Mathematics and Science Questionnaire (TIMSS & PIRLS, 2009), DCSF (2009), and Trumper et al., (2000), who in turn drew their questions from a number of previous validated studies on energy concepts which are summarised in Appendix C2.

According to Sadler (1998, p. 267), “…qualitative methods have been and continue to be the most productive way of investigating children’s ideas in science, multiple-choice tests offer some benefits” and as such, this study utilises a combination of multiple-choice, open-
ended (essay) and true/false formats to access the common understandings of the energy concept of pre-service IP students. The questionnaire also set out to ascertain the student’s confidence in their accuracy and/or validity of many of the items. Two approaches were utilised, namely, implicitly within the options and explicitly by means of separated subsequent items.

5.4.3 Pedagogical content knowledge (PCK) questionnaire: energy concept (PCK-EC)

According to Rohaan et al. (2007), a number of methodologies and techniques have been used to examine PCK in science education. They categorised these methodologies into three groups, namely, concept mapping techniques, multi-media evaluations and select-response instruments (e.g. multiple-choice questions). In addition to these three categories, Riese and Reinhold (2010) measured what they referred to as declarative PCK and procedural PCK by means of open-ended questions. By using these methodologies, a number of researchers (Millar 2005; Yuenyong & Yuenyong 2007) have identified the key elements of PCK that a primary school teacher should possess to enable them to teach the concept of energy. These elements of PCK can be divided into two broad themes, namely, the scientific idea of energy and the everyday idea of energy. These two themes formed the basis for the items used in the PCK-EC questionnaire.

Despite the above investigations into PCK in science education, Lange, Kleickmann and Moeller (2010) claim that, before their investigation of PCK in the primary school, direct measures of PCK that allow for statistical analysis, were rare in science education and almost non-existent in primary science education. The structure of the Pedagogical Content Knowledge: Energy Concept (PCK-EC) questionnaire developed for this study, followed a
similar test construction as the one used by Lange et al., that is, multiple-choice and free-response items that assessed two aspects of PCK, namely, ‘knowledge of learners’ understandings’ and ‘knowledge of instructional strategies.’ Knowledge of instructional strategies involved questionnaire items that required teachers to provide snippets of teaching strategies that would assist them in promoting learner understanding of energy, while items related to learner alternate conceptions were used to evaluate the student’s knowledge of learner understandings. As was the case in the development of the SCK-EC questionnaire the ideas and concepts used in the PCK-EC questionnaire were drawn from the literature surrounding the teaching of the concept of energy.

5.5 The toy workshops

This study, with its focus on the effectiveness of toys as an educative curriculum material to assist in the development of Intermediate Phase students’ understanding of energy, requires an appropriate setting in which to be sited. The Intermediate Phase BEd pre-service programme at the NMMU has such a vehicle in one of the Natural Sciences modules of the programme. This specific module, PICN301 – Energy and Change, is a second-year one-semester module consisting of 14 weeks of contact sessions, where two 90-minute lectures are scheduled per week.

A number of different aspects of energy are included in the module (e.g. energy in food chains, energy in sustainable development etc.), however, it is during the first half of the module that the concept of energy is introduced from a teaching and learning perspective. Lectures during this time focus on subject content knowledge and pedagogical content knowledge with respect to energy and, while toys might be used at different times to illustrate
some aspect of the lecture, it is in two 90-minute workshops, devoted exclusively to the use of toys in the understanding of energy, that one can investigate the appropriateness of toy as and educative curriculum material to impact on pre-service students’ understanding of energy. The aim of the workshops was to promote a clearer understanding of energy by encouraging students to identify and explain the relationship between the toys and various aspects of energy.

During this series of two toys workshops, students actively worked with toys and responded to a number of different questions related to the concept of energy. These questions were both orally from the lecturer and fellow students, and written, on a prepared worksheet. Each student interacted with at least seven different toys during the two workshops, and each toy was chosen to explore a slightly different aspect of energy. The actual toys used varied from year to year, but they all required differing depths of understanding of the energy concept.

The workshops were divided into three parts. Parts I and II consisted of eight and seven groups of toys respectively. The first workshop contained only Part I, while the second workshop contained Parts II and III. Each group of toys was grouped with respect to the certain commonalities, for example, one group consisted of toy guns, another was a group of toys cars, or there was one consisting only of musical wind instruments etc. The students were required to ‘play’ with a total of 11 toys (one from each of six groups in Part I and one from each of the five of the groups in Part II). Part III of the questionnaire, in the second workshop, required students to respond to a number of questions that referred to their confidence in understanding energy, the impact, if any, of using the toys in the development
of their understanding of energy and whether they would use toys (similar to the toys used in the workshops) when they started to teach energy to IP learners.

As a result of the pilot studies carried out in previous years it became clear that with a large group of students one could not simply have 30 – 40 different toys spread around a room. The organisation of the workshop was too complex and difficult. As a result of these pilot studies it was decided to group toys with similar characteristics, or other commonalities, together and let students work in groups with collections of toys. In this way students could, within a group, still work with their own individual toy and in addition benefit from interacting with their colleagues.

Part III of the toys workshop consisted of 16 questions. Students were required to complete all 16 questions. Some of the questions required students to respond on a five point Likert-scale, while others required open-ended responses.

5.6 Web-based content knowledge assessment

A week after completing the two toy workshops on energy, all students answered a web-based assessment consisting of 12-objective type questions (i.e. multiple-choice, true/false etc.) involving the understanding of energy content. This assessment was completed electronically online by each student in their own time (i.e. asynchronously). One of the potential pitfalls of asynchronous web-based assessments is the potential for one student to simply duplicate the responses of another student. For this reason the assessment was structured in such a way so that no two students had exactly the same assessment. This was achieved by using the Moodle® feature that allowed for the random selection of questions from a data bank of questions. While five of the questions were the same, or
common, for all students, the remaining seven questions were randomly chosen by the computer from a question bank of 20 questions. This question bank contained six questions based on two of the toys used in the toy workshops (viz. ‘Angry man’ and ‘Kreepy Crawlie’) and 14 of the ‘energy statements’ used in the subject content knowledge questionnaire (see Appendix C4). One of the common questions asked of all students was a question that asked them: “How confident are you that you will be able to teach energy to an IP class?” This question was not used to determine a final score for the student.

5.7 Post-course written assessment

On the completion of the energy intervention on which this study is based, students were given a written assessment involving items related to PCK. The lecture group was too big for one venue, so two slightly different assessments were constructed. The items included in these assessments can be found in Appendix D3.

Four PCK concepts were addressed in these written assessments. The first item dealt with a teaching strategy that involved energy conservation and the Sankey energy diagram (see Figure 2 in Chapter 2). The second item assessed students’ understanding of what makes energy difficult to teach, while the third item attempted to assess the students’ understanding of the confusion that arises in learners as a result of the difference between the ‘scientific’ and ‘everyday’ interpretation of the energy concept. Lastly, students were asked to identify two common misconceptions related to energy, and to offer possible teaching strategies that could effectively address these misconceptions.
5.8 Assignment: Teaching energy in the Intermediate Phase

On the completion of the series of lectures on energy and the toy workshops the students had to complete an assignment entitled: *Teaching the Energy Concept in the Intermediate Phase*. This assignment was assessed and formed part of the student’s final assessment for the module. The form that the assignment took was an essay, but the required headings were prescribed for them in a supplied pro-forma (Appendix D2). After the assignments were assessed they were scoured for themes or threads that appeared to be common to the majority of assignments. As the assignment had to be completed on a prescribed pro-forma these threads or ideas were more easily identified than would have been the case in a free-writing essay. The pro-forma structure of the essay required students to discuss the following energy related ideas:

- Alternative and/or misconceptions related to energy
- The transfer/transform energy debate
- The use of toys as an educative curriculum material in the teaching of energy

6. DATA ANALYSIS

A mixed-methods approach was used in this study and as such both quantitative (statistical) as well as qualitative methods of analysis were generated. Data were collected from eight sources or instruments, namely, participant writings, three questionnaires (STEBI, SCK and PCK), toys workshops, web-based assessment, written assessment or test and a written assignment (see Appendix A). The data generated by these sources dictated two types of data analysis, namely, statistical and qualitative. Statistical analysis involved the use of
Microsoft Excel® and an online web-based calculator (Wessa, 2010) for both descriptive and inferential statistics, while the qualitative analysis used mainly a coding method of analysis.

The data for the various questionnaires, namely, subject content knowledge (Appendix C1), pedagogical content knowledge (Appendix D1) and science teacher efficacy belief instrument (Appendix E1) were analysed to obtain descriptive and inferential statistics. The descriptive statistics that were obtained included sample sizes (n), medians, mean or average scores (x̄), standard deviations (SD), change in mean scores (∆x̄) and percentage gain (Appendix B1). Cronbach’s alpha (α) for internal reliability and Cohen’s d for effect size were also calculated.

A number of inferential statistics were also used in this study and a summary can be found in Appendix B1. The Student’s t-Test together with degrees of freedom (i.e. df = the sample size n – 1) and statistical significance p, as well as Cohen’s d for effect size were all determined. This p-value gives an indication of the believability of the relationship between the variables and is referred to as statistical significance. The standard acceptable value for p that would indicate a relationship that is not random, in other words, that the difference (variance) is possible due to an intervention and not merely random, is p < .05 for this type of social sciences study (StatSoft, 2010). This value of p < .05 is, however, referred to as borderline statistically significant and the ideal is to have p-values that are smaller than p ≤ .01. The higher the p-value the less one can believe that the differences are due to a particular intervention and a value of p ≤ .05 still involves a high level (5%) probability of error. Results that are significant at the p ≤ .01 level are commonly considered statistically significant and those where the p-value is less than or equal to .005 or .001 levels are often called referred to as ‘highly’ significant (StatSoft, 2010).
Cohen’s d is an effect size used to indicate the standardised difference between two means and its value is considered to be trivial if $d < .2$, small when $d$ is in the range of $[.2 \text{ to } .5)$, moderate significance occurs when $d$ is in the range $[.5 \text{ to } .8)$ and if the $d$-value is $0.8$ or higher, then the significance is considered to be high.

As noted previously in this chapter (Section 5.4.1), Roberts et al., (2001) introduced the concept of the ‘ceiling effect’, that is, respondents who initially scored high on an instrument have little room to demonstrate improvement (e.g. a person who initially scores 90 out of 100 can only improve by a maximum of 10, while someone who scores 50 out of 100 at the first attempt can subsequently improve by a maximum of 50). Roberts et al., (2001) raised the relevance of the ceiling effect for efficacy-instruments only, however, the effect might be just as relevant to other forms and types of questionnaires as well. The statistician (D. Venter, personal communication, September 28, 2010) consulted in this study suggested an innovative approach that, faced by the challenge of the ceiling effect, could act as a better indicator of change, namely, ‘percentage gain of potential.’

The concept of ‘percentage gain of potential’ was considered a more productive route than simple increases in raw scores, or difference or percentage difference, as an indicator of improvement (D. Venter, personal communication, September 28, 2010). Percentage gain of potential is defined as the percentage of the maximum possible improvement that an individual respondent could make. For example, if a person scored 90 out of a possible 100 in the initial test, and then scored 95 in the post-test, their gain was 5 out of a maximum possible gain of 10, giving a percentage gain of potential of 50% of the maximum possible gain. On the other end of the scale, a person who improves from 50 out of 100 to 75 out of 100, also has a 50% gain (i.e. an improvement of 25 points out of a maximum possible improvement of
50, thus giving a percentage gain of potential of 50%). It should be noted that percentage gain of potential can also be negative, that is, where the decrease in score is taken as a percentage of the maximum possible decrease in score.

The above descriptive statistics describe only the specific sample group of this study. It is possible to use the data from this study to present some inferential statistics, that is, to test if these data could be utilised in a more general manner.

7. SAMPLE AND SETTING

According to Brown and Dowling (1998, p. 29), “The selection of an empirical setting is very often a matter of seizing an opportunity.” The sampling method used in this study might be considered to be opportunity or convenience sampling as the sample consisted of a controlled (fixed) number of students in a particular course or programme that had been designed by the researcher. Lankshear and Knobel (2004) have referred to this form of sampling, where the respondents are hand-picked, as purposeful sampling. Whatever definition one wishes to adopt for this type of sampling (i.e. opportunity, convenience or purposeful), the opportunities to generalise are rather limited. As noted above, this research study follows a quasi-experimental design and the sampling technique can be categorised as purposeful sampling, that is, a technique where the units (i.e. the individuals) were selected based on their suitability to provide possible answers to the research questions. The research questions in this study refer to a particular group of students (viz. pre-service Intermediate Phase students) who are registered for a particular module (viz. PICN301: Energy and Change) in which a specific educative curriculum material (viz. toys) plays a dominant role, and as such, purposeful sampling is the most appropriate sampling method to use. In other
words, the respondents were selected with a specific purpose in mind, rather than through a random selection process (Teddlie & Yu, 2007).

8. ETHICAL CONSIDERATIONS

A number of writers suggest that researchers have a right to collect data from people by various means, such as interviews, questionnaires, observation et cetera, but, not at the expense of the rights and privacy of the people supplying the data (Cohen et al., 2007; Mouton, 2001). Bell and Opie (2002, p. 44) stressed that when researching within one’s own organisation, as is the case in this study, that one can never assume that it is “bound to be all right” (i.e. that respondents will automatically give their implicit permission to use their data and that all data one collects, by whatever means, is available for use without first obtaining explicit permission to use the data). In this study ethical approval was obtained from the research ethics committee of the Nelson Mandela Metropolitan University (Appendix H1).

With respect to ethical considerations all researchers should be aiming at the principle of ‘informed consent’ (Bell, 1999, p. 39, Cohen et al., 2007). Within this principle respondents are clearly informed about the research and the possible implication to them of taking part, after which they are given the option to take part or not (Cohen et al., 2007). This principle was adhered to by sending an email to all students registered for the energy module, before the start of the module, in which they were told about the purpose of the research (Appendix H2). The concept of informed consent was the reason for the inclusion of the first item in the various questionnaires, where respondents were given background information about the research (e.g. the purpose of the research, contact details of the researcher, implications for confidentiality and anonymity etc.) and they could then chose to continue or
not to continue with the questionnaire (Appendices C1, D1 and E1). The acceptance by the student to continue with the questionnaire (item #1 of the various questionnaires) was considered sufficient to constitute written permission for the use of their data in this study.

Anonymity and confidentiality are always going to present an issue when data are collected via the Web. The ethical standards of any questionnaire are of great importance and another possible cause of non-responsiveness for web-base questionnaires (Couper, 2000). Many people may have in the back of the minds a quote from (Gaiser & Schreiner, 2009, p. 14) “Can someone ever really be anonymous online?” To make it quite clear that the possibility exists to negate anonymity, students were told up front, that this possibility existed, but that it was not the intention of the researcher to exploit this avenue. It was made clear via the first item on all the questionnaires and on introductory and follow-up emails, that while anonymity was not guaranteed, confidentiality was promised.

9. METHODOLOGICAL LIMITATIONS

One of the biggest methodological limitations in this study is the limited generalisability. Also the lack of random assignment in a quasi-experiment design has the effect of potentially lowering the internal validity when compared to a ‘true’ experiment (Lankshear & Knobel, 2004, p. 152). Despite this, a number of data sources were used to provide ‘credibility’ via triangulation (Creswell & Plano Clark, 2007) and as such the findings of this study should be able to contribute to the debate in science education research concerning the concepts of self-efficacy, subject content knowledge and pedagogical content knowledge.
10. CHAPTER SUMMARY

This chapter started with an outline of the overall methodology and design of the research study, this was followed by a description of the participants and the motivation for choosing these particular participants. A number of data-collection instruments were identified, namely, participant writing, questionnaires and various assessment instruments. Each of these instruments was discussed in general terms as data collection instruments, and finally, as to how the data were to be analysed. The chapter concluded with a summary of the ethical issues involved and possible methodological limitations were considered.
CHAPTER FOUR

RESULTS AND FINDINGS

1. INTRODUCTION

The data generated in this study are presented in three main reporting types: two forms of statistical reporting, namely, descriptive and inferential statistics and the third type of reporting, namely, examples of qualitative responses of the students. The main thrust of the results in this study revolve around a series of pre- and post-questionnaires dealing with science teacher self-efficacy beliefs (STEBI-B), subject content knowledge focussing on the energy concept (SCK-EC) and pedagogical content knowledge that also dealt with the energy concept (PCK-EC). These questionnaires were administered just prior to, and just after, a four-week section of work or intervention that included, lectures, tests, assignments and two workshops that used a particular type of educative curriculum material, namely, simple children’s toys.

A general thread that is drawn throughout from these questionnaires is the student’s feeling of confidence with respect to their understanding and teaching of science (in particular energy). Links between improved science teacher self-efficacy, confidence, SCK and PCK are investigated and these data are interrogated with respect to the impact of the toys used in the workshops as educative curriculum materials, on these factors. These findings are complemented by data collected from participant writings, web-based content knowledge assessment, a written assessment and a written assignment on the teaching of energy, and finally, worksheets completed during the toys workshops.
2. DEMOGRAPHICS

The Bachelor of Education (Intermediate Phase) at the NMMU is a four year full-time pre-service programme that offers students a choice of one of two major study areas. Students may choose to follow a Bachelor of Education (Intermediate Phase) programme that focuses on preparing them to teach languages, or they may choose a BEd IP programme where the focus is on the teaching of mathematics and science. The respondents in this study had all chosen to follow the mathematics and science option. In this science and mathematics option they are required to complete three semester-long modules of the Natural Sciences. In their first year they take one Natural Sciences module: ‘PICN201 – Investigations and Scientific Literacy’. In their second year of the programme they complete the second and third modules, namely, ‘PICN202 – Matter and Materials’ and ‘PICN301 – Energy and Change’. It is this final Natural Sciences module, ‘Energy and Change’, that is the focus module in this study.

The four year period (2007-2010) saw a dramatic change in the demographics of students following the BEd (IP Science and Mathematics) programme. The 2010 fourth-year cohort of students, who started their programme in 2007, were recruited just prior to the full-scale implementation of the Fundza Lushaka bursary scheme, which targeted increasing the number of teachers in ‘scarce’ subjects (e.g. science and mathematics), as well as broadening the demographics of students who were to be trained as teachers, by focussing on previously disadvantaged students (viz. Black students and students from rural areas). As such the 2010 cohort of fourth-year students consists of 18, mainly white female students, while the 2010 first- and second-year cohorts, as a consequence of the Fundza Lushaka bursary scheme, are much larger (93 and 89 students respectively) and are culturally mixed. These two cohorts,
unlike the fourth year, and to some extent the third-year groups, represent a wide range of schooling background, as these students are drawn from a wide variety of schools (e.g. urban and rural, private and public, well-resourced and very poorly-resourced schools). As such it is important to note that the group of students on which this study is focused (i.e. the 2010 second-year cohort), are a ‘transition’ between classes which were previously dominated by students from ‘advantaged’ schools and the 2010 first-year cohort which is populated largely by students from previously disadvantaged schools.

Fleisch (2008), in his study of achievement in international, regional and national assessments (tests), identified a bimodal distribution of achievement in all the South African results, irrespective of the test or assessment. The majority, (between 70 and 80 percent) of school children from disadvantaged schools, achieved results that are shockingly low by international and even regional standards, while a minority (mainly learners from previously white and private schools), achieve around about the international norm. The pre-service students in this study came from each of the two modes of schooling mentioned by Fleisch (2008), and this is reflected in their participant writings.

3. VALIDITY AND RELIABILITY OF DATA COLLECTION INSTRUMENTS

Seven factors were identified for study (see Table 3). The three ‘confidence factors’ (i.e. confidence in teaching, confidence in understanding content and confidence with respect to pedagogical content knowledge) were extracted from the three main quantitative data collection instruments, namely, the Science Teaching Efficacy Belief Instrument for pre-service teachers (STEBI-B), the Science Content Knowledge for Energy Instrument (SCK-EC) and the Pedagogical Content Knowledge for Energy Instrument (PCK-EC). The STEBI-
B instrument provided two factors, namely, Science Teacher Outcomes Expectancy (STOE) and Personal Science Teaching Efficacy Belief (PSTEB). All seven of the factors’ data were presented on a 10-point scale with 0 being the minimum and 10 being the maximum value. This 10-point scale was decided on so as to facilitate possible comparisons of different factors’ data.

Cronbach’s alpha reliability coefficients (α) were used to measure the internal score consistency of the seven factors described previously for the students’ responses to the questionnaires they were required to answer. Table 3 provides the Cronbach’s alpha scores for both the pre-and post-questionnaires for each of the seven factors identified above.

Table 3

*Cronbach’s alpha (α) for the Seven Factors Isolated from the STEBI-B, SCK-EC and PCK-EC Questionnaires*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Code</th>
<th>Pre-questionnaire</th>
<th>Post-questionnaire</th>
<th>Cronbach’s alpha (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science Teacher Outcomes Expectancy</td>
<td>STOE</td>
<td>0.64</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Personal Science Teaching Efficacy</td>
<td>PSTEB</td>
<td>0.78</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Confidence in Teaching</td>
<td>Conf-T</td>
<td>0.58</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Confidence in Content</td>
<td>Conf-C</td>
<td>0.85</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>Confidence in Pedagogical Content Knowledge</td>
<td>Conf-P</td>
<td>0.71</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>Science Content Knowledge</td>
<td>SCK</td>
<td>0.70</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>Pedagogical Content Knowledge</td>
<td>PCK</td>
<td>0.47</td>
<td>0.72</td>
<td></td>
</tr>
</tbody>
</table>
Nunnally (1978, p. 226) argued that, while Cronbach’s alpha coefficients of greater than 0.70 are the recommended minimum value for reliability and internal consistency, in the early stages of basic research, coefficients between 0.50 and 0.69 are sufficient evidence of adequate reliability. With the exception of the two 0.47 indices, all the remaining indices fell above the minimum of 0.50, as required for reliability for the early stages of basic research. For the purpose of this basic exploratory study, the cut-off of 0.50 was sufficient to indicate adequate reliability (i.e. that the respondents understood what was being asked and that their responses were not random). Eight of the observed Cronbach’s alpha coefficients in Table 3 (plus possibly the 0.68) fulfilled the recommended minimum value for reliability, while two (0.47) fell just short. It can therefore be confirmed that while two of the summated scores derived from the individual measuring instruments fell short of the cut-off point, the remaining indices confirmed the reliability of the questionnaire items.

4. SCIENCE BACKGROUND

All the students involved in this study arrive for their first science module of the BEd (IP) programme with a varied school science background. A measure of their experiences of science was determined by two approaches, namely, by means of their highest level of school science and via participatory writings in the form of reflective essays.

4.1 Highest level of school science experience

The students, all of whom were Intermediate Phase Science and Mathematics pre-service teachers in their second-year of university study, were asked to indicate the highest
school level (year or grade) at which that took science and biology\(^4\). There were three possible subjects that they could have taken, namely, Natural Sciences (NS), Life Sciences (LS) and Physical Science (PS). In South African schools the Natural Sciences is only offered up to the end of the ninth year of schooling (Grade 9 or age 15) and is limited to a very basic understanding of a number of content areas (e.g. physics, chemistry, biology and earth sciences), while the Life Sciences and Physical Sciences are offered up to the end of formal schooling (i.e. Grade 12 or age 18). These data were summarised into three main categories, namely:

- students who had ended their school science experience with the Grade 9 Natural Sciences (this included some physics, chemistry, biology and earth sciences)
- students who had completed Grade 9 Natural Sciences and Grade 12 Life Sciences (this means that they had no Physical Science beyond Grade 9), and
- students who had completed Grade 9 Natural Sciences and Grade 12 Physical Science.

Figure 6 graphically illustrates these three groupings. As will be explained in the discussion that follows Figure 6, it is only the third category (i.e. the group that completed both the Natural Sciences and Physical Science) that can be considered to have had more than just an introduction to energy at school level.

\(^4\) The term ‘Biology’ was used in the questionnaire in place of ‘Life Sciences’ because the terminology has changed over the years and it is sometimes confusing to students.
An important aspect to keep in mind, especially during the discussion in the next two subsections (i.e. the subsections dealing with the impact of school science experience on subject content knowledge and on confidence), is that these three groups are not equal in number. The group with the lowest school science qualification (NS only) consisted of 18 students (25% of the sample), and they would have had no further school science experience. This implies that their experience of school science is only three years more than the level at which they will be expected to teach when they start their teaching careers. The other two groups, namely the NS and LS group and the NS and PS group, comprised 38% and 37% of the sample respectively. As far as having encountered the energy concept at school level, this would have been done by all the students who completed Grade 9 Natural Sciences, and then, at a higher level, only by the students who completed Grade 12 Physical Sciences. This means that 63% of the sample (i.e. the NS group and the NS & LS group) had only done

Figure 6. Number of students in each school science category.
enough school science to have covered energy at a very basic, or introductory level, while a
just over a third (37%) of the students (i.e. the NS & PS group), would have completed a
course involving the energy concept at an advanced (for school) level.

*Impact of school science experience on subject content knowledge*

All the students who answered SCK-EC questionnaire (n = 71) were grouped into three
categories according to their score on SCK-EC. The lowest category, ‘low-score’, were those
who scored less than 4 (maximum 10 on SCK-EC questionnaire), the middle category,
‘moderate-score’, were those with scores of between 4 and 6 (inclusive), and the highest
category, ‘high-score’, were those who scored more than 6 on the SCK-EC questionnaire. It
is suggested that to have sufficient understanding of energy content knowledge, and therefore
competent to teach the concept of energy to an IP class, the student should have a ‘high-score’
on the subject content knowledge questionnaire (i.e. a score greater than 6). As such, the
following discussion focuses only on students with scores greater than 6 on the SCK-EC
questionnaire.

Figure 7 is a graphical illustration that relates the number of students in the ‘high-score’
category, based on the scores in the SCK-EC questionnaire, to their highest level of school
science completed in both the pre- and post-intervention questionnaires.
Figure 7. Number of students in the ‘high score’ category as a function of the highest level of school science completed.

These data in Figure 7 can be used to show three ideas. Firstly, there is a positive relationship between the highest level of school science completed and the number of students in the pre-intervention SCK-EC questionnaire who were categorised in the ‘high-score’ category. Only 33% of students, who had the lowest level of school science completed, (i.e. NS only), were found to be in the ‘high-score’ category. On the other hand, 73% of the students who could be considered to have the highest level of school science completed, (i.e. NS & PS), could be categorised as ‘high-score’ students. The middle group, (i.e. NS & LS), had 48% of their members being categorised as belonging to the ‘high-score’ category. This indicates a clear positive relationship between highest level of school science completed and understanding of subject content knowledge with respect to the concept of energy.
A second idea that can be identified from Figure 7 is the positive impact of the intervention on the understanding of energy by each of the three groups (i.e. NS, NS & LS and NS & PS), as measured by the percentage of the group in the ‘high-score’ category for the pre- and post-intervention questionnaires. The largest increase, between the pre- and post-intervention questionnaire scores, of students in the ‘high-score’ category was in the NS group, where the percentage of students in this category increased from 33% to 66% of the group. There was a slightly smaller increase in the NS and LS group (from 48% to 78%) and the smallest increase occurred in the NS and PS group (73% to 92%). This smaller increase could be attributed to the so-called ceiling effect that was referred to in Chapter five, Section 5.4.1 (Roberts et al., 2001).

Finally, for all the students who completed the SCK-EC questionnaire, the percentage of ‘high-score’ respondents increased from 54% in the pre-intervention SCK-EC questionnaire to 80% of the total (n=71) in the post-intervention questionnaire.

*Impact of school science experience on confidence in subject content knowledge*

Embedded within the SCK-EC questionnaire (Appendix C1) were a number of items that were utilised to access the students’ confidence in their understanding of energy. This factor was labelled Conf-C (i.e. confidence in content knowledge). In a similar vein to the previous section on subject content knowledge, the Conf-C scores were divided into the same three categories (i.e. ‘low’ for scores less than 4 out of 10, ‘middle’ when the Conf-C scores were 4 to 6 inclusive and ‘high’ for score that were above 6). As was previously the case, only those students in the ‘high-score’ category were considered, as it is suggested that it only
students with high confidence in their understanding of content can make a positive impact on teaching this content.

Figure 8 is constructed to illustrate the impact of school science experience on confidence in content knowledge. Three trends, similar to those in Figure 7, were identified.

Firstly there is a positive correlation between school science experience and initial confidence in the understanding of content knowledge as measured on the pre-intervention questionnaire. The percentage students in the ‘high-score’ category for each group were 17% (NS), 41% (NS & LS) and 54% (NS & PS). Secondly, the intervention did appear to have a positive impact on confidence in that the percentage students in the ‘high-score’ category for each level of school science increased by 50% in the NS group, 11% in the NS and LS group and 23% in the NS and PS group.

Figure 8. Comparison between highest school science level completed and confidence in subject content knowledge SCK (Conf-C).
Finally, the overall increase for the whole sample of students in the ‘high-score’ category went from 39% before the intervention to 65% after the intervention.

4.2 Participant reflective writings

The second data source for school science experience was generated by participant writing. All pre-service primary teachers at the NMMU are given an assignment at the start of their very first science module. The assignment is entitled: “My experience in science during my school years.” The instructions are: You are required to write a 500 – 800 word reflective essay on your experiences in science during your school years. Include your experiences with conducting experiments and investigations. Discuss whether you think your past-experiences will affect your future performance as a science educator.

A number of common recurring themes were identified in these reflective writings. These themes represented either positive or negative experiences of school science and included: the role of the science teacher, the role of practical work, the perceived difficulty of the science, classroom environment, interest in the science as a subject.

4.2.1 The role of the science teacher

Of all the themes identified, it was the role of the science teacher in the student’s school science experience that tended to dominate all the pieces of reflective writing. The students’ reflective writings suggest that school science teachers have a profound effect on their learners when they are at school. Almost without exception, the students mentioned the role played by the teacher in their school science experience. These influences varied between being extremely negative to a reasonable number of positive impacts. As an illustration of this influence one student wrote: “I believe teachers influenced almost all my feelings towards
science. All this from my teacher unfortunately changed the way I valued science and I did not feel that science was that important to me (S085).” Another student was even prepared to put a number to the teacher’s impact: “To me I believe fifty percent of how a child does at school depends on the teacher (S033).” The quote below is indicative of ‘ebb and flow’ impact that different science teachers have on their learners’ attitudes towards science.

I have noticed that my whole attitude towards Science has changed over the years. The reason for this has been my teachers. If my teacher was positive about Science, I loved Science and I did well, but if the opposite occurred then I wasn’t interested in doing Science. (S054)

Many responses referred to primary school science teachers as making science exciting and enjoyable, but that at high school the science teachers became a more negative influence as a consequence of their using methodologies that often simply required rote learning from a textbook, after which regurgitation of facts in tests and exams were the order of the day.

I can distinctly remember my science teacher drilling cold hard facts everyday in class. During the lesson we had to underline certain facts in that book. After the lesson the teacher would hand out notes which were an exact repetition of the underlined ones in the textbook. It was expected of us to study these notes word for word, because we would have to produce this information in a test or exam. (S094)

and

There always seemed to be a feeling of uneasiness in his classroom. Because of this the classroom environment was always very dull and boring which nobody enjoyed. Although it may sound strange, this played a big part of me not enjoying science at school. (S046)

Teacher influence was often the dominant factor that students considered when they had to choose between continuing with, or dropping, science at the end of compulsory school science (Grade 9). Nearly a quarter of the students who wrote reflective essays (24% or 19
students) did not attempt either science or biology at the Grade 12 level. As noted by one respondent “Maybe if I had a better grade nine teacher I would of carried on with science (S071).” Taking at least one science module is mandatory for all prospective primary school teachers and many students still carry the negative school science teacher influence into their pre-service training. As one student noted “I have been scared of science because of my last teacher (S084).” Bursal (2008) claimed that if teachers were negative towards science this negatively affects their self-efficacy, and eventually leads to ineffective science teaching. This could have been the cause of many of the students’ views that they were exposed to ineffective science teaching at school.

Interestingly, it was not only the teacher who influenced students’ attitudes towards science. A number of students referred to their fellow learners as having a positive influence on their attitudes towards science, especially in the practical work. “I found that my classmates made a huge impact on my enthusiasm for the subject, even more than the teacher had (S063)” and “My classmates had a big influence on me, we all had this urge to find out what all science had to offer us therefore we always encouraged and motivated each other to work harder…(S051).”

4.2.2 The role of practical work

School science is seen by many pre-service teaching students as having something unique, something that has the potential to make it both enjoyable and exciting. This ‘something’ was referred to by students in a number of different terms, for example: experiments, practicals or practical work, investigations, hands-on, et cetera.
A number of different ideas with respect to practical work surfaced during this reflective writing exercise. The enjoyment, interest, excitement and motivational factor were well represented in all the writings. Comments similar to the following were common: “Doing some experiments kept everyone interested and focused (S017)” and “I enjoyed doing experiments…(S051)” and “I was never a fan of the science classroom, but one thing I enjoyed about science was the practical work, experiments and the scientific investigations (S044).” For a number of students, possibly because of the interest and enjoyment factors, practical activities were often the only thing that was remembered of their school science, for example “…, making a toy car move with elastic bands…(S004)” and “The way in which the experiments were presented has left a lasting impression on me (S056).”

It would appear that for some students the role of practical work in promoting science should not be underestimated, for example “Experiments were fun and interesting. They helped me question how things worked instead of accepting that it works (S054).” Some students saw the practical work as being complementary to the so-called theory, others saw it in a very different light: “I was always first in line when it came to the practical work in the science lab, but fell back when the time came to do the theory (S053),” and “I was never a fan of the science classroom, but one thing I enjoyed about science was the practical work, experiments and the scientific investigations. I hated the theory part of science… (S044).”

4.2.3 The perceived difficulty of science

In the eyes of many students, science is perceived as a difficult subject. Some of their sentiments are illustrated by the following extracts from their reflective writings:
• “Many learners view the word “science” as something to be feared …science has been made to seem intimidating to many people…” (S063)

• “Science, everybody thinks it is a difficult subject to understand. In some cases I would agree with those people.” (S078)

• “Science as a subject at school has always been dreaded by many students and I was one of them.” (S033)

In some cases the difficulty of science is real for many learners. The following example illustrates what many students expressed: “I left science in grade 9 because I felt I would struggle too much which left me with a negative attitude (S057).” Many myths concerning the difficulty of science surfaced on a number of occasions in the student writings. The stereotypical myths surrounding gender and social and intellectual standing can be seen in the following extracts:

• “Some learners believe that science is a subject only for A-students or only for boys…” (S063)

• “Significantly more females than males found science difficult to understand, whereas more males find science destructive and dangerous, as well as more suitable for boys.” (S026)

• “Our science teacher adopted the attitude that only selected people could do science and this made me feel stupid and incapable.” (S006).

The aura of ‘difficulty’ that surrounds science as a school subject caused one student to commented that many learners “…did not enjoy the difficulty of the subject” and that
“Science was seen as a ‘scary’ subject (S014).” Not surprisingly the difficulty, or perceived difficulty, was often related to, or the cause of boredom in the science classroom, for example: “In my opinion, science isn’t the easiest of subjects, it’s very dense and if not approached correctly, can be an absolute bore (S089).” In a number of instances the perceived difficulty of science was combined with the attitude and ability of the teacher, and as one student lamented: “He made the learners, most of them including me leave science because we no longer enjoyed and understood the subject (S018).”

4.2.4 The science classroom

The impact of the physical appearance of the classroom in which science was done appeared as a recurring theme in the students’ reflective writings about their school science experiences. This was a theme that could be identified when reference was made to science in the primary school. The following extract could be seen as summarising what many students felt.

The classroom should reflect the subject. In our primary science classroom plants, posters, animals in jars and a lot of other things were out on display. It kept us interested. When you got into that classroom you would get into the mood to learn more about science. (S017)

4.2.5 Interest and self-efficacy/confidence in science

This study involved pre-service teachers’ science teaching self-efficacy beliefs. It has been shown in Chapter two that self-efficacy beliefs have in some instances been linked to confidence, and in the light of this, it might be of interest to tease out some of the references to confidence in the students’ participatory reflective writings.
The following extract from one student’s writing encapsulates what many students felt:

They always told me to not take it (*science*) as a subject because I would not make it. I believed I was too stupid to do science and I did not want to be a Doctor (*sic*) or an engineer so I left science and did something else. (S059)

One student linked lack of confidence in science directly to the difficulty of the subject “The fact that people generally believe that science is difficult and only for gifted learners, causes learners to loose confidence and interest in their ability to learn science (S010).” This resonates with another student who made the link between content knowledge and her confidence in science “To have confidence, a teacher must have knowledge (S021)”. A common reflection on school science is illustrated by the comment that “Many learners do not possess an interest in science and do not feel confident (S052).” The lack of confidence in science knowledge and skills were expressed in a number of different ways by the responding students. The following extracts illustrate these interesting observations:

- “I just wish there was a way in which I could study it (science) without it being my ‘master’ or me being a ‘slave’ to science.” (S031)

- “Science period always made me feel as if I was a simple person living a complicated life.” (S074)

- “Even the word ‘science’ is synonymous with fear and anxiety.” (S028)

Students acknowledge the importance of having a teacher who is confident in his/her science knowledge, and this can be seen in this typical comment: “If a teacher is confident the learners will feel it and the class environment will become conducive for learning (S077).” In accepting this potentially non-negotiable condition for being a science teacher some students went on to reflect on what it meant for them – given their shortcomings with respect to
confidence in science. “My experience with science at school level definitely has an effect on my self-confidence in terms of having science as a subject, since I tend to doubt and have insecure feelings in terms of science (S032).” And finally, one student, after reflecting at length on his school science experience, concluded his assignment by saying “I question whether my limited knowledge (will) be enough to sufficiently, confidently and effectively uplift the children’s knowledge and skills (S091).”

In conclusion it can be seen that while many students had both positive and negative school science experiences, an overriding desire was to be better science teachers than those that they had experienced at school. One student concluded her assignment by saying “I am looking forward to teaching (science) and eradicating the fear of science as a subject (S011).”

5. SUBJECT CONTENT KNOWLEDGE

This study used two web-based online instruments to assess students’ subject content knowledge. The first instrument, Subject Content Knowledge - Energy Concept (SCK-EC), was administered as both a pre- and post-intervention activity. It consisted of a number of items, the majority of which could be considered items that assessed subject content knowledge, with the subject focus being the concept of energy (Appendix C1). The other items in the SCK-EC questionnaire were used to access demographic information of the respondents (students) and to determine their confidence in the understanding of the subject content knowledge. The SCK-EC questionnaire contained both objective-type items (i.e. multiple-choice questions, word matching, true or false questions etc.) and items that required the students to write short explanatory paragraphs or to express their own opinions.
The second instrument was a post-intervention web-base online quiz or test (Appendix C4), and unlike the SCK-EC questionnaire that consisted of both object and open-ended responses, this instrument consisted only of objective-type items (e.g. multiple-choice items, true or false items etc.). While some of the items in this second instrument were similar to those found in the SCK-EC questionnaire, they differed in that they were focused on some of the actual toys used in the toy workshops (e.g. ‘Angry man’ and ‘Kreepy Crawlie’).

5.1 Subject content knowledge questionnaire – energy concept (SCK-EC)

The difference between the pre- and post-intervention questionnaires was limited to three items that collected demographic information (i.e. items #2, #3 and #4 in the pre-questionnaire) as it was deemed unnecessary to collect this same information again in the post-intervention questionnaire. This resulted in 46 items common to both the pre- and post-SCK-EC questionnaires. Identical items from each questionnaire were compared to each other, but they did not necessarily have the same item number in both questionnaires, and as such, the item numbering of the pre-intervention questionnaire was selected for use in the following reporting on the data.

Data from the subject content knowledge questionnaire was generated in both quantitative and qualitative formats, and as such the following reporting on the data is divided into these two categories.
5.1.1 Quantitative data derived from the SCK-EC questionnaire

Thirty one items in the SCK-EC questionnaire were used to obtain both descriptive and inferential statistical data. The total raw score for SCK was calculated out of a maximum of 40, which was obtained by allocating one point for the correct response to each of the items (including the ten sub-items from item #6) used in the calculation of SCK. Item #6, (similar to a true/false-type item) required student to tick any of 16 energy-related statements that they considered or believed to be accurate or true. Despite a pilot study being carried out prior to the full administering of the questionnaire, five of the statements (Appendix C3, item #6 statements #6.3, #6.5, #6.7, #6.11 and #6.12) were identified as being problematic. Appendix C3 is a summary of these items and the reasons for their exclusion from the data. As a consequence of repeated references during the intervention to the misconception that “Energy is a result of an event or process” this item was added as item #6.17 to the post-intervention questionnaire. Item #6, statement #6.16: “Energy has always been confusing for me” was used in the confidence analysis of SCK. In the analysis on Microsoft Excel® spreadsheet, any tick that the students made received a coding of ‘1’ (i.e. they believed that the statement was true). This coding of a ‘1’ remained if the statement was in fact true, but if the statement was false, then the ‘1’ was changed to ‘0’.

The next batch of subject content knowledge items (Appendix C1, items #7 through to #33) consisted of 27 statements about energy (eight of these items were directly related to the energy ideas surrounding a toy similar to one that was used in the toys workshop (Appendix G1). Each question was designed in such a way so as to serve two purposes, firstly, to identify students who believed the statements to be ‘true’ or ‘false’, and secondly, to enabled

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5 Item #6 contained a number of individual sub-items. Ten of these items were used in the calculation of SCK.
students to express their degree of confidence in their answer (see section 8.2 of this chapter). The method that was used to achieve this can be seen in Figure 9. The statements were either true or false. If it was a true statement then the student could chose either of the first two options in Figure 9 and be credited with making the correct choice. Their confidence in their choice could then be gauged by whether they chose the first option (i.e. absolute confidence in the truth of the statement) or the second one, where the student would exhibit a certain degree of doubt in the correctness of their response. A similar argument is followed for the last two options if the statement were false. The middle option is supplied to allow for the student who really has no idea of the correct response to the statement.

- I know this is TRUE (You have absolute confidence you know the statement is true).
- I think this is TRUE (You somehow think the statement is true, but you are not 100% confident it is true).
- I have no idea (Choose this option if you understand the statement and context, but that you really do not know the correct answer, or that at best, your answer would be a ‘wild’ guess).
- I think this is FALSE (You somehow think that the statement is false, but you are not 100% confident it is false).
- I know this is FALSE (You have absolute confidence you know the statement is false).

*Figure 9: Options available to students for items #7 through to #33 in the SCK-EC questionnaire - Appendix C1*

The original coding ranged from ‘1’ = “I know this is false” through to ‘5’ = “I know this is true.” For the purposes of obtaining a score for SCK, the items were recoded. If the statement were ‘false’ then all the “I know this is false” statements remained coded as ‘1’ and the other responses all reverted to ‘0’. If the statement were ‘true’ then “I know this is true”
was recoded to a ‘1’ while the other four options reverted to ‘0’. Items #15 “Respiration uses energy” and #16 “Photosynthesis makes energy” were not included in the calculation of a SCK score because a number of students suggested words such as ‘uses’ and ‘makes’ created confusion for them (see the discussion of the open-ended item #34, where students were invited to comment on the energy statements and also see Appendix C3).

Item #35 (The Roller Coaster) was coded ‘1’ through to ‘6’ with ‘1’ representing position B and ‘6’ representing position G. These were recoded for SCK knowledge with the correct response (position F) allocated the number ‘1’, while the rest were all coded as ‘0’. This particular item could also be linked directly to the toy workshops where there were roller coaster toys (Appendix G1).

All of the remaining items that were directly relevant to SCK, (viz. items #40, #42, #44 and #46) were originally coded with the first option being allocated a ‘1’ and subsequent options being given sequential numbers. For the purposes of calculating the SCK score these items were re-coded so that only the correct option was allocated a ‘1’ and the distractors all received a ‘0’ code.

The above quantitative data were able to be used to obtain descriptive and inferential statistics. These data were subjected to various statistical functions using Office 2007 Microsoft Excel® and Statistica® V9. (A table containing all the descriptive and inferential statistics derived in this study can be found in Appendix B1 and B2).

The scores for both the pre- and post-intervention questionnaires were initially calculated as percentages and then reworked to a maximum of 10. This was done in discussion with a consulting statistician (D Venter, personal communication, September 28,
so as to facilitate the comparisons between the seven factors used in this study (viz. STOE, PSTEB, Conf-T, Conf-C, Conf-P, SCK and PCK, see Table 3).

The data set for SCK-EC was n = 71 (i.e. 82% of the class of 87 students completed both the pre- and post-intervention questionnaires). The mean for the pre-intervention questionnaire was 5.89 (SD = 1.36) and for the post-intervention questionnaire the mean score out of a maximum of 10 was 6.80 (SD = 1.39). The mean percentage gain in potential for SCK for this group of students was 21% (SD = 26.53).

The results of the paired Student’s t-Test for significance (t-value = 5.63, d.f. = 70 and p = .000) were statistically significant, in other words the change that was noted between the pre- and post-intervention questionnaire data, cannot be ascribed to a random change due to chance, that is, a p-value of ≤ 0.05 indicates that there is a 95% probability that the change is not due to chance. The descriptive statistic Cohen’s d, measures the effect size and encompasses three categories; small (d ≤ 0.2); medium (0.2 < d < 0.7) and a large effect size (d ≥ 0.7). In the case of these data Cohen’s d was 0.67, indicating that the effect size can be considered to be near the high end of the medium category, and as such the change can be ascribed to the whole data set and not just a few instances of the data.

5.1.2 Qualitative data derived from SCK-EC questionnaire

In an attempt to access the ideas about energy that students might have, item #5 asked them to write down the first three things that came into their minds that they associated with energy. A study of the responses to this item identified eight words/ideas/themes that appeared to dominate the students’ responses\(^6\). An unforeseen and unexplained occurrence

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\(^6\) The idea that ‘Energy causes something to happen’ surfaced only in the post-questionnaire.
was the sudden appearance in the post-questionnaire of the idea that energy acts as a trigger and cause things to happen. While this idea was not mentioned at all in the first questionnaire, it occurred as 6% of the words/ideas/themes identified in the post-questionnaire.

Figure 10 uses two pie-charts to graphically show the proportional prevalence of certain key words in both the pre-and post-questionnaires. Not all students wrote down three things, so no descriptive statistical data could be processed, but it might prove useful to compare the prevalence of these words/ideas/themes within a questionnaire and between questionnaires. Figure 10 illustrates the prevalence (as a percentage) of the idea within each questionnaire. It might be possible, by comparing the two pie-charts, to identify a change in prevalence of the ideas between the pre- and post-questionnaires, but this must be done cautiously, as the number of instances is different for the two questionnaires (i.e. 112 words/ideas/themes in the pre-questionnaire and 116 in the post-questionnaire).

The data revealed a reduction in the number of times unacceptable scientific ideas were mentioned in the post-questionnaire as compared to the pre-questionnaire. The main misconceptions that were less prevalent in the post-questionnaire were:

- Energy has to be linked to movement (down by 3%)
- Energy only applies to living organisms (down by 9%)
- The confusion between the terms energy and force (down by 12%)

The prevalence of acceptable scientific words/ideas/themes (viz. Energy conservation and the use of the term transfer) increased by 5%.
Figure 10: The percentage prevalence of key words/ideas/themes when students were asked to write down three words that came to mind when they heard the word ‘energy’.
The prevalence of the term ‘form’ increased from 15% to 30% in the pre- and post-intervention questionnaires. This term was previously used frequently in both textbooks and science teacher vocabulary, but recently there has been a move away from using the terms ‘forms of energy’ and ‘energy changing from one form to another’ towards the more acceptable concept of energy transfer (Millar, 2005). A possible explanation for this increase could be the frequent use of the term by students during the toy workshops.

Item #34 of the subject content knowledge questionnaire (SCK-EC) was an open-ended item that invited the students to comment on their understanding of energy and, where appropriate, to link these comments to their school science experiences with respect to the concept of energy. One student commented:

I found some of the wording tricky e.g. ‘respiration USES energy’. Technically energy is not used up, but is that what the question implied? Or did it imply with the word ‘use’ that energy is required for the process to work. (S041)

In the post-intervention questionnaire this same student commented

I still always think twice about statements which say things like ‘Respiration USES energy, because I am not sure if the question is asking whether energy is required for the process to work, or if the question is testing whether or not we know that energy is never ‘used’ up. (S041)

It was comments such as these that influenced the removal of some statements’ scores from the determination of the SCK score (e.g. items #15 and #16). While some comments (in item #34, pre-intervention questionnaire) illustrated an awareness of the concept of energy conservation, for example “At school we were taught that energy cannot be created or destroyed,…(S005)” the majority of comments were indicative of a state of confusion: “I never really understood the concept of energy and at school we didn’t do it in depth. So I am
still a bit puzzled (S074),” and “I’m not sure whether energy can be created or destroyed but the disappearing of it doesn’t seem true (S025),” and “I get confused with the terms force and energy (S013).”

Responses to item #34 in the post-intervention questionnaire did show that some students felt that they had a better understanding of energy after the intervention:

- “Compared to the first questionnaire, I think I am more informed and have a conceptual understanding of energy, even though I still have a problem with a few but all in all, my understanding has changed positively.” (S054)
- “I am getting to know something about energy now.” (S083)
- “I believe that there are many perceptions and misconceptions about energy, it is not always understood and often confused by other concepts. I for one am one of those people but slowly but surely I am beginning to understand energy a little better.” (S047)

One student ascribed her improved understanding directly to the toys “I learnt a lot these past few days about energy when we ‘played’ with the toys (S058).” On the other hand there were some student comments that clearly indicated that not all shared these feelings of improved understanding, for example, “I am honestly still a little confused (S044)” and “I get a little confused when we say force and energy are interchangeable!” (S072).

Item #37 was an open-ended item that asked for an explanation to the response given in item #35 (the roller coaster). The diagram that accompanied roller coaster item can be seen in Figure 11.
Figure 11: Diagram accompanying item #35 of SCK-EC: The Roller Coaster.

Students were asked to explain their choice of position to which they believed that the ball, originally in position A, would rise to when release. This open-ended item provided a pot-pourri of responses ranging from acceptable scientific explanations through to “I have no idea how to explain this question (S049).” No detailed analysis was possible for this item, except to consider the relationship between correct responses to item #35 and the explanations for these correct answers. Four categories of explanations were used:

- **Scientifically acceptable explanation:** e.g. “If the energy of the ball remains the same, it should reach the same height at which it was released.” “I don’t think the ball will reach G, unless more energy was put in.” “The ball can only go as far as it's potential energy, if the surface was flat the ball will go on and on.”

- **Partially correct idea:** e.g. “Position A and F is the same height and I don’t think the ball will go higher than that.” “Because it depends on how quick or how slow the ball is being released.” “if you release the ball it will always go to it original height.”
• Scientifically incorrect explanation: e.g. “It will definitely reach F as there is enough gravity in the downward movement to propel it to reach F.” “A force is being released when the ball rolls down from the rollercoaster.” “I think the height reached will be determined by how heavy the ball is and how much speed it travels by.”

• Just a guess or left blank: e.g. “I’m not sure it is just what I am thinking.” “I have no idea.”

Figure 12 does not give actual numbers, they are expressed as a percentage of number of students who correctly predicted the highest position that the ball would reach when released in item #35. These pie-graphs indicate that the proportion of students who gave scientifically acceptable explanations, or partially correct explanations, is noticeably larger in the post-questionnaire (69%) than in the pre-questionnaire (48%)
Trumper’s (1997) article provided the stimulus for items #38 and #39. A set of eight ‘energy’ diagrams were presented to the students and they were required to choose any two and write a sentence or two about the respective pictures using the word ‘energy.’ Figure 13 shows all eight diagrams from which the students could choose.

Figure 12. Explanations for correct answers to the Roller Coaster item #35.
Figure 13. Set of eight pictures used in items #38 & #39 of the SCK-EC questionnaire.

The method used to report on the data generated by items #38 and #39 was similar to that used in item #5 above. Because not all students chose two pictures in each of the pre- and post-intervention questionnaires, the number of times that a picture was selected was only utilised to indicate the popularity of the particular picture with respect to the other pictures chosen. The number of times that the picture was selected by students was expressed as a percentage of total number of times all the chosen pictures were selected within a particular questionnaire.

Figure 14 indicates that the pictures containing people (viz. ‘Pushing a box’ and ‘Football Player’) were popular choices in both questionnaires. Their combined popularity was 34% and 37% in the pre- and post-intervention questionnaires respectively.
Figure 14. Choices of 'energy' pictures.

Item #48 of the SCK-EC questionnaire asks students to comment on the statement: “If energy is conserved, why are we ‘running’ out of energy?” This item speaks directly to the issue of energy being made more complex as a result of the mismatch between a scientifically acceptable explanation of energy and the everyday use of the term. The pie-charts in Figure 15 follow the same style as was used in reporting the results of item #35 (see Figure 12). A
similar methodology was followed as with item #35, that is, the responses were categorised into four categories, namely:

- Scientifically acceptable explanation: e.g. “We are not running out of energy as energy is an abstract idea. However, we are running out of the fuels.” “No, you are wrong you are asking a wrong question; let me tell you we are not running out of energy, we still have energy, but it is a un-useful energy.”

- Partially correct idea: e.g. “We are not running out of energy, but are rather wasting energy by releasing too much of it. This energy that is wasted cannot be transformed into usable energy.” “Energy can neither be created nor destroyed.” “I think we are running out of fuel or energy resources which uses up energy and becomes useless to us.”

- Scientifically incorrect: e.g. “Energy cannot be conserved.” “The resources that we use to create energy are being used up.” “Because we are using different methods to make energy.”

- Just a guess or left blank: e.g. “that is just how it works I guess.” “I honestly do not know.”
Figure 15. Explanation for why we are ‘running out of energy’ item #48.

It can be seen from Figure 15 that the intervention had a substantial impact on students’ understanding of the relationship between the scientific concept of energy and the everyday idea.
The final item in both the pre- and post-intervention questionnaires was the open-ended response item #49, where students could add any additional comments that they might consider relevant to the teaching of energy in the primary school. As could be expected, based on Millar’s (2005) claim that energy is poorly taught and understood at schools, the comments in the pre-intervention questionnaire tended to be negative. A small selection of comments from the pre-intervention questionnaire, highlight this negativity and illustrate a lacuna in the teaching of energy at primary school, for example:

- “Energy was something that was not explained well in Primary school” (S011)
- “I urge that junior primary children be taught the truths and not just facts and myths about topics” (S033)
- “This is a very confusing topic and I believe that if teachers can clarify and correct their misconceptions then we have the opportunity to give children a better understanding of this topic in particular” (S035)

The comments in the corresponding post-intervention questionnaire illustrate a more positive perspective and reflect some of the activities carried out in the course of the intervention, especially with respect to the use of the educative curriculum materials, namely, the toys:

- “I enjoyed learning about energy. I will now be better equipped to teach it to my learners one day” (S015)
- “I think I’m feeling a bit more confident now to teach energy” (S046)
• “The teaching and learning of energy is a challenge, by using toys it is easier to understand the energy concept” (S048)

• “I think that the teaching of energy is a very interesting topic, it really does stimulate the mind process and allows you to draw your own conclusions when it comes to ideas about energy and its different forms. I think that it also creates a challenge for IP teachers as it is not always easy to explain the various concepts in simpler terms for the learners to understand. Once the concept is understood I think it will be very interesting for learners and fun especially when using toys to demonstrate various types of energy” (S005)

5.2 Web-based content knowledge assessment

This web-based assessment was completed by 93% of the 87 students who were required to complete it. The average score was 72% (SD = 12) and the scores ranged from 43% through to 97%. This average score is similar to the average score of 68% (SD = 13) achieved in the SCK post-intervention questionnaire (see section 5.1.1 previously in this chapter).

A tentative suggestion that the toys could have played a substantial role in the students’ improved SCK, lies in the fact that one third (11 out of 33) items in the SCK were based, either on identical or slight variation, of the toys that were ‘played’ with in the toys workshop, and 50% of the web-based assessment contained questions that can be directly linked to toys used in the toy workshops. However, the intervention consisted of a number of different teaching and learning opportunities (e.g. lectures, assignments, various forms of assessments, questionnaires etc.) that included the two toys workshops, and as such, it would be very
difficult to ascribe the positive changes in SCK solely or directly to a single specific educative curriculum material such as the one used in this study, namely, the toy workshops.

6. PEDAGOGICAL CONTENT KNOWLEDGE (PCK)

Three different tools were used to access students’ PCK. The main instrument used to measure PCK was a web-based questionnaire and these data were supported by two other instruments, namely, a written test and assignment, both of which had PCK as their main focus area. The combination of both quantitative and qualitative data from these three sources enabled the building of a picture of the students’ PCK. These quantitative and qualitative data are discussed in the following sections.

6.1 Pedagogical content knowledge questionnaire (PCK-EC)

The pedagogical content knowledge questionnaire (see Appendix D1) was designed to achieve two purposes, firstly, to determine a pre- and post-intervention scores for PCK and secondly to obtain a pre- and post-intervention scores for confidence in PCK. Both the pre- and post-questionnaires were identical and consisted of the same 32 items. The first item simply asked the students for their permission to participate and reminded them of the confidentiality of their responses. The items in the PCK-EC questionnaire that refer directly to confidence in PCK are not discussed in the section below as they are addressed in section 8.3 of this chapter.

6.1.1 Quantitative analysis

Items #2 and #4 were open-ended questions that required students to briefly describe each of the two teaching models (i.e. the transformation and the transfer models), by using typical words that a teacher who was teaching with the particular model might use. The
responses were coded using a ‘1’, if there was an idea of understanding, and ‘0’, if there was no understanding or no comment. Table 4 gives a few examples of the scoring.

Table 4

*Examples of the Scoring Used in Items #2 and #4 of the PCK Questionnaire*

<table>
<thead>
<tr>
<th>Item #2: Transformation Model</th>
<th>Item #4: Transfer Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Changing energy into something different (1)</td>
<td>• Movement of energy (1)</td>
</tr>
<tr>
<td>• If different forms or types of energy were named (1)</td>
<td>• Energy transferred from one object to another (1)</td>
</tr>
<tr>
<td>• Converting (1)</td>
<td>• Energy transferred between places (1)</td>
</tr>
<tr>
<td>• Transformation is the changing of something (1)</td>
<td>• Convert (0)</td>
</tr>
<tr>
<td>• If only the word ‘transformed’ was written down with no indication of what could be transformed (0)</td>
<td>• Change (0)</td>
</tr>
<tr>
<td>• Mentioned that the object was transformed (0)</td>
<td>• Types or different types (0)</td>
</tr>
<tr>
<td>• Changing for the better (0)</td>
<td>• Just say the word ‘transfer’ with no indication of what is transferred (0)</td>
</tr>
</tbody>
</table>

Items #3, #5 and #7 were used in the confidence in PCK section (Conf-P). Items #6, #8 and #10 referred to the two teaching models and the curriculum that the students will be required to use in schools. There was more than one acceptable response in item #8 (#8.2, #8.6 and #8.7), these all scored ‘1’. Scores of ‘1’ were allocated for the accepted responses to items #6 and #10.
The following three items required open-ended comment on these models. Only item #13 (the disadvantages of the transform model) was considered. In this item, examples of statements that were scored with a ‘1’ were:

- Implication that using different names for energy implied that there were different energies (1)
- An implication of a ‘concrete’ nature of energy (1)
- Introduction of an unnecessary variable (1)
- Learners will simply learn labels (1).

Item #11 was not used as it was simply an opportunity for general comment on the two models, and item #12, in which advantages of the transform model were required was also not used. It was also not considered as there should be little or no advantages of this model for the teaching of energy at IP level (DCSF, 2009; Millar, 2005).

Items #14, #15 and #16 all involved the typical terminology that could be used by a teacher who was teaching using a particular model. A score of ‘1’ for a correct response and a score of ‘0’ for an unacceptable response was allocated to items #14 and #15. Item #16 was coded with a score of ‘1’ being allocated when terms such as: ‘process’, ‘from place to place’, energy transferred from to …’ et cetera were used. When unacceptable terms such as: ‘changes to…’, ‘convert’, ‘energy used up’, ‘forms of energy’, ‘types of energy’, ‘transferred and changed’, et cetera were used, then a score of ‘0’ was allocated. Item #17, (viz. It has been suggested that it is better to introduce the energy concept in Grade 6/7 by associating it with fuels and food. What do you know about the teaching and learning of the energy concept that would support the above suggestion?) was not used in the calculation of the PCK score
as, in retrospect, it appeared to be misinterpreted by the students, in that the vast majority, in both the pre- and post-intervention questionnaires, simply referred to ‘facts’ that they knew about energy. During the course, associating fuels with foods was considered, but it was not used to introduce the energy concept, so students could not be expected to comment on this aspect of the association between fuels and food. Item #18 is not discussed here as it is another one of the ‘confidence in PCK’ items.

The next six items in the questionnaire all involved a consideration of various potential barriers to the understanding of energy. Items #20 and #21 both addressed a similar idea, which is the ‘using’ of energy. This in itself was problematic for some students (see Section 5.1.2, where student S041 commented on the interpretation of the term ‘uses’ in the context of discussing energy). As a consequence of this, item #20 was not utilised. The scoring was ‘1’ for an acceptable suggestion and ‘0’ for a suggestion that was not correct or unacceptable. When a student simply repeated the statement or said “I don’t know” then these responses were allocated a score of ‘0’. Examples of these barriers to learning about the concept of energy, and illustrations of acceptable and unacceptable items are illustrated in Table 5.
### Table 5

**Scoring of PCK Items that Referred to Barriers to Learning**

<table>
<thead>
<tr>
<th>Item (Barriers to the teaching of energy)</th>
<th>Acceptable (score ‘1’)</th>
<th>Unacceptable (score ‘0’)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item #19: Energy causes event to happen</td>
<td>● Energy does not cause events to happen, but rather makes the transfer from one thing to another</td>
<td>● This is true</td>
</tr>
<tr>
<td></td>
<td>● All events do not require energy to happen</td>
<td></td>
</tr>
<tr>
<td>Item #21: Energy is used up when doing exercise</td>
<td>● Some reference to transfer to surroundings</td>
<td>● Energy is not lost when doing exercise</td>
</tr>
<tr>
<td>Item #22: Energy is fuel</td>
<td>● Some reference to fuel being an energy resource</td>
<td>● Form of energy</td>
</tr>
<tr>
<td></td>
<td>● Energy is not a fuel</td>
<td></td>
</tr>
<tr>
<td>Item #23: Energy and force are interchangeable</td>
<td>● Need energy to exert a force</td>
<td>● Energy and force are not the same</td>
</tr>
<tr>
<td>Item #24: The world is running out of energy</td>
<td>● Energy sources are limited</td>
<td>● Because of global warming</td>
</tr>
<tr>
<td></td>
<td>● Energy cannot run out it is just transferred</td>
<td>● Energy is not used correctly</td>
</tr>
<tr>
<td></td>
<td>● Running out of energy resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Energy transferred to where we cannot use it</td>
<td></td>
</tr>
</tbody>
</table>
The next eight pairs of items were each initiated by a statement that referred to energy. The first item of each pair required the student to decide whether the statement was a misconception and/or whether, as a consequence of a lack of precision in the wording or terminology, it could be considered problematic from a scientific perspective. The second item of the pair required students to identify whether the statement was related to one of the misconceptions that were listed in the item-options (viz. energy is used up or created; energy is a kind of stuff; fuels are energy; energy makes things happen or energy and force are similar ideas). Three additional options were given in the event of the statement not being a misconception or not one of those listed or simply that the statement sounded like a misconception to the student. Students could tick as many of the options as they liked. Acceptable choices were allocated a score of ‘1’ and any options that were not acceptable were ignored in the calculation of the final score for PCK.

Item #41 referred to a teaching tool that is used to teach the conservation of energy. The model, the Dennis the Menace Model for Energy Conservation, was adapted from Richard Feynman’s work on the various models that could be used to illustrate energy transfer (DCSF, 2009). A score of ‘1’ was allocated for any, albeit on a basic level, understanding of the Dennis model. The final item in the questionnaire (item #42) was an open-ended one where students could add any additional comments on the teaching of energy.

Sixty eight or 78% (n = 87) of the students completed both the pre- and post-intervention questionnaires. The mean for the pre-intervention questionnaire was 2.25 (SD = 1.00) and for the post-intervention questionnaire the mean score, out of a maximum of 10, was 3.33 (SD = 1.47), (Appendix B1). Percentage gain of potential was used as an indicator
of improvement in PCK. The mean percentage gain of potential for PCK for this group of students was 9.47% (SD = 25.70).

Another method of considering change in PCK is to consider the categorisation of the PCK-scores into three categories (see Section 4.1 where this technique is first introduced), namely, ‘high’, where the PCK score is greater than six out of a maximum score of ten, ‘medium’, scores of four to six inclusive, and ‘low’, when the score is less than four. All three categories are presented in Table 6. This is different to the two previous sections, where this three-category approach was used (viz. Figures 7 & 8, SCK and Confidence in SCK), in that, they only reflected the ‘high-score’ category. Table 6 shows the categorised scores for both the pre- and post-intervention measure of PCK.

Table 6
The three-category grouping of PCK-scores for the pre- and post-intervention PCK-EC questionnaire.

<table>
<thead>
<tr>
<th>PCK-score (Max of 10)</th>
<th>Pre-intervention questionnaire</th>
<th>Post-intervention questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘low’ [0 – 4]</td>
<td>65</td>
<td>51</td>
</tr>
<tr>
<td>‘medium’ [4 – 6]</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>‘high’ (6 – 10)</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

A notable feature in Table 6 is large number of students in the ‘low-score’ category for both the pre- and post-intervention scores. This is despite explicit teaching of PCK strategies in lectures and the use of the toys as an educative curriculum material.
The results of the Student’s t-Test for significance (t-Value = 5.34, d.f. = 67, p = .000) indicate that these pre-post test data are statistically different (p < 0.00), while Cohen’s d for effect size was 0.65, indicating a medium to large effect size that indicates that the change can be ascribed to the whole group and not just a few individuals.

6.2 Post-course written assessment

On the completion of the intervention the students were given a written assessment involving PCK-type questions. The items in this assessment were considered to be of a PCK-type in that they included topics such as, Sankey energy diagrams, misconceptions and teaching strategies to address these misconceptions, as well as items related to the confusion caused by the different scientific and everyday interpretations of energy (see Appendix D3). Question one asked about the application of the Sankey energy diagram in either of two situations. A Sankey diagram (i.e. a specific graphical flow diagram that illustrates transfers of energy between processes and where the width of the arrows are proportional to the quantities of energy in the different processes), is an important PCK tool employed when teaching conservation of energy. The assessment allocated eight marks to this question on Sankey diagrams. A mark of seven or eight could be construed as indicating a sound knowledge of the Sankey diagram. Unfortunately, just over a quarter of the student (28%, n=23) were able to achieve at this level. A mark of between four and six (inclusive) was considered to show some understanding, but not at the level of mastery required to teach the concept effectively. Just under 50% (n = 41) of the students in this study fell into this category. A disappointing 23% (n=19) of students obtained three or less marks for the Sankey diagram and can thus be considered to be not competent in terms of using the Sankey diagram, which is an important piece of PCK.
The second question attempted to identify if the students knew the two ideas that Millar identified as making energy difficult to teach (Millar, 2005). Having an understanding of why energy is difficult to teach is probably one of the most fundamental aspects of PCK, and yet just over one third (36%, n=30) of the students had this knowledge or understanding, that is, they were able to mention both the abstract nature of the concept of energy and the muddling of the scientific definition and the everyday understanding of the concept. While a substantial majority (78%, n=65) mentioned the abstract nature, 14 students (16%) gave no indication of their knowing why energy is difficult to teach.

The final PCK-type item addressed in the written assessment revolved around energy misconceptions and the various teaching strategies that might be used by teachers when confronted by learners holding these misconceptions. Table 7 lists the misconceptions mentioned by the students as well as the number of times the particular misconception was chosen by them.
Table 7

*Number of Times a Misconception was noted in the Written Test*

<table>
<thead>
<tr>
<th>Possible alternative conceptions or non-scientific beliefs</th>
<th>Number of times it was mentioned (n = 83 x 2)(^7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Energy is seen as a type of fluid or concrete entity/Energy is a thing/Energy is fuel/Energy and energy resources are the same thing</td>
<td>50 (30%)</td>
</tr>
<tr>
<td>2 Energy gets lost/Things use up energy/We are running out of energy</td>
<td>44 (27%)</td>
</tr>
<tr>
<td>3 Energy has to do with movement or activity/Objects at rest have no energy</td>
<td>23 (14%)</td>
</tr>
<tr>
<td>4 Energy has to do with living things (Anthropocentric and an anthropomorphic)</td>
<td>19 (12%)</td>
</tr>
<tr>
<td>5 Failure to differentiate between energy and other physical terms e.g. force, gravity</td>
<td>8 (5%)</td>
</tr>
<tr>
<td>6 Energy makes things work/Energy is created by some action</td>
<td>3 (2%)</td>
</tr>
</tbody>
</table>

### 6.3 Assignment: Teaching energy in the Intermediate Phase

At the end of the intervention (i.e. lectures and toys workshops) the students had to complete an essay entitled: *Teaching the Energy Concept in the Intermediate Phase*. This assignment was assessed as part of their final assessment for the module. A pro-forma sheet

\(^7\) Each student was required to identify at least two possible alternative conceptions, hence the possible number of responses is 83 students multiplied by two. But not all students did in fact give two misconceptions, hence the percentages in Table 7 do not add up to 100\%.
(see Appendix D3) with the required headings, was provided to guide the students in their essay writing. A total of 83 students (98%) completed the assignment. After the essays were assessed they were scoured for themes. As the essays were completed according to a prescribed pro-forma these threads or ideas were more easily identified than would have been the case in a free-writing essay.

The reporting of the results from the essay follows the following threads: alternate conceptions of the energy concept; the transfer/transform debate; and toys as an educative curriculum material used to teach energy.

6.3.1 Identification of alternate ideas

A number of alternative ideas concerning the teaching of energy have been identified in the literature (Gilbert & Watts, 1983; Trumper, 1997; Trumper et al., 2000; Watts, 1983). The ideas suggested by these authors were used to categorise the alternative conceptions that were identified by the students. Students were required to identify three possible alternative conceptions, explain them, and then suggest possible strategies that might be useful when these misconceptions emerge during teaching.
Table 8

*Misconceptions as Identified in the Written Assignment*

<table>
<thead>
<tr>
<th>Possible alternative conceptions or non-scientific beliefs</th>
<th>Number of times it was mentioned (n = 83 x 3)(^8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Energy is seen as a type of fluid or concrete entity/</td>
<td>54 (22%)</td>
</tr>
<tr>
<td>Energy is a thing/Energy is fuel/Energy and energy</td>
<td></td>
</tr>
<tr>
<td>resources are the same thing</td>
<td></td>
</tr>
<tr>
<td>2. Energy gets lost/Things use up energy/We are running</td>
<td>50 (20%)</td>
</tr>
<tr>
<td>out of energy</td>
<td></td>
</tr>
<tr>
<td>3. Energy has to do with movement or activity/Objects at</td>
<td>43 (17%)</td>
</tr>
<tr>
<td>rest have no energy</td>
<td></td>
</tr>
<tr>
<td>4. Energy has to do with living things (Anthropocentric</td>
<td>29 (12%)</td>
</tr>
<tr>
<td>and an anthropomorphic)</td>
<td></td>
</tr>
<tr>
<td>5. Energy makes things work/Energy is created by some</td>
<td>11 (4%)</td>
</tr>
<tr>
<td>action</td>
<td></td>
</tr>
<tr>
<td>6. Failure to differentiate between energy and other</td>
<td>5 (2%)</td>
</tr>
<tr>
<td>physical terms e.g. force, gravity</td>
<td></td>
</tr>
</tbody>
</table>

The six alternative conceptions listed in Table 8 were the most common chosen by students. A number of other alternate conceptions were also listed but these were limited to one or two students. One student (S007) introduced a novel misconception, “Rest is a way to refuel the body. Energy within the body is increasing (while resting) – when you have rested your body has restored and refreshed itself.” Her remedial action involved having children

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\(^8\) Each student was required to identify at least three possible alternative conceptions, hence the possible number of responses is 83 students multiplied by three i.e. 249. Not all students did in fact mention three misconceptions in their essays.
come to school without eating anything and, after the first period checking whether they felt hungry. Her explanation was “This will prove to them that resting on its own is not the body’s fuel.” This identified alternative conception might be comparable, but not quite identical, to the ‘depository’ ideas of Watts (1983), (i.e. a model of energy in which objects are thought to contain energy and also have the ability to be recharged with energy, in other words, energy can be ‘deposited’ into them). This same student also suggested that another possible misconception was seeing “Energy as an object – Energy can be mistaken for an object for example if you eat a chocolate it might seem as an object of energy (S007).”

Some students identified a misconception, but in their explanation of the misconception they exhibited a murky understanding of the misconception themselves, for example, one student said:

*Energy is not conserved! Because we are running out of it.* It is quite obvious that this statement is false. People are confused with the terms energy and electricity. Electricity is a form of energy but not energy as a whole. Electricity is scarce nowadays therefore people might think that energy is running out, this is untrue. (S009)

and

Energy is not limited nor can it be used up, e.g. your body stores some energy but you need to continue eating because your body gets energy from the food you eat. (S012)

Some students also struggled to move away from the transformational model, e.g. “The Law of Conservation of Energy states that energy cannot be created or destroyed, but can change its form (S015).”

The belief that energy can be lost is often closely related to living things and to personal experience of getting tired. A student commented that “Some believe that energy can be lost. This for me is associated with the fact that, we eat and we become hungry; so people thinks
(sic) of energy as something that is lost (S018).” While students might be able to recite the Law of Conservation of Energy, during their writing they exhibited a lack of deep understanding. An example of such a misunderstanding is revealed in the following response:

*Energy changes completely from one form to another without loss of energy taking place.*

This statement is false. When using a torch, the children think that the electrical energy from the cells is directly transformed to light energy which they observe. This is not the case, however, since energy is lost in the form of heat energy. (S028)

Many students’ reported strategy for fixing alternative conceptions was simply to ‘tell them the correct or scientific concept’, for example: “A simple way to correct this understanding is to tell the learners that energy cannot be created or destroyed (S055).”

6.3.2 The Transfer/transform debate

According to Gilbert and Watts (1983), many students studying energy arrived in class with three non-scientific beliefs, namely: that energy has to do with living and moving things; that energy makes things work; and that energy changes from one form to another. It is the latter belief that fuels the transfer/transform debate. It is only because of the notion that there are many different forms of energy that the idea of transformation enters the science discourse and initiates and sustains this transfer/transform debate. The support for, and explanation of, the transfer model can be illustrated by student (S004) who claims that “Energy is not a tangible concept in science, therefore, the abstract idea of something not ‘real’ being transformed from one form to another is certainly very misleading and could lead to a great deal of confusion” and later, when describing energy transfer, he refers to transfer being “…how something is transferred from place to place…” and “…the main idea concerning the transfer model of energy is that energy merely flows around from place to place and manifests
itself in the different ways in which we experience this energy.” This support for the transfer model, while not quite coming to grips with, or being able to clearly explain both the concepts of energy and energy transfer, was a common thread throughout a number of the student’s discussions of the transfer/transform debate.

Despite spending a number of weeks constantly dealing with the idea of energy transfer and working through the whole polemic regarding the scientific acceptability, or not, of the concept of energy transformation, many students, while acknowledging the supremacy of the transfer model to develop an understanding of energy, still remained focused on the transform model. Nowhere is this illustrated better than by the student, who quoted the following from an internet source to support their standpoint:

Energy transformation is the process of changing energy from one form to another. This process is happening all the time in the world around us and even in us. When we consume food our bodies utilizes the chemical energy in the bonds of the food and transforms it into mechanical energy, a new form of chemical or thermal energy. Energy transformation is an important concept…The ability for energy to be transformed…(S087)

On numerous occasions students showed their support for the transfer model, but then continued to say that they would use both models when it came to their own teaching. One student explained “I believe the transfer model is the preferred option to be used to explain energy as learners understand concepts best in the simplest terms possible …I think that learners should be taught both models of energy so as to have a broader understanding of it (energy) S010.” In general, the students’ responses showed that, in their eyes, this debate is by no means over.
6.3.3 Toys as educative curriculum material

In this section of the assignment the students were required to discuss possible advantages and disadvantages of using toys as an educative curriculum material to teach energy. They were also required to state their personal position with respect to using toys to teach the concept. Advantages and disadvantages of using the toys as ECM involved two main aspects, namely, motivational and conceptual understandings.

When the motivational factors were mentioned, words such as ‘fun’ ‘interest’, ‘enjoyment’, hands-on, et cetera dominated the discussion, on the other hand, and this was often linked to the conceptual understanding of, or lack of understanding of energy, it was felt that many children would just simply ‘give up’. In a pilot study that was carried out in a previous year, just after a toy workshop, some students noted that gender could also be a de-motivational factor – but this was not mentioned by any of the students in this main study. The problem with gender arose because many, if not all the toys used, were considered to be ‘boys’ toys. At best, only a few toys used in the workshops could be considered to be gender neutral or ‘girl-friendly’.

An issue that was mentioned was the perception of science being a difficult subject and consequently it is then approached with trepidation. One student who saw toys as being a possible way to alleviate this situation stated: “Most learners think sciences are beyond their capabilities but I think when you mention toys, they’re not ‘afraid’ of it anymore (S061)” while another said that “I really like using toys when teaching science because learners enjoy science and get to know it better (S083)” and “I enjoyed it (the toys workshop) myself when it was done with us as I have never experienced science in a way where you can actually play
while learning (S085).” An often mentioned idea was the possible way that the toys could link science to the everyday world of the child, “…, because children get into contact with toys everyday of their life’s (sic) we can use this to not only enhance energy concepts but they can start seeing science all around them (S079).” While the promotion of developing the ability to work within a group can be achieved by many different strategies there appeared to some support for the idea that using toys could promote this, “Playing with the toys promotes group work seeing as the learners will work together (S065).”

Not surprisingly with pre-service and novice teachers the very practical issue of control was often raised. Words used to illustrate these reservations were, ‘discipline’, ‘noisy’, ‘destruction’ (of the toys) et cetera.

The above factors are best summarised by the following observation by a student:

These toys will ensure the learners have fun and the topics can include the energy of motion, stored energy, energy conversion, and much more. However, the learners may get overexcited which may then cause them to become rowdy. They might lose focus of what the teacher wants them to learn because they start to focus more on the toys themselves rather than follow instructions. (S064)

Abstract understanding was considered to be very important in the light of the abstract nature of the concept of energy. A number of students mentioned this, for example: “An advantage of using toys to explain energy is that learners are making sense of something abstract (energy), by connecting it to everyday objects (toys) (S065)” and “The teaching of energy in primary school should be focused on because a lot of science teachers do not want to teach it because of its abstractness or some just touch on it which probably cause more misconceptions than before… (S087)” and
The concept of energy and energy conservation is difficult to teach and understand, because it is an abstract idea. By using toys learners get hands-on learning, they can experience what is happening, show more interest, because toys are relevant to them and this as well as a little playfulness might motivate them to learn more about energy and get a better understanding. (S037)

During the course of the workshops, researcher field notes\(^9\) revealed a great deal of the discussion around the energy considerations of the toys, including the concept of transformation. One of the toys (Appendix G1 Group 7) was a transformer toy car that was used as an analogy to illustrate the point that even if the car were transformed into a robot, it still consisted of the same parts as the original car, that is, it is still the same. This particular toy had the disadvantage in that it confused the students as to which model, transfer or transform, to use. This is illustrated by the following comment: “Using a transformer toy helps by explaining to learners that it takes on different forms but it is still the same toy, and it is exactly how the energy concept works, it is the same energy but it only takes on another form (S052).”

The comments made about the use of toys were largely positive, such as: “Energy has become more interesting now because I understand more of how it works and also noticed that it is a non-stopping process (S077).” However, a number of disadvantages about the use of toys were also suggested. A student, who based on his experiences in the toys workshop, expressed reservations about the use of toys as an educative curriculum material claimed that:

Using toys to teach energy concepts is something new for me as I have never seen teachers using toys in a science classroom. Personally I would not use toys in my class to teach energy concepts because, through my own experiences of playing with toys in this module, I felt that I lost sight of the real point of using toys and I concentrated more on

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\(^9\) These field notes and observations were too brief and erratic to be used as a source of data in this study.
just playing. This might be even more the case in younger learners. I am all for mixing learning with play but I am sure there are other methods other than toys. (S021)

One disadvantage perceived by a student was that toys can waste the teachers’ time “…because the teacher has to take time and look for toys that are useful for the class and plan and make the activities (S083).” Another disadvantage was observed by a student who felt that apart from their ‘scientific’ usefulness, some toys might be inappropriate, for example “…toy guns are not the perfect toys to use seeing that as we live in South Africa where gun-related violence is a problem (S047).”

Nevertheless the majority of students who completed Part III of the toys workshop worksheet concluded that the strategy of using toys was fruitful for the teaching and understanding of energy (Appendix G1, Q7, Q9 & Q14). The results obtained from Part III of the toys workshops showed that 72 students (98%) agreed that ‘playing’ with toys did have an impact on their understanding of energy and 70 (95%) stated that they would consider using toys when teaching energy in their future Intermediate Phase science classes. Sixty eight (92%) claimed that ‘playing’ with the toys had motivated them to understand the energy considerations involve in the various toys. This is illustrated by two student comments that: “It worked for me and I understand energy much better after using the toys and I will definitely use it in my science class one day (S030) and:

Toys play an important role in (the) science classroom when you teach energy, because they are readily available and often inexpensive. A toy does not only spark interest but makes scientific principles accessible and understandable to students of almost any age. Using toys allows students to see, in a hands-on manner how science extends beyond the classroom into their everyday lives. The power and applicability of toys cannot be overstated for they may be used to introduce a topic, develop concepts qualitatively or
quantitatively, and assess student understanding. The beauty of using toys to teach is that your students will start to see the science in everything. (S084)

7. **SCIENCE TEACHER SELF-EFFICACY BELIEFS (STEBI-B)**

The instrument used in this study to access science teacher self-efficacy, namely, the STEBI-B instrument, was tested for validity and reliability by Enochs and Riggs back in 1990 (Enochs & Riggs, 1990, p. 704). As noted before, the questionnaire has two subscales or factors, namely, the Science Teaching Outcome Expectancy (STOE) scale and the Personal Science Teaching Efficacy Belief (PSTEB) scale. STEBI-B has been analysed in many different ways over the years and the most obvious, and simplest, method is to add the scores in each of the two separate subscales. Considering that there are ten questions in the STOE scale and 13 questions in the PSTEB scale and that the lowest score per item is allocated a value of 1, the absolute lowest possible scores are 10 and 13 respectively and the maximum scores are 50 and 65 respectively. Table 9 shows the results for the ‘raw’ scores for both factors that were generated in this study.

Studies that have attempted to correlate self-efficacy beliefs with other variables such as subject content knowledge (SCK), pedagogical content knowledge (PCK) have categorised scores from STEBI subscales as either high or low (Finson, 2001; Finson et al., 2000; El-Deghaidy, 2006). El-Deghaidy (2006) chose to define these two extremes by calculating a ‘high’ self-efficacy as being where the self-efficacy score is equal to or more than one standard deviation above the mean, while a ‘low’ self-efficacy is categorised by a score that is equal to or less than one standard deviation below the mean.

Table 9 summarises the average scores, the median score and percentage, the minimum and the maximum score and the number of students who could be classified as having a ‘high’
self-efficacy (using the one SD rule) as well as the number of students who were categorised as having a low self-efficacy for each of the two subscales (STOE and PSTEB).

Table 9

*Results from the STEBI-B Questionnaire (n = 61)*

<table>
<thead>
<tr>
<th></th>
<th>STOE</th>
<th>PSTEB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-intervention</td>
<td>Post-intervention</td>
</tr>
<tr>
<td>Average score (x)</td>
<td>35.75 (SD = 5.05)</td>
<td>36.25 (SD = 5.45)</td>
</tr>
<tr>
<td>Median</td>
<td>35</td>
<td>36</td>
</tr>
<tr>
<td>Median as %</td>
<td>70%</td>
<td>72%</td>
</tr>
<tr>
<td>Min - Max</td>
<td>(24 - 47)</td>
<td>(26 - 50)</td>
</tr>
<tr>
<td>High self-efficacy</td>
<td>n = 12 (20%)</td>
<td>n = 8 (13%)</td>
</tr>
<tr>
<td>Low self-efficacy</td>
<td>n = 8 (13%)</td>
<td>n = 7 (12%)</td>
</tr>
</tbody>
</table>

*Note: The scores used in this table are the raw scores and not scores reworked out of a total of 10, as is the case in all the other instruments used in this study.*
7.1 The ceiling effect in the STEBI-B measuring instruments

Roberts et al. (2001) reported on the so-called ‘ceiling’ effect of self-efficacy instruments. They felt that many of the instruments limited the range for indicating improvement in self-efficacy as a result of some intervention for individuals who initially started with high self-efficacy. This study was no different with the ceiling effect also being noticeable. Table 9 contains the median raw scores for each of the pre- and post-intervention STEBI-B self-efficacy questionnaires and it can be seen that the pre-intervention questionnaire median scores were greater than or equal to 70%. This means that 50% of the students scored more than 70% of the maximum possible score for the pre-intervention questionnaires. In the post-intervention questionnaire the greatest improvement was 2%. This illustration of the ceiling effect prompted a reassessment of how improvement in self-efficacy could be expressed.

7.2 Descriptive and inferential statistics for STEBI-B

In this section the reporting on the data will always reflect the two independent factors that have been identified in the STEBI-B questionnaire (viz. STOE and PSTEB). In order to facilitate any future comparisons between these two factors and the other five factors investigated in the study, the raw data was reworked out of a maximum of 10, and as such all further data in this study is presented with reworked scores, where the maximum score is ten.

The internal reliability of the factors for both the pre- and post-questionnaire was calculated, and apart from the STOE pre-questionnaire (α = 0.64), the reliability for the other measures were acceptable at greater than 0.70 (STOE post- = 0.77, PSTEB pre- = 0.78 and PSTEB post- = 0.87). A full summary of the descriptive data can be found in Appendix B1,
but it is worth noting that the percentage gain of potential of STOE and PSTEB was 8.20% and 6.74% respectively, in contrast to the difference of the means which showed a very small gain for STOE (1%) and a decrease of 1% for PSTEB. The inferential statistics for STOE and PSTEB (i.e. the Student’s t-Test and Cohen’s d) were not statistically significant (see Appendix B1).

8. CONFIDENCE

In this study, three factors were identified as measures or indicators of confidence with respect to the understanding and teaching of the Natural Sciences in general, and the concept of energy in particular. These factors were:

- Confidence in teaching the Natural Sciences (NS) at the Intermediate Phase (IP) level (Conf-T)
- Confidence in the understanding of subject content knowledge (SCK), with particular reference to energy (Conf-C)
- Confidence in the teaching of energy at the IP level, in other words pedagogical content knowledge (PCK), (Conf-P)

These confidence factors were determined using data generated by all eight data-collection instruments (viz. STEBI-B, SCK-EC, PCK-EC, participant writings, toy workshops, web-based assessment, written assessment and essay – see Appendix A).

In this study the responses to all items that measured confidence were plotted onto an ordinal scale where the lowest level of confidence scored a ‘1’ (e.g. definitely not confident, just guessing, no idea etc.) and the highest level of confidence was rewarded by a score of ‘5’
(e.g. very confident, I know this is true, definitely yes etc.). A score of ‘3’ indicated a degree of uncertainty in the response (e.g. I think..., not sure..., etc). The structure of some of the confidence items was such that not all five levels of confidence could be mapped onto the item options, and as such, adaptations were made to the scoring of these items. The exact scoring schedule for particular items is presented when these specific items are reported on in the following sections.

8.1 Confidence in teaching the Natural Sciences at IP level (Conf-T)

The items which linked to student’s confidence in their ability to teach science (Conf-T), that is, items #27 and #28 in the STEBI-B questionnaire, were attached at the end of this self-efficacy questionnaire (Appendix E1). The first item asked: If given a choice would you choose to teach science to an IP class? Five options were available to choose from, namely, definitely no (1); probably no (2); not sure (3); probably yes (4) and definitely yes (5). The scores in brackets were used to indicate degree of confidence, on an ordinal scale, as opposed to a continuous scale. The second of the Conf-T items asked: How would you rate your effectiveness to teach IP Science? The scoring for this item also used the five-point confidence scale and ranged from the lowest confidence: low, below average; average; above average and finally to superior. The internal reliability, as measured by Cronbach’s α, for Conf-T pre- and post-intervention questionnaires were α = 0.58 and α = 0.47 respectively. According to Nunnally (1978) these values could be considered as barely acceptable for a new instrument (see Section 3 of this chapter). As this instrument relied on only two items, and bearing in mind that α-values may increase with the number of items, the relatively low α-values are not surprising. The Student’s t-Test, that compared the mean difference between
the pre- and post-intervention questionnaires, indicated that the difference in means was not statistically significant (p > 0.05). The percentage gain in potential was only 5%.

It should be borne in mind that the only actual ‘teaching experience’ that these students probably have, were two weeks of classroom observation at schools at the beginning of the academic year when this study took place, and that the intervention made no provision (either in actual classrooms or simulated micro-teaching opportunities) to get exposure to actual teaching. It is therefore not surprising that there is no statistically significant change in confidence to teach as a consequence of the intervention. However, when the question of confidence to teach science was specifically linked to energy and toys, a different picture of students’ perception of their confidence to teach emerges. The final web-based online assessment contained a single item linked to confidence, that is, “How confident are you that you will be able to teach energy to an IP class using toys? The responses to this question are shown in the pie-chart in Figure 16.
Figure 16. How confident are you that you will be able to teach energy to an IP class using toys? (n = 81).

A total of 66% of the students who responded to this item (n=81) felt that they were either confident or very confident to teach energy to an IP class using toys as educative curriculum material.

8.2 Confidence in subject content knowledge linked to energy (Conf-C)

Items seven through to #33 of SCK-EC questionnaire were designed in such a manner so as to be able to identify subject content knowledge, as well as to obtain a score for confidence in subject content knowledge. The options that they could choose from for these items were:

- I know this is TRUE (5 – very confident)
- I think this is TRUE (3 – not confident)
- I have no idea (1 - guessing)
- I think this is FALSE (3 – not confident)
- I know this is FALSE (5 – very confident)
Cronbach’s alpha was utilised to obtain the internal reliability of the pre- and post-intervention questionnaires. High measures of item reliability were exhibited in the pre-intervention questionnaire ($\alpha = 0.85$) and the post-intervention questionnaire ($\alpha = 0.90$). The Student’s t-Test for the mean difference between the pre- and post intervention questionnaires generated the following inferential statistics ($t$-Value $= 6.60$; $df = 70$; $p = .000$) indicating that the difference in mean scores for Conf-C were statistically significant. The large Cohen’s $d$ ($d = .78$) indicated that the effect size could be categorised as ‘high’, thus showing the practical significance of the difference in the mean scores for Conf-C. There was also a substantial percentage gain of potential (26%) for Conf-C.

Pearson Correlation Coefficient was utilised to investigate the relationship between subject content knowledge (SCK) and the student’s confidence in their SCK. According to Urdan (2005) correlation coefficients of between -0.2 and +0.2 (inclusive) are considered weak, between 0.2 and 0.5 (both positive and negative) are said to be of moderate correlation and correlation coefficients greater than 0.5 (positive and negative) are considered to be strong correlations. The correlation between SCK and Conf-C was determined to be 0.69 ($p = .000$) and as such this correlation is statistically significant and indicative of a strong correlation relationship between the two factors (viz. SCK and Conf-C).

### 8.3 Confidence in pedagogical content knowledge linked to energy (Conf-P)

Three items from the pedagogical content knowledge (PCK-EC) questionnaire were dedicated to ascertaining an indication of the student’s confidence in their PCK with respect to the concept of energy. These three items consisted of a four-point scale ranging from ‘Just
guessing’ through to ‘Very confident’. Therefore the scoring scale used for items #3, #5 and #7 was:

- Just guessing (1)
- Not confident (2)
- Confident (4)
- Very confident (5)

If $\alpha = 0.70$ is the cut-off value for internal reliability on the Cronbach’s alpha then the Conf-P items partially succeeded in terms of being reliable (pre-intervention questionnaire $\alpha = 0.71$ and post-intervention questionnaire $\alpha = 0.68$). The percentage gain of potential for Conf-P was 39%. The Student’s t-Test for the mean difference between the pre- and post-intervention questionnaires generated the following inferential statistics ($t$-Value = 8.41; $df = 67$; $p = .000$) indicating that the difference in mean scores for Conf-P were statistically significant. The large Cohen’s $d$ ($d = 1.02$) indicated that the effect size could be categorised as ‘high’, thus showing the practical significance of the difference in the mean scores for Conf-P.

A useful descriptive statistics technique in SCK and Conf-C was to categorise the students according to their scores on the various instruments, that is, a score of less than four was categorised as a ‘low-score’, scores between four and six were categorised as moderated scores and those greater than six were categorised as ‘high-scores’. This categorisation was also applied to the Conf-P scores and the results can be viewed in Table 10.
Table 10

*Students categorised into the low, moderate and high score categories based on their Conf-P scores*

<table>
<thead>
<tr>
<th></th>
<th>n = 68</th>
<th>Low-score</th>
<th>Moderate-score</th>
<th>High-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conf-P Pre-intervention questionnaire</td>
<td></td>
<td>39 (58%)</td>
<td>20 (29%)</td>
<td>9  (13%)</td>
</tr>
<tr>
<td>Conf-P Post-intervention questionnaire</td>
<td></td>
<td>11 (16%)</td>
<td>23 (34%)</td>
<td>34 (50%)</td>
</tr>
</tbody>
</table>

As was the case above (section 8.2) with the relationship between SCK and Conf-C, Pearson Correlation Coefficient was utilised to investigate the relationship between pedagogical content knowledge (PCK) and the student’s confidence in their PCK. The correlation between PCK and Conf-P was determined to be 0.39 ($p = .000$) but, while the correlation is statistically significant, it represents only a moderate correlation relationship between the two factors (viz. PCK and Conf-P).

9. **EDUCATIVE CURRICULUM MATERIALS: TOYS’ WORKSHOP**

The focus in this section deals with the student responses to the items in Part III of the toys workshop. This part of the toys workshop consisted of a pro-forma worksheet. In this part of the workshops the students were required to complete a number of items related to, amongst other things, their perceptions of the influence of the toys on their understanding of energy and their confidence in this understanding. The instructions to the students concerning the five-point rating scale were that a rating of 1 would indicate no confidence, while a rating of 5 would indicate that they felt very confident.
9.1 The influence of the toys workshops on confidence

The first set of three items were grouped together and dealt with the confidence that students had in relation to their understanding of energy. The first two items of the set attempted to identify to what extent the students felt their confidence in understanding energy had improved as a consequence of the specific approach of using toys as the focus for addressing the concept of energy. The questions were:

- *How confident were you about your understanding of energy before the start of these two workshops using toys?*
- *How confident are you now at the end of these two workshops using toys?*

It must be borne in mind that students were asked about their own perception of their confidence (self-efficacy), so the results might in no way indicate a link to any actual evidence, or lack of evidence, of improved understanding of the concept of energy. Evidence of actual understanding of energy can be obtained from the analysis of the subject content knowledge questionnaire (SCK-EC) reported on in Section five above. Table 11 indicates how students perceived their understanding of energy to have changed as a result of the toys workshops.
Table 11

_Change in Perceived Understanding of Energy as a consequence of the Toys Workshop_

<table>
<thead>
<tr>
<th>Change in rating</th>
<th>Percentage of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>No increase in rating</td>
<td>11% (n=8)</td>
</tr>
<tr>
<td>Increase of 1 scale point</td>
<td>54% (n=40)</td>
</tr>
<tr>
<td>Increase of 2 scale points</td>
<td>24% (n=18)</td>
</tr>
<tr>
<td>Increase of 3 scale points</td>
<td>10% (n=7)</td>
</tr>
<tr>
<td>Increase of 4 scale points</td>
<td>1% (n=1)</td>
</tr>
</tbody>
</table>

Only a small percentage (11%, n=8\(^{10}\)) of the students felt that their confidence had not improved as a result of the toys workshop, while the vast majority felt that their confidence in their understanding of energy had improved as a direct result of the workshops. A more valuable insight into any improvement in perceived confidence of an understanding of energy can be obtained when a rating of either 1 or 2 is seen as being indicative of a low level of confidence, while a rating of 4 or 5 is seen as representing a high level of confidence (i.e. confident or very confident). Using these criteria it can be seen that 55% (n = 41) of the students rated their confidence level as low before the start of the two toys workshops, while only 8% (n = 6) of the students rated their confidence as high (i.e. a rating of 4 or 5). After the workshops the picture of their perceived confidence changed substantially with only 3% (n = 2) of the students rating themselves as still having low confidence, while those who now

\(^{10}\) Of these 8 students, two had initially noted a score of 5, so they could not improve on this score
saw themselves as having high confidence in their understanding of energy rose to 69% (n = 51).

Students were asked in an open-ended question to comment on what specifically may have influenced the change in their perceived confidence while taking part in the toy workshops. Their responses were grouped according to common threads. The themes that emerged were:

- Working with toys is a practical activity and this was perceived as automatically leading to better understanding with a consequential increase in confidence.
- The toys workshops increased knowledge (sometimes new knowledge and sometimes enhancements on existing knowledge) and this led to an increase in confidence.
- Interaction with other students during the workshop was perceived as assisting with understanding and confidence

Unless it was a particularly interesting response, responses that were unique to only a few students or responses that were not classifiable were not considered to be a thread and were excluded from the list.

Just under a quarter of students (23%) believed that practical work was linked to understanding, which they, unsurprisingly linked to confidence. Some examples of responses that caused allocation to this thread were:

- “I had a better perception of these ideas once I could physically see the process.”  
  (S079)
• “(I) Didn’t really understand the concept of energy, but this playing made it somewhat clearer for me (S006).”

• “The toys helped a lot, I could see and hear the changes and sounds of certain toys (S074).”

• “When actually doing the activity and seeing it (toy) and how it works it made it a bit easier than just imagining it (S087).”

In this study close on 30% of students indicated that their enhanced understanding was caused by the toys workshops and that this led to an increase in confidence when dealing with the concept of energy. Comments such as “I actually understood how energy works a bit better because I had little previous understanding of science…(S046)” and “I always thought that it is very difficult to understand energy until I started working it out using toys (S064)” are examples of typical responses that suggested that the toys workshops promoted a better understanding of energy and that caused an increase in perceived confidence amongst students.

In this study students were divided into small groups of four or five students working with a group of different toys that had some commonality (e.g. five different types of toy guns). While this was not a dominant thread, the perception that interaction with fellow students within the group enhanced confidence, was noted by a number of students. Student (S059) summed up this idea with her comment “My prior knowledge about energy was average, but at least I knew something. I explored these toys with my friends/peers and by combining all our knowledge about energy they taught me something, as well as me teaching them something.”
Some 10% (n = 8) of the students did not perceive that their confidence had increased and it is worth noting some of their comments concerning their perceived lack of improved confidence. It would appear that this lack of improvement boils down to whether their knowledge and understanding increased or not. “Mine (My) knowledge did not change, but it could have if we had more time while doing this activity. Half the time I was lost and copied from my group because there was no time to explain and ask questions (S029)” and “I have learnt something but I still don’t have enough confidence, because I am still confused about something (S025).”

9.2 The influence of the toys workshops on understanding of the concept of energy

The previous section (students’ change in confidence) is directly linked to this section in that students closely link their understanding and knowledge with their confidence “I need more examples to increase my confidence (S013).” In the next set of three items (using the same style as the first set of three items) the students’ belief in their content knowledge of energy was addressed. The first two questions asked the students to gauge their improvement in knowledge, but not specifically as a result of the toys workshops, but as a possible consequence of the whole intervention.
Table 12

*Change in Student Understanding of Energy as a Consequence of the Toys Workshop*

<table>
<thead>
<tr>
<th>Change in rating</th>
<th>Percentage of students (n=74)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No increase in rating</td>
<td>8%</td>
</tr>
<tr>
<td>Increase of 1 scale point</td>
<td>35%</td>
</tr>
<tr>
<td>Increase of 2 scale points</td>
<td>41%</td>
</tr>
<tr>
<td>Increase of 3 scale points</td>
<td>16%</td>
</tr>
<tr>
<td>Increase of 4 scale points</td>
<td>0%</td>
</tr>
</tbody>
</table>

As with the confidence section of Part III above, only a small number of students (8%) felt that their knowledge of energy (subject content knowledge) had not improved as a result of the course on energy (including the toys workshops). Similar to the previous section, their perceived knowledge of their understanding of energy was divided into a low and a high category. At the start of the course 74% (n = 55) of the students felt that they did not have a good understanding of energy and by the end of the toys workshop this had dropped to just two students indicating that they did not have a better understanding of energy. The change in the number who had a high understanding of the energy concept moved from 5% (n = 4) prior to the commencement of the course, to 58% (n = 43) after the toys workshops.

It is important to remember that in these three questions, students were asked about the change in their content knowledge of energy in the context of a number of lectures, activities and the toys workshops. According to student (S0046) “After the lessons and toy exercises its simpler to understand energy now because I have a better idea of what energy is.” If a thread
could be determined in the responses to these questions then it must be that students started to understand what energy is, and what it is not, and this small distinction created their perceived improvement in content knowledge “These units gave me a clue to what energy is about…(S083)” and finally “One never thinks of energy in such detail, but after experiencing it like this, I became curious (S085).” Student (S041) summed up the experience:

We had to think about energy, wrestle with the concepts etc. We were required to spend time considering our knowledge about the topic (energy) and challenged as to why we believed certain things. The collective ideas of our peers and the guidance of the lecturers helped us rebuild our ideas and learn new ‘truths’ about energy.

Item #7 dealt with the impact that ‘playing with toys’ might have on the students’ understanding of energy. A very large percentage (97%) of the respondents agreed that ‘playing with toys’ did have a positive impact on their understanding of energy. Item #8 was an open-ended response item, namely, “Comment on your response as to whether the ‘playing’ with toys had an impact on your understanding of energy”. The following threads or themes were identified:

- Playing leads to understanding
- Visual experience helps
- Easier to understand

Although the vast majority of students acknowledged the role played by toys in their improved understanding of energy, there were a few reservations, for example, “Yes and no, in some ways playing with toys has been fun and I did learn a bit, on the other hand playing with toys confuse (sic) me even more with regards to the concept of energy (S021)” and “It drew my attention but still I don’t understand it fully (S029)” and finally “Toys only help to a
certain extent (S026).” As noted earlier, despite these types of reservations there were many comments that supported the idea of using toys as an educative material:

- “I basically ‘practiced’ my understanding of energy, for example I learnt more and more (with every toy) about energy transfer.” (S023)

- “Using toys helped me understand energy much better because it is easy to relate to them than a bunch of theories that tends to be difficult to comprehend.” (S064)

- “Most definitely, by actually seeing it helped me to understand the transfer of energy.” (S060)

- “I tried to think how toys worked and in that way identified different energy concepts.” (S048)

Items #11 and #12 asked the students to identify the toy that they found the most ‘enjoyable’ and they had to explain why they had made that particular choice. A number of reasons emerged for their selections, namely, ‘enjoyable, fun, interesting’ and ‘intriguing, appearance’. On the other hand, Q13 asked the students to identify the toy that taught them the most about energy and what exactly it was that they learnt from the toy. Nearly 50 different toys, grouped into 15 groups, were available for students to work with, and yet they appeared to limit their choice of toys down to less than 20 toys, of which only 11 were chosen by five or more students. The most popular toy in both questions was “The Angry Man” – a toy that was selected by over a quarter of the respondents (28%, n = 21) as the most enjoyable toy and by 12% (n = 9) of students as the toy from which they learnt the most about energy. Some of the reasons for their choice are noted in the next paragraph. This toy was also the
toy used for eight items (items #22 - #29) in SCK-EC and the online test. A list of the most popular toys is to be found in Appendix G2.

The reasons for choosing these particular toys were obviously different for the two questions. Clearly the most enjoyable toys elicited words such as ‘attention grabbing’, ‘simple’, ‘amusing’, ‘unusual’, ‘interesting’ etc. Student (S040) summed up the general feelings when he commented on his reasons for choosing ‘The Angry Man’ as the most enjoyable toy wrote: “Because it is funky and it is fun to see it pop.” The reasons for choosing a toy as the most useful for teaching the energy concept also revolved around the toy’s ability to provide clarity of understanding and new insights into the concept of energy. “I never realised how energy could be stored in certain objects (S060).”

The final question in this worksheet asked students if playing with toys had motivated them to try to understand the energy considerations of the toy. More than 75% (n = 57) said ‘yes’, that playing with toys had indeed motivated them to understand more about energy.

10. CHAPTER SUMMARY

In this chapter the presentation of results begins with a section on the demographics of the students (the respondents in this study) and short explanations of their science background (as elicited from the participant reflective writings) and describes their perceptions of their attitudes towards science before they started the science part of their training to be teachers of the Natural Sciences in the IP.

The qualitative data gathered from the various instruments, such as the three questionnaires (viz. SCK, PCK and STEBI-B), assignments and assessments, are presented in an effort to complement both the descriptive and inferential statistics that were obtained from
the quantitative data provided by the three questionnaires. The chapter concludes with the collation and presentation of qualitative and quantitative data taken from the toys workshop worksheets. The data gathered from all these different sources forms the basis of the discussions of the findings in the next chapter.
CHAPTER FIVE

DISCUSSION OF RESULTS

1. INTRODUCTION

The focus of this chapter is the answering of the main and subordinate questions posed in Chapter one by critically examining the quantitative and qualitative data generated by the various data collecting instruments and reported on in Chapter four. These data are grouped and discussed with respect to their relevance at answering each specific subordinate question and finally, these data are interrogated in an effort to come to a conclusion on the impact of using a particular educative curriculum material, namely toys, on pre-service primary school Natural Sciences teachers’ subject content knowledge (SCK-EC), pedagogical content knowledge (PCK-EC), self-efficacy (STEBI-B) and confidence in the teaching of energy. A summative section will serve as a precursor to final chapter of this study that will discuss the conclusions with reference to the main aim of the study, which was to assess whether specific educative curriculum materials had a measureable and significant impact on a primary schools Natural Sciences teachers’ understanding of energy.

2. PRE-SERVICE TEACHER’S SUBJECT CONTENT KNOWLEDGE

The first sub-question in this study: “Does this type of approach to pre-service training in the Natural Sciences improve teacher’s subject content knowledge?” is addressed in this section.
A number of researchers (Belfort & Guimarães, 2002 & 2004; Grossman et al., 1989; Leinhardt et al. 1991; Preece et al. 2004; Shulman et al. 1987) have stressed the importance of subject content knowledge for teaching. Belfort and Guimarães (2004, p. 504) go so far as to claim that “…a solid subject content knowledge may be essential for a successful teacher.”

In the following sections it will be argued that the intervention did in fact have a positive impact on the students’ subject content knowledge, but this is premised on the fact that the main instrument used to measure SCK, which is the subject content knowledge - energy concept questionnaire (SCK-EC), is valid and reliable.

2.1 Issues of validity and reliability of the SCK-EC questionnaire

The measure of subject content knowledge was derived from a questionnaire that was specifically constructed for this study, to measure students’ SCK with respect to energy (SCK-EC questionnaire – see Appendix C1) and, as such, its validity and reliability needed to be established before any argument can be made for the impact of this study’s intervention on students’ SCK. The majority of items used in this SCK-EC questionnaire were used in their original or adapted forms, based on research carried out by a number of researchers and organisations (DCSF, 2003 & 2009; Finegold & Trumper, 1989; Kruger et al., 1992; TIMSS & PIRLS, 2009; Trumper, 1998) and, as such, the previous work done by these researchers provides the basis for judging the SCK-EC questionnaire to be both valid and reliable.

The reliability of the questionnaire items were calculated using Cronbach’s alpha (α) (Appendix B2). The Cronbach’s α for the SCK-EC pre-questionnaire was α = 0.70 and for the post-questionnaire was α = 0.76. The range of Cronbach’s α would normally be between
0 and 1 and that an internal consistency of greater than 0.9 would be considered excellent. George and Mallery (2003) have suggested the following rule of thumb:

- $(0.7 – 0.8)$\(^{11}\) – Good
- $(0.6 – 0.7]$ – Acceptable
- $(0.5 – 0.6]$ – Questionable
- $[0.5$ and lower - Poor

Based on the above interpretation, the internal reliability of the questionnaire is considered to be acceptable to good.

Once the validity and reliability of the SCK-EC questionnaire has been established it is worthwhile considering the science background of the students in this study, because they did not have the same, or even similar, school science experiences. While the following section does touch on the impact of different teachers on the quality (and quantity) of the school science experiences of individual students, the focus is on the highest school level to which science was taken as a school subject.

2.2 Science background and content knowledge

Appleton (1995) claimed that the origin of teachers’ lack of confidence to teach science can be traced back to their poor science background knowledge. A number of other researchers also suggest that the amount of school science content knowledge that students are exposed to at school (i.e. the number of grades they complete with science as one of the subjects) influences the amount of subject content knowledge that they are competent in when

\(^{11}\) The conventional symbols are used here, i.e. the ‘round bracket ’)’ implies excluded and the ‘square bracket ]’ means included.
they enter pre-service teacher training (Appleton & Kindt, 2002; Arends & Phurutse; 2009; Borko, 2004; Flecknoe, 2000). So it is inferred in this study that the fewer grades in which they take science, the less SCK they would know. A further matter for consideration is the difference between taking science in primary school and high school. A number of researchers (Illes, 2002; Summers et al., 1998; Tambyah, 2008) have suggested that there is not only a difference in focus between science in the lower levels of school (i.e. primary and junior high school) and the senior levels (i.e. science in the senior secondary school is more discipline and content focused than science in the lower school levels), but that the type of teachers are also different, in that most primary school science teachers are non-experts in science. In this study nearly two thirds (64%) of the students did not do any physical science beyond the Grade 9 level, and can therefore be considered to have experienced science only as it is presented in the lower levels of schooling. In this study students completed a pre- and post-intervention questionnaire that focused on SCK with a specific emphasis on energy. When you consider Figure 7, where a comparison was made between school science experience and SCK in both the pre- and post- intervention questionnaires, you will see that the number of ‘high-score’ category students (SCK score of greater than 6) was substantially higher in the NS and PS group (i.e. the group that had had the most school science).

Figure 7 also shows that, irrespective of the level of their school science experience, all three groups (i.e. NS, NS & LS and NS &PS) showed substantial increases in the number of students who could be classified as being in the ‘high-score’ category for SCK. These increases (NS from 33% to 66%; NS & LS from 48% to 78% and NS & PS from 73% to 92%) would appear to indicate that the intervention did have the potential to substantially increase the SCK of a number of individual students. It must also be noted that the ceiling
effect could play a role here, in that the group of students with the smallest initial SCK score with respect to energy (i.e. the NS only group), showed the greatest percentage increase of students moving to the ‘high-score’ category, while the student group with the highest initial number of high-score individuals (i.e. the NS & PS group), exhibited the smallest number of individuals who moved up to the ‘high-score’ category. Overall, irrespective of their school science background, the number of students in the ‘high-score’ category went from 54% in the pre-intervention questionnaire to 80% (n = 71) in the post-intervention questionnaire.

2.3 Discussion of descriptive and inferential statistics with reference to SCK

The simple answer to the question: “Is there an improvement in SCK?” might lie in considering the change in mean scores between the pre- and post-intervention SCK-EC questionnaires. The change in the mean scores for SCK was from 60% to 68%.12 This 8% increase does not adequately describe the improvement because of the potential impact of the ‘ceiling effect’ on the SCK scores of those students who arrived at the course with a high level of school science experience (i.e. the NS & PS group). One way of interpreting change in the light of the ‘ceiling effect’, is to use the descriptive statistic that has previously been referred to in this study as the percentage gain of potential (refer to Chapter three Section 6). The percentage gain of potential for SCK was 21% and this suggests that there was a substantial improvement in subject content knowledge. However, the question that needs to be addressed is ‘Are these results considered to be statistically significant?’

It can be seen from the inferential statistics carried out in this study that the Student’s t-Test for significance produced a p-value of .000 (Appendix B1). This is highly statistically

12. The scores given in Appendix B1 have all been obtained by reworking the factors’ raw score to a ‘new’ score out of 10. In this case, the score, out of 10, are reported as percentages.
significant and implies that the changes in subject content knowledge cannot be ascribed to chance, in other words the null-hypothesis (i.e. that the intervention will have no impact on the student’s SCK) is rejected. The practical significance (or effect size) that was measured by means of Cohen’s $d$ was 0.42. This effect size is considered to fall within the ‘medium’ category for effect size, which means that the change can be ascribed to changes in a reasonable number of the instances and is not limited to large changes in only a few cases.

The mean score of the post-intervention web-based assessment was 73%. This web-based assessment consisted of items that assessed similar content as that found in the SCK-EC questionnaire. There was no pre-intervention assessment to compare this to, but the high mean score suggests that overall the students had a reasonable understanding of the content of the work that they had just completed.

2.4 Discussion of qualitative data from SCK-EC

A number of items in the SCK-EC questionnaire were included to elicit qualitative responses that might reveal changes in students’ ideas concerning energy. Millar (2005) identified two key points that he believed made the teaching and learning of energy very difficult, namely, the abstract nature of the energy concept and the mismatch between the scientific and everyday understandings of energy. The last of these two, the mismatch or misunderstanding of energy terminology in the scientific arena and its everyday use often creates a great deal of confusion in the teaching of energy is (DCSF\textsuperscript{13}, 2003; 2009; Millar, 2005). One of the open-ended items in the SCK-EC questionnaire (item #48) invited students to comment on the statement: “If energy is conserved, why are we ‘running’ out of energy?”

\textsuperscript{13} The Conservative Government elected in 2010 changed this departments name to ‘Department of Education’ on 12 May 2010.
This item, succinctly juxtaposes the scientific and the everyday views of energy. The two pie-charts in Figure 15 show that, initially, approximately 25% of students had a scientifically acceptable response and about 15% had responses that showed some scientifically acceptable understanding. What is encouraging is that, in the post-intervention questionnaire, three quarters of the students had an acceptable scientific response to the item, suggesting that the intervention did have a positive impact on at least this one aspect of the two ideas that normally make energy difficult to understand.

The point that it is the abstract nature of energy that makes it difficult to understand, begs the question: *How do students perceive the concept of energy?* This is addressed in item #5 of the SCK-EC questionnaire where students were asked to write down three key words or phrases related to energy. The two pie-charts in Figure 10 (i.e. one for the pre-intervention and one for the post-intervention responses) noted the prevalence of the students’ words/ideas or themes that they associated with energy. Not surprisingly these words/ideas/themes were very similar to those identified by a number of researchers (Duit, 1984; Gilbert & Watts, 1983; Trumper, 1997; Trumper et al., 2000; Watts, 1983). Post-intervention responses indicated that the prevalence of three of the four most commonly mentioned misconceptions had reduced, for example, the associating of energy with living organism and people occurred 4% of the time in the post-intervention questionnaire, a substantial reduction from the initial 13% in the pre-intervention questionnaire. The reduction (i.e. 17% to 5%) in the prevalence of another one of the misconceptions mentioned by students, namely, equating the term ‘force’ (a concrete concept) with ‘energy’ (an abstract concept), might be, as a consequence of the intervention, indicative of a movement towards the understanding of energy as an abstract concept.
It is therefore suggested that the pre- and post-intervention results of at least two of the items in SCK-EC (items # 48 and #5) indicated a measure of success of the intervention with respect to the two ideas that have traditionally made energy difficult to teach and learn.

Where possible, this study attempted to link SCK to the toys workshops by using toy examples to introduce some items in the SCK-EC questionnaire and the web-base assessment (e.g. Angry Man, Kreepy Crawlie, Roller Coaster etc. see Appendix G1). Roller coaster is a good example that directly illustrates the impact of the toy workshop on content knowledge. Figure 12 shows that in the pre-intervention questionnaire 17% of the students had a scientifically correct explanation for the height reached by the ball on the roller coaster and after the toy workshops this number had increased to 27%, while those students with scientifically incorrect explanations had decreased from 39% to just 12%, suggesting that this turnaround might be influenced by the actual ‘playing’ with the roller coaster in the toy workshops.

It has been shown above, and in sections four and five of Chapter four, that in a number of areas and measures that the SCK of the students has increased between the pre- and post-intervention questionnaires (e.g. a 26% increase in number of students in the ‘high-score’ category for content knowledge – Figure 7; an increase in the mean score for the SCK-EC questionnaire of 10%, and a 21% mean percentage gain of potential in SCK – Appendix B1 etc.). The results of this part of the study suggest that an intervention focused on interacting with toys has the potential to improve pre-service science teachers’ SCK. The positive changes in SCK of the students in this study can be considered important, especially in the

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14 Students who did not respond to this item, and those who were categorised as having partially correct ideas, to some extent distort these figures.
light of the existing poor understanding of science held by many South African science teachers (Rollnick et al., 2008).

Rollnick et al., (2008) have suggested that a high level of subject content knowledge can be shown to complement a thorough understanding of pedagogical content knowledge and as such, this study proceeded to investigate possible changes in students’ pedagogical content knowledge as a result of an intervention that focused on toys.

3. **PRE-SERVICE TEACHER’S PEDAGOGICAL CONTENT KNOWLEDGE?**

This section discusses the second sub-question in this study, namely: “*Does this type of approach to pre-service training in the Natural Sciences improve teacher’s pedagogical content knowledge?*”

While some researchers (Garden, 1997; Rollnick et al., 2008) have stressed the importance of a solid content knowledge base for teaching, others, such as Summers et al., (1998), have focused on the idea that to bring about effective learning in learners it is not enough to merely improve the teachers’ subject content knowledge, but that the “…key issue is how teachers can make this knowledge accessible to pupils (1998, p. 154).” This pedagogy, when focused on particular content, has been referred to as pedagogical content knowledge. Since Shulman (1986 & 1987) first introduced the concept of pedagogical content knowledge (PCK) it has become one of the focus areas of many teaching training initiatives. This, of itself, is not surprising, in that when Shulman was expanding on the idea of a knowledge base for teaching, he claimed that “…the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy.” (Shulman, 1987, p. 15)” and it was this intersection that he called pedagogical content knowledge.
In the following sections it will be argued that while PCK did improve as a result of the intervention, the post-intervention measures indicated that the overall PCK of the students remained low. This, however, is not surprising in that PCK is a construct that is focused on actual classroom practice (Van Driel et al., 1998; Van Dijk & Kattmann, 2007) and the students in this study had, at this stage of their training, not done any teaching.

3.1 Issues of validity and reliability in terms of the PCK-EC questionnaire

The instrument used to determine pedagogical content knowledge was a questionnaire consisting of a number or items (PCK-EC Appendix D1). As was the case with the SCK questionnaire, the PCK-EC questionnaire was specifically constructed for this study and as such, its validity and reliability need to be addressed. The validity in the determination of PCK in this study rests on the questionnaire’s content validity. The items used, albeit with modifications and adaptations to turn them into suitable questionnaire items, all originated from the literature where they occurred as teaching strategies, teaching hints, common misconceptions and barriers to understanding (DCSF, 2003, 2009; Illes, 2002; Millar, 2005). The validity of this study’s PCK-EC questionnaire rests on the notion that the elements of PCK taken from the literature have stood the test of time and been accepted into the science teaching community as accurate and valid elements of science PCK.

Some of the items in this questionnaire were numerical and could be coded and interrogated using descriptive and inferential statistics, and as such, their reliability could be determined using statistical analysis, while other item responses were open-ended allowing for free responses wherefrom trends and traits could be identified. Cohen et al., (2007, p. 135), using Hammersley’s suggestion concerning the validity of qualitative research, suggest
that the term ‘certainty’ be replaced by the term ‘confidence’ when doing qualitative research and further claim that “…as reality is independent of the claims made for it by researchers, our accounts will be only representations of that reality rather than reproductions of it.” It is this construct of ‘confidence’ rather than ‘certainty’ that should be considered when interpreting the qualitative data generated by the PCK-EC questionnaire.

The internal reliability of the PCK questionnaire items was determined by the calculation of Cronbach’s α scores. The Cronbach’s α for the pre- and post-intervention questionnaires differed by a great deal (pre-α = 0.47 and post-α = 0.72). At first glance, and using George and Mallery’s (2003) ‘rules’ for Cronbach α, it would appear that while the α for the post-intervention questionnaire could be categorised as being ‘acceptable’, the pre-intervention questionnaire’s α is considered to be in the ‘unacceptable’ range. This low pre-intervention questionnaire value, or rather the large difference between the two values, can be commented on from two perspectives. Firstly, as noted in Chapter two by Van Dijk and Kattmann (2007, p. 887), PCK is described as where “…curriculum and instruction intersect, that is, mainly at the classroom level.” This view that PCK ‘happens’ at the practical level in the classroom is supported by a number of researchers (Barnett & Hodson, 2001; Rollnick et al., 2008; Veal & MaKinster, 1999; Verloop et al., 2001). The respondents in this study were all pre-service students in their second-year of study and, apart from a two week period of classroom observation at the start of their second year of study, they had no exposure to classroom teaching at all. If it is accepted that PCK has a large practical and contextualised element to it, then it is conceivable that many of the students did not actually understand many of the items in the PCK-EC questionnaire when they were exposed to them for the first time before the course. The second perspective that could be considered when viewing the
pre-intervention questionnaire’s α-value, is that for basic exploratory research (as is the case in this PCK questionnaire) a cut-off of 0.50 is sufficient for acceptable internal reliability of the items, and so with an α-value of 0.47, the internal reliability of the items in the pre-intervention questionnaire can be considered reliable (Nunnally, 1978).

3.2 Discussion of descriptive and inferential statistics with reference to PCK

The first descriptive statistic to be used in an attempt to answer the question as to whether this type of intervention is able to increase the student’s PCK is the mean scores of the pre- and post-intervention PCK-EC questionnaire. As noted previously, none of the students had any previous teaching experience and that many researchers (Van Driel et al., 2002, Shulman, 1987; Veal & MaKinster, 1999) believe that PCK is rooted in classroom practice. So it is not surprising therefore that both the pre- and post-PCK scores are low (pre-intervention questionnaire’s mean score is 2.25 which translates into 23%\(^{15}\) and the post-questionnaire mean is 33%). While there is a substantial and statistically significant (p = .000) increase of 10% in the mean scores and this chance had practical significance (d = .67 on Cohen’s d), the scores remained woefully low. This could be attributed to the fact that none of the students had any actual classroom experience. When the descriptive statistic, which in this study has been referred to as percentage gain in potential, (i.e. difference between the improved score and the initial score expressed as a percentage of the maximum possible improvement) is considered, the improvement is also in the order of 10%. The intervention, despite focussing on PCK from, what at best could be termed a theoretical perspective, had no actual classroom teaching component, and hence no opportunity to gain

\(^{15}\) For ease of comparison all the scores recorded in Appendix B1 were reworked from the raw scores to a score out of 10. Multiplying the final score by 10 gave the percentage score.
PCK in a ‘real’ classroom. This suggests that if one wants to improve students’ PCK as well as ensure that the final level of PCK is at a high level (in this study a ‘high-score’ had been one that is greater than 6 out of 10 see Chapter four Section 4.1) then any intervention requires a component consisting of actual teaching practice.

In a similar fashion to what was done with the subject content knowledge, the individual students were grouped into categories with respect to their PCK-EC scores. Unlike in the SCK discussion where the increase in the number of students in the ‘high-score’ category were considered, the overall low scoring in PCK suggests that a consideration of the decrease in the number of students in the low-score category might be more informative (see Table 6). Initially 96% of the students were categorised as ‘low-score’ students and this decreased to 75% in the post-intervention questionnaire. While this 20% decrease in the number of ‘low-score’ students might appear encouraging, the almost zero increase in the number of ‘high-score’ students indicates that students who did improve their category, only improved by one category to the middle category.

The two post-intervention assessment activities, namely, the written test and written assignment, also cast some light on the level of PCK of the students after the intervention. For example, in the written assessment, students were asked about Millar’s (2005) two aspects of energy that make it difficult to teach (i.e. the abstract nature of energy and the mismatch between the scientific and everyday understanding of energy). This type of question can be considered as constituting PCK because if students and teachers are aware of the barriers to teaching and learning then it will make the teaching of the subject content matter more teachable (Summers et al., 1998). Just over one third of the respondents (36%) were able to identify and explain both aspects of energy that make it difficult to teach, 47% were able to
explain one or the other aspect and 17% had no idea, or provided an unacceptable scientific responses (see Figure 15).

However, some of the answers to questions in the post-assessment and assignment show that many of the students in this study understood what constituted energy misconceptions. For example, the misconception identified by Trumper (1998) where respondents viewed energy from a ‘flow-transfer’ or ‘quasi-material perspective’ was referred to most often when students were asked to identify and explain common energy misconceptions, (30% in the post-assessment and 22% of the time in the assignment). Similar patterns could be discerned with other common energy misconceptions, that is, misconceptions related to conservation of energy, energy and movement, energy and living organism, energy and force, et cetera (see Tables 7 & 8).

Van Dijk and Kattmann (2007) say that pre-service and beginning teachers have very little, if any useful PCK. This claim is supported by the data generated in this study, where in the post-intervention PCK-EC questionnaire, less than 6% of students could be classified as having a ‘high-score’\(^{16}\) for PCK. In response to the initial question asked in the section as to whether the intervention was able to improve the students’ PCK, one can suggest that the intervention did make a difference as there were notable improvements in both the mean score on the PCK-EC instrument (10%) and in the percentage gain of potential (10%). The post-intervention test and assignment also indicated that students had a working knowledge of the possible misconceptions related to energy, possibly as a result of the intervention, but it is the consideration of the categorisation of students into low, medium and high categories of PCK understanding that is the most illuminating. While the number of students in the ‘high-score’

\(^{16}\)That is a score of greater than 6 out of 10 for PCK.
category remained low, there was a substantial decline (20%) in the number of students in the ‘low-score’ category.

4. **PRE-SERVICE TEACHER’S SELF-EFFICACY?**

This section considers students' perception of their self-efficacy. These perceptions help to answer the third sub-question in this study: “Does this type of approach to pre-service training in the Natural Sciences improve teacher’s self-efficacy?”

Unlike the previous two sections of this report where students responded to items dealing with subject content knowledge and pedagogical content knowledge and where their responses could be considered to be objective, the self-efficacy data that were generated provided subjective insights into the participants’ concepts of self-efficacy, which involves their belief in their ability to achieve or do something (Bandura, 1994).

The instrument that was used to determine science teacher self-efficacy was the STEBI-B questionnaire. As noted previously, two independent factors were determined by this instrument, namely, Personal Science Teaching Efficacy Beliefs (PSTEB) and Science Teaching Outcomes Expectancy (STOE). PSTEB is a teacher’s belief in his or her ability to teach science effectively while STOE is a teachers’ belief in his or her ability to impact on the science learning of learners. Staver (2007, p. 8) proposed a number of principles that underpin the teaching of science. Principle number one is: “Think of science teaching as a purposeful means to an important end: student learning.” When this principle gets unpacked it becomes clear that teachers who embrace it will have a high degree of outcomes expectancy. Effective science teaching implies, according to Staver (2007, p. 8), that teachers have to “…accept some measure of responsibility for their students’ struggles and failures.” This then
links directly to the statements related to outcomes expectancy as found in the STEBI-B instrument.

4.1 **Issues of validity and reliability in terms of STEBI-B**

Tschannen-Moran and Woolfolk-Hoy (2001) claim that the measurement of self-efficacy has always been problematic and researchers have struggled to develop effective instruments to measure it. Validity issues have been continually raised in the literature and these usually revolve around the exact meaning of the two factors embedded in STEBI-B, namely, outcomes expectancy and personal self-efficacy. Despite these potential problems and disagreements, Tschannen-Moran & Woolfolk-Hoy (2001) claim that studies of teacher efficacy have borne much fruit and have been used in a number of studies, both in its original format, as developed by Riggs and Enochs (1990), or adapted and/or translated by a number of researchers over the years (Bleicher, 2004; El-Deghaidy, 2006; Gencer & Cakiroglu, 2007; Yilmaz-Tuzun & Topcu, 2008). Bleicher (2004) claims that, despite the above reservations concerning STEBI-B, the robustness of the instrument has been proved, both in a variety of contexts and with a number of modifications. As such, the STEBI-B instrument was used as the data generating instrument for self-efficacy in this study.

Reporting of data acquired using STEBI-B is always split into the two factors that were originally identified by Riggs and Enochs’ (1990) factor analysis of the instrument, namely STOE and PSTEB. The internal reliability of STEBI-B has been calculated by a number of researchers, for example, El-Deghaidy (2006) and Finson et al. (2000), and has consistently produced a high degree of internal reliability. The Crombach α score for this study compares favourable with both of the above studies in that the α-score for the items fall within the
'acceptable’ to ‘good’ internal reliability categories (George & Mallery, 2003; Nunnally, 1978). This study’s α was 0.64 in the STOE pre-intervention questionnaire, and 0.77 in the post-intervention questionnaire (Appendix B2). El-Deghaidy’s study (2006) had an α of 0.75, while Finson et al. (2000) obtained an alpha of 0.78 in their study for STOE. A similarly favourable comparison can be made for the PSTEB. In this study the pre-α = 0.78 while the post-intervention α = 0.87, and in the comparison studies referred to above α = 0.82 (El-Deghaidy, 2006) and 0.89 (Finson et al., 2000). The internal reliability of the study appears to be sound, but as will be seen in later sections of this chapter, the validity of the instrument might be questionable.

4.2 Discussion of descriptive and inferential statistics with reference to PCK

The two factors, STOE and PSTEB, which comprise the STEBI-B questionnaire, will be discussed separately. During the discussion that follows one must take cognisance of the so-called ‘ceiling effect’ that has been identified by Roberts et al. (2001) as a relevant factor in pre- and post-STEBI-B investigations (see Chapter four, Section 7.1). Roberts et al. (2001) noted that because of the initially high scores in self-efficacy instruments, there might only be a small improvement because there is often little room left for improvement, as self-efficacy questionnaires often have a fixed number of items and as such a fixed maximum score (Woolfolk-Hoy, 2008). This might provided an explanation for the findings of Aydin and Boz (2010) who concluded that there was no consensus amongst researchers on the effect of teacher education programmes on pre-service teachers’ self-efficacy beliefs. On the other hand, Morrel and Carroll (2003) citing Henson, suggest that teaching self-efficacy is a construct that can only develop over a long period of time, so short interventions might have little or no effect on self-efficacy.
4.2.1 Science teaching outcomes expectancy (STOE)

The descriptive statistics for STOE were considered from two perspectives, firstly by using the raw scores from the questionnaires themselves, that is a score that ranged from one through to five per item, and secondly, the scores were reworked using Microsoft Excel® to establish a scale that had a maximum value of 10. This procedure of reworking the raw scores out of a maximum of 10 was to enable comparisons to be made between the various factors investigated in this study. These reworked scores also formed the basis of the three scoring categories (viz. ‘low-score’, ‘moderate-score’ and ‘high-score’).

The increase in mean scores for STOE was only 1%, and it is suggested that this unsubstantial increase, could be attributed to the ceiling effect, as the initial STOE median score was 35 out of a possible 50 points. This implies that 50% of the respondents scored more than 70% of the maximum score in the initial questionnaire. The implication of this is that the students’ initial self-efficacy was reasonably high. Morrel and Carroll’s (2003) tentative claim that self-efficacy can be improved by improving subject content knowledge is tempered by their own caveat that improvement might only be the case when teachers start with a relatively low science teaching self-efficacy.

Another way of analysing the data was suggested by El-Deghaidy (2006), that is to categorise a high self-efficacy as being one that has a score of greater than one standard deviation above the mean or average score and when the respondent’s score is lower than the mean minus one standard deviation, then this is considered to be a low self-efficacy. Even when this method was used for the students in this study, there appeared to be no meaningful improvement in the number of students in the high category.
As a consequence of the ceiling effect, the most useful and informative descriptive statistic to consider is the percentage gain of potential (Appendix B1). The percentage gain of potential was statistically significant \( (p = .022) \), but the gain was only 8%.

The inferential statistics tabulated in Appendix B1 for STOE show that apart from the percentage gain of potential that was statistically significant, the other changes in scores were not statistically significant.

A number of researchers (Bursal, 2008; Dellinger et al., 2008; Tschannen-Moran et al, 1998) have all noted possible problems and complications that have plagued researchers working in the area of self-efficacy. Bursal (2008) in particular, has noted inconsistencies in the interpretation of STOE. He suggests that when STOE was first mooted, schooling focused on teacher-centred classrooms, where the teacher did have more control over learning, and that nowadays there has been a shift from a teacher-centred to a more learner centred approach, and that this shift has influenced how STOE is interpreted by respondents. Whatever the explanation may be for the findings in the STOE measures of previous research in self-efficacy, the data generated in this study supports the notion that the administration of the STOE-questionnaire reveals very little whenever it is used to evaluate short-term interventions.

4.2.2 Personal science teaching efficacy beliefs (PSTEB)

The trends noted in the STOE factor are also noticed in PSTEB. No improvement was noted in the students’ PSTEB raw scores and there was no substantial increase in number of students who could be classified as having a high PSTEB. In cases where the initial scores
are very high it is useful to calculate the percentage gain of potential, and in the case of PSTEB, this was 7%, which suggests that the ceiling effect may play a role here as well.

Bleicher (2004) provides the motivation for the imperative of increasing pre-service primary school teachers’ self-efficacy and outcome expectancy beliefs because he claims that this translates directly into increased teaching confidence, a valuable asset when they eventually find themselves in the classroom. On the other hand, Mulholland and Wallace (2001, p. 244) suggest that “Teachers with low science teaching efficacy beliefs avoided science teaching even though their outcome expectancy beliefs about teaching generally were high.” The conclusion reached by Aydin and Boz (2010) was that researchers have not been able to reach consensus on the effect of teacher education programmes on pre-service teachers’ self-efficacy, for example, Morrell and Carroll (2003) found that intervention programmes with pre-service teachers significantly impacted on PSTEB, but that there was no change to STOE, while Jarrett (1999) suggested that an increase in science content knowledge as a result of some form of intervention (especially hands-on activity) had the effect of increasing science teacher efficacy, as measured by STEBI-B.

So to conclude this section on science teacher self-efficacy, it might be prudent to suggest that while self-efficacy is acknowledged as an important factor in the study of pre-service teachers’ training, the actual measurement of it and measures of improvement in self-efficacy as a result of a particular intervention should be treated with caution.
5. **PRE-SERVICE TEACHER’S CONFIDENCE**

The fourth sub-question in this study: *“Does this type of approach to pre-service training in the Natural Sciences improve teacher’s confidence to teach energy at school?” is addressed in this section.*

The nature of the PSTEB items might at first appear to be closely linked to teaching confidence (Appendix E1), but Pajares (1996) cautions that one should not use general self-efficacy instruments to measure confidence in a specific area, and while STEBI-B is specifically designed for science, it might, from Pajares’ perspective, not have been focused enough for this present study that homed in on a one particular science topic, namely energy. In contrast, other researchers have linked confidence to two of the factors considered previously in this chapter, namely, SCK and self-efficacy. Bleicher and Lindgren (2002) and Jabot (2002) claim that there is a meaningful link between self-efficacy and confidence, while Summers and Kruger (1992) have suggested an important positive relationship between subject content knowledge and confidence to teach science.

In this study, confidence was classified into three separate factors, namely, confidence in teaching (Conf-T), confidence in the understanding of subject content knowledge (Conf-C) and confidence in level of pedagogical content knowledge (Conf-P). The data for each of these confidence factors were obtained from items embedded in the various questionnaires (Appendix F).

5.1 **Reliability scores**

The internal reliability of the items used to determine the various confidence factors was determined using Cronbach’s alpha for both the pre- and post-intervention data. The
reliability of items in two of the factors, namely, Conf-C and Conf-P were classified as acceptable to good, (the pre-intervention scores were $\alpha = 0.85$ and $\alpha = 0.71$ respectively), and the post-intervention Cronbach’s alpha values were 0.90 and 0.68. The items in Conf-T had $\alpha$-values of 0.58 (pre-intervention) and 0.47 for the items in the post-intervention questionnaire. These values for internal reliability of Conf-T are considered to be, at best ‘questionable’, and at worst ‘poor’ (George & Mallery, 2003). Cronbach alpha is affected by the number of items in the questionnaire, and up to a point, the more items the higher the Cronbach alpha value will be. This assertion is supported by Domino and Domino (2006) who say “…alpha increases as the number of items increases (and also increases as the correlations among item increases), so that .80 may be too harsh of a criterion for shorter scales.” In the calculation of $\alpha$ for Conf-T there were only two items in each questionnaire and this small number of items could possibly account for the unacceptable $\alpha$-values for Conf-T.

5.2 Discussion of changes in confidence

This discussion on the changes in the various confidences dealt with in this study take place in three parts: confidence with respect to subject content knowledge, confidence with respect to pedagogical content knowledge and confidence with respect to teaching.

5.2.1 Confidence with respect to teaching (Conf-T)

As noted earlier, confidence in the ability to teach was measured primarily by two items attached to the end of the STEBI-B instrument (Appendix E2). These were items where students were asked to speculate on, if given the choice when they started to teach, whether
they would indeed choose to teach science, and secondly, if they were to teach science in the future, how would they view their teaching performance.

There was no measurable difference between the pre- and post-intervention questionnaires’ mean scores for Conf-T. In this study, as a consequence of students scoring high on the initial questionnaires and thus having little room to improve their scores in the post-intervention questionnaires, the statistical concept of percentage gain of potential was introduced (see Chapter 3, Section 6). The determination of the percentage gain of potential in this case (i.e. Conf-T), introduced an interesting problem associated with calculating the percentage gain of potential. A clue to the origin of this problem was the drop in the number of students whose scores could be considered (viz. n = 61 down to n = 59). This change indicated that two students had already scored the maximum on the initial questionnaire, and on a two-item instrument this is not difficult to achieve and as such they had no potential to improve. Therefore the percentage gain of potential of 5% must be treated with caution and in any case on the Student’s t-Test the changes were shown not to be statistically significant.

While Conf-T was determined by the two items in the pre- and post-intervention questionnaires, there was one other potential indicator of teaching confidence, and this was in the form of a question asked of all students in the post-intervention web-based assessment (Appendix C4). In response to the question: “How confident are you that you will be able to teach energy to an IP class using toys?” 66% of the students indicated that they were either very confident or confident that they would be able to teach energy to an IP class using toys. Khwaja (2006) determined that teachers’ confidence in their teaching could be traced back to their own science background and their understanding of SCK and, as such, it is suggested that the toys workshops, which in this instance of a post-intervention question, had become
part of the students’ science background and had contributed to their understanding of energy, and as such did in fact positively influence their confidence in their ability to teach the concept of energy. It should be borne in mind that none of the students had at the time of this study any teaching experience, so these expressions of confidence were purely speculative on their part.

Researchers such as Appleton (1995) and Khwaja (2006) have directly linked subject content knowledge and confidence in subject content knowledge to effective teaching. One of the first data sets collected in this study was linked to the students’ background experiences of science. This was in the form of ascertaining the students’ highest level of school science and perusing their reflective writings on their school experiences of science.

Figure 8 illustrates the comparison between school science experience, as measured by the highest level of school science completed, and the number of students in the ‘high-score’ category for confidence in their understanding of content knowledge (viz. Conf-C). The intervention did appear to have a positive impact on the students’ Conf-C in that the overall number of students in the ‘high-score’ Conf-C category increased from 39% in the pre-intervention questionnaire to 65% in the post-intervention, and as such, it can be suggested that the intervention did in fact make a difference to the students’ confidence in content knowledge.

As a result of their school experiences, many students did not continue with science past Grade 9. As can be seen in the reflective writings (Chapter four, Section 4.2), the reasons for not continuing with science may not be exactly the same for each student, but certain themes

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17 The ‘high-score’ category was the category where Conf-C scores were greater than six on the ten-point scale.
could be detected in their writings about their school experience. One of the overriding themes involved confidence and comments such as “…only selected people could do science and this made me feel stupid and incapable”, “…science is a subject only for A-students…” appeared to dominate the writings of the group of students who had the lowest level of school science. Encouraging signs from the results of this study are that, in the group of students mentioned above (i.e. those with the lowest level of school science who also had the lowest initial levels of confidence, in both their Conf-C scores and in their reflective writing) showed the highest levels of improvement in confidence in SCK (i.e. a 50% increase in the number of ‘high-score’ Conf-C students between the pre- and post-intervention questionnaires).

This study used both toys as an educative curriculum materials (viz. a set of toys workshops), as well as conventional lectures on the topic of energy. Two closely connected and recurring themes in the students’ reflective writings were the interlinked roles of the science teacher and the doing of practical work in school science. A number of researchers (Carr, et al., 1994; McDonnough & Matkins, 2010; Shulman, 1987) have noted the link between insufficient subject content knowledge and a teaching methodology that is dominated by the transmission mode of teaching. The students’ reflective writings highlighted the importance of a science teaching methodology that includes a practical work. The use of a hands-on or practical approach to teaching science is important in the eyes of the students and this can be seen by some of their comments, for example, “They helped me question how things worked instead of accepting that it works.” The post-evaluations indicate that a substantial number of individuals (n = 18) or 25% had improved their SCK confidence scores to such an extent that they could be re-categorised as ‘high-score’ Conf-C students. While this improvement in confidence cannot be directly ascribed to the toys workshops alone, it will be
shown later in this chapter (Section 6) that a number of students did in fact link their improvements in SCK, PCK and confidence to the ‘playing with toys.’

The internal reliability of Conf-C was very good ($\alpha > 0.80$) for both the pre- and post-questionnaires and the change in mean scores between the pre- and post-intervention questionnaires is statistically significant ($p < 0.05$) with a large practical significance or effect size.

The percentage gain of potential (26%) for Conf-C is substantial and is of a similar magnitude as the percentage gain of potential for SCK (21%). It would, therefore, be tempting to suggest a relationship between SCK and Conf-C. Some researchers (Appleton, 1995; Summers & Kruger, 1992) have suggested a link between inadequate subject content knowledge and low confidence and one could reasonably expect that an increased SCK should give rise to an increased level of confidence in subject content knowledge. In an attempt to determine if there was any correlation in this study between SCK and Conf-C a Pearson Correlation Coefficient $r$ was calculated on the SCK and Conf-C post-intervention scores. The correlation coefficient was strong ($r = 0.69$) and it was determined to be statistically significant ($p = .000$), however, Harlen and Holroyd (1997) caution that despite a common sense expectation that there should be a positive correlation between confidence to teach something and an understanding of that concept, there are other influences that impact on teachers’ confidence. While they did find, that for the majority of the teachers in their study, confidence and understanding did correlate, there were a significant number of instances where this was not the case. They found that factors such as gender, age groups taught, the teacher’s own school and personal experience et cetera all impacted on confidence.
An item in Part III of the workshop questionnaire asked students to respond to how confident they were in their subject content knowledge just prior to, and just after, the toys workshops. Judging by these responses the students felt that the toys workshops had a substantial impact on their understanding of energy. The number of students who were confident in their understanding of energy before the toys workshop (8%) increased to 69% after completing the workshop. This 61% percent increase in the number of students who were more confident of their understanding of energy could be considered to be an indicator of the effectiveness of using toys as educative curriculum material to improve students’ confidence in their understanding of energy.

5.2.3 Confidence with respect to PCK (Conf-P)

Confidence in pedagogical content knowledge (Conf-P) was measured using three items in the PCK-EC pre- and post-intervention questionnaire. Despite this factor being measured by only three items the internal reliability of these items managed to make the cut-off point of $\alpha = 0.70$ (i.e. the recommended value to indicate internal reliability of item) in the pre-questionnaire and $\alpha = 0.68$ in the post-questionnaire.

The substantial improvements in this factor (Conf-P) and for PCK can be ascribed to an effect that is almost the opposite of the ceiling effect. None of the students had any practical teaching experience, let alone science teaching experience, and because PCK is seen as rooted in practical classroom experience (Van Driel et al., 1998), it is to be expected that the pre-intervention PCK and Conf-P scores should be low because all the students would have had no experience of teaching. The difference in the mean scores of 27% may seem impressive, but the students started from such a low base and the intervention did focus on the PCK
aspects of energy – especially in the form of the educative curriculum material (viz. the toys workshops) that a substantial improvement in PCK from such a low base is almost inevitable. One other area of interest might be to investigate the relationship between PCK and Conf-P. The relationship between the post-intervention PCK and Conf-P scores was determined by the Pearson Correlation Coefficient r, and while the correlation was statistically significant (p = .000), the correlation itself was moderate (r = 0.39).

One way of considering the student’s Conf-P was to allocate them into one of three categories based on their Conf-P score. Allocated to the ‘low-score’ category were those students whose scores were below four on the ten-point scale. The middle category (‘moderate-score’) was from four to six and the ‘high-score’ category consisted of students who had scores above six. A large number of students fell into the low-score-category in the pre-intervention questionnaire (58%) and only 13% were initially placed in the high-score category. The post-intervention questionnaire reflected a reversal of the initial trends per category with 50% of the students being categorised as having a high confidence in their PCK and only 16% still having a low confidence in their PCK. In the light of the fact that the PCK scores of the students remained low after the intervention (33%), these findings highlight that confidence, like self-efficacy, is not based on actual abilities, but on individual perceptions of reality (Bandura, 1994; Tschannen-Moran & Woolfolk-Hoy, 2001).

Two of the three different confidences investigated in this study (i.e. confidence in content knowledge and confidence in pedagogical content knowledge) were found to have improved statistically significantly between the pre-and post-intervention questionnaires. The confidence factor, confidence in teaching (Conf-T), was found not to have reliability as
measured by Cronbach’s alpha and not to be statistically significant (p > 0.05) and this shows that measures used to measure Conf-T must be revisited.

In the above discussion of the seven factors investigated in this study it has not been possible to directly link or ascribe the change directly to the use of the educational curriculum material used in the study, namely, toys. However, the following section will discuss the student’s perceptions of the use of toys, as in the toys workshop, on their SCK, PCK, Conf-T, Conf-C and Conf-P.

The importance of having a sound content knowledge base has been shown by Bleicher and Lindgren (2002) to impact on teaching confidence and by Riggs and Enochs (1990) to impact on self-efficacy, which give credence to the notion that the changes are in fact attributable to the use of toys.

6. TOYS AND UNDERSTANDING OF ENERGY

As noted above, it would be very difficult to statistically ascribe improved SCK and PCK directly, and only, to the toys workshops and lectures. Improvements in SCK and PCK could just as easily be a result of self-study or any number of other factors (e.g. Television, conversations with peers and mentors etc.) Straver (2007) does, however, claim that hands-on and familiar phenomena do encourage the construction of abstract concepts in learners. One way to assess the impact of the toys workshops on understanding of energy is to ask the students to respond to questions that ask how confident they are about their understanding of energy before and after the toys workshops, and if they felt that these workshops had influenced this understanding in any way. A consideration of items #1 and #2 of Part III of the workshop, which asked: “How confident were you about your understanding of energy
before the start of these two workshops using toys?” and “How confident are you now at the end of these two workshops using toys?” and required a response on a Likert-type scale, where ‘1’ meant ‘no confidence’ and a ‘5’ meant ‘very confident’, indicated that the workshops had improved the students’ confidence, in terms of the understanding of energy, of 60% of the students. An analysis of the types of responses in the follow-up open-ended item (i.e. item #3 in Part III of the toys workshop’s worksheet) indicated that the practical (hands-on) aspects were believed to play a prominent role in the perceived increase in understanding of many of the students. Key comments such as “I always thought that it is very difficult to understand energy until I started working it out using toys” illustrate the positive impact that the students believed toys had on both their understanding of energy and the consequential benefit to their confidence in understanding energy. These first two items in Part III of the toy workshop’s worksheet are coupled with items #7 and #8 (i.e. Item #7: “Did ‘playing’ with toys have any impact on your understanding of energy?” and item #8 “Comment on your response to the question just above?” – item #7). These two questions concerned the perceived impact of playing with toys on the understanding of energy and the responses indicated that the students were almost unanimously (98%) in agreement that ‘playing with toys’ did have a positive impact on their understanding of energy. This is in agreement with Tytler (2002) when he suggested that most toys, by their nature, exhibit scientific principles in one form or another and generate interest and motivation in learners. Toys provide a focus where, through play, learning takes place.

The positive impression that the toy workshops left with the students is best illustrated by their responses to an item in the web-based assessment where they were asked if they would be able to teach energy to an IP class using toys. This question encompasses both
subject content knowledge and pedagogical content knowledge, and approximately 45% of the students claimed that after the intervention they were confident or very confident that they had both the SCK and the PCK to use toys to teach energy to an IP class.

7. **CHAPTER SUMMARY**

This chapter addressed the four sub-questions of this study and considered whether there was a positive change in the student’s subject content knowledge, pedagogical content knowledge and their outcomes efficacy and science teaching efficacy as a consequence of the intervention. There is also a discussion of changes in the students’ confidence in their SCK, PCK and their ability to teach energy to the IP learner.

In the case of SCK it was shown that while there was an overall improvement in SCK of the group, this increase was most noticeable in students who had the least school science background.

The initial level of PCK amongst the students was very low and, despite a substantial increase in PCK, this factor remained low, reflecting the low base from which it started. This is not surprising in that PCK is closely aligned with actual teaching practice and these students had no classroom teaching experience.

The solid history behind the STEBI-B instrument gives it both validity and reliability as an instrument to access both science teaching outcomes expectancy and personal science teaching efficacy beliefs. However, probably as a result of the ceiling effect, the changes in both these efficacy factors in this study were, at best, inconclusive, something which has been repeated by numerous researchers who have studied self-efficacy in science education (Aydin & Boz, 2010; Bursal, 2008; Morrel & Carroll, 2003).
Of the three confidence factors, confidence in teaching, did not generate an acceptable reliability coefficient (Cronbach’s alpha) and therefore very little significance can be attached to these results. The data generated in terms of the other two confidence factors (viz. confidence in SCK and PCK) were found to be reliable and illustrated substantial improvements in the students’ confidence over the course of the intervention.

Based on students’ open-ended responses to items, the workshops and lectures focussing on toys to teach the concept of energy, did impact on both the participants’ SCK with respect to energy and their confidence and perceived ability to teach energy using toys.
CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

1. INTRODUCTION

This study attempts to answer one particular question by focusing on the use of toys as educative curriculum materials and their contribution to student’s subject content knowledge, pedagogical content knowledge, self-efficacy beliefs and confidence to teach energy in the primary school. Toys were used as the educative curriculum material in an intervention that consisted of, amongst other elements, lectures, assignments and toy workshops, with the latter being a key driver. The choice of toys as the educative curriculum material was motivated by the fact that the intervention focused on energy, and that there is a huge variety, and plentiful supply (at reasonable cost), of toys that can be used to demonstrate the concept of energy from both theoretical and practical perspectives.

The intervention that was researched was essentially part of a standard science module and, as such, can be viewed as part of the normal programme in a pre-service teaching programme. This being the case, the potential exists for the introduction of any number of innovative educative materials into the normal pre-service science teacher programme. Examples of innovative materials that could be considered are: concept cartoons (Kabapinar, 2005; Keogh & Naylor, 1999); Science UpD8 worksheets (Science UpD8, 2010; Association for Science Education, 2005); hands-on investigations (Huber & Moore, 2001) et cetera.
2. MAIN FINDINGS

This research revealed that when an appropriate educative material is integrated into a topic in science-teacher education, there is a substantial positive impact on these pre-service teachers’ confidence in both their understanding of the science content and their perceptions of their ability to teach this content. Conclusions that also can be drawn are that the use of toys in the preparation of pre-service primary school teachers has the potential to substantially improve their SCK and PCK.

An important finding was that, despite being used by so many researchers over many years (Aydin & Boz, 2010; Bleicher, 2004; Bleicher & Lindgren, 2005; Bursal, 2008; De Laat & Watters, 1995; Enochs & Riggs, 1990; Morrel & Carroll, 2003; Watters & Ginns, 1995; Yilmaz-Tuzun & Topcu, 2008), the STEBI-B questionnaire provided the least valuable information in this study, in that there was little change in student’s self-efficacy between the pre- and post-intervention applications of the questionnaire in both factors that it purports to measure, namely, STOE and PSTEB. This was surprising; given its history it can almost be considered part of science education folklore. However, all the other factors in this study, even the ones that have been aligned with self-efficacy (viz. the confidence factors), to a greater or lesser extent showed at least some change between the pre- and post-intervention questionnaires. This begs the question: “Is it not time to reassess the usefulness of STEBI-B in present pre-service science education programmes?”

The other two questionnaires, SCK-EC and PCK-EC, were developed specifically for this study, and while it will always be a challenge to construct ‘new’ questionnaires that are both valid and reliable, this study has shown that even with complex, subjective constructs,
such as confidence in subject content knowledge and pedagogical content knowledge, it is possible to do so. While not without problems, such as too few items available to determine the value of factors such as confidence in teaching (Conf-T) and confidence in pedagogical content knowledge (Conf-P) and, on the other hand, too many items used to determine the values of subject content knowledge (SCK) and pedagogical content knowledge (PCK) that resulted in questionnaires that were too long, the questionnaires were able to both statistically and confidently determine values and levels of confidence in both SCK and PCK. As such, based on the experience of this study, it can be suggested that valid and reliable instruments to measure SCK, PCK and confidence in these constructs, can probably be developed for just about any topic in the pre-service science teaching curriculum.

Another finding of importance is that, while standard techniques of data analysis (e.g. Student’s t-Test, Cronbach’s alpha, Cohen’s d, identification of themes etc.) were used successfully in this study, two other methods stood out as being helpful, namely, the percentage gain of potential and what was referred to as the ‘low-score’/’high-score’ categorisation. The percentage gain of potential was introduced as a consequence of the prevalence of the ‘ceiling effect’ that was noted in some of the constructs in this study (Roberts et al., 2001). This effect is noticed when the initial scores of a factor are high, that is, before the intervention, thus leaving little room for actual improvement as a result of the intervention, and as such, there is a ‘ceiling’ that prevents ‘unlimited’ improvement. The percentage gain of potential tries to negate this effect by firstly asking the question “How big is the maximum amount that the respondent can improve?” that is, what is the maximum potential gain. The next question is: “How much, expressed as percentage, of this potential gain was actually achieved?” The effect of this ‘percentage gain of potential’ analysis is to
give a real sense of improvement of individuals, not in terms of raw scores, but in terms of how much of the potential that they could improve, did they really improve.

The second technique used in this study was to categorise students as a result of their scores into three categories, that is, a low-score, moderated-score and high-score categories. Improvement, as a result of an intervention, was thus measured in such a way so as to illustrate the success or not of the intervention in terms of the increase in numbers of students in the ‘high-score’ category or conversely in terms of decrease in numbers of students in the ‘low-score’ category. The techniques of percentage gain of potential had the effect of providing an opportunity to assess improvement of individuals irrespective of how well or badly they score on the pre-intervention questionnaires, while the categorisation of students provided a tangible indication of the impact of the intervention on different ability groups of the students involved in the intervention.

As this study is situated within the broad conceptual framework of teacher learning the conclusions drawn from the main and sub-questions contribute to polemic surrounding this topic. As seen in this thesis, the contribution made to the debate surrounding teacher learning includes issues of the:

- design of short-duration interventions that use innovative educative materials
- suitability of particular constructs to access teacher learning
- development, adaptation and evaluation of data generating tools or instruments to measure changes in these constructs
- assessment of methodologies used to make sense of the data generated by the measuring tools and instruments.
Fishman et al., (2000) identified a number constructs related to teacher learning, namely, subject content knowledge (SCK), pedagogical content knowledge (PCK), and beliefs and attitudes towards teaching science, with these last two portraying a certain similarity to two of the constructs investigated in this study (viz. self-efficacy and confidence). The importance of subject content knowledge in contributing towards teacher effectiveness has been established (Belfort & Guimarães, 2002 & 2004; Grossman et al., 1989; Leinhardt et al., 1991; Preece et al., 2004; Shulman et al., 1987) and as such any technique, method or innovation that contributes towards improving pre-service teachers’ subject content knowledge is to be welcomed. Certainly this study showed that the intervention was able to improve the students’ SCK and it is suggested that the integration of toys into the intervention did play a substantial role in this improvement in SCK. This is supported by the students who, almost unanimously, acknowledged the positive role played by toys in the improvement in their SCK.

However, the role played by the type of intervention used in this study in impacting on pre-service teachers’ pedagogical content knowledge must be approached with caution. In fact the whole question of the capability of pre-service programmes to impact on PCK is the topic of much debate in teacher training circles. This is not surprising, given that PCK is to a great extent practice-based and gets developed and improved during actual classroom practice (Van Driel et al., 1998). Having said this, it appears to still be possible to initiate an understanding of PCK via a misconceptions-based approach in pre-service teacher training. Aydin et al. (2010) have suggested that while practicing teachers develop their PCK during their teaching in their classrooms, the main source of pre-service teachers’ PCK is based on their school and university experience (including teaching practice). This study was able to show that, at least
from a theoretical perspective, the intervention was able to positively impact on the students’ PCK. The caveat here is that while there was a statistically significant improvement in PCK, the final level of PCK after the intervention was still disappointingly low. These are important factors to bear in mind when considering contributions to effective teaching, because a confidence in understanding of content and teaching ability have been directly linked to effective teaching (Appleton, 1995; Khwaja, 2006).

3. **LIMITATIONS OF THIS STUDY**

The conclusions drawn from this study should be viewed from the rather limiting perspective of a single topic (energy), using a single, albeit appropriate and innovative, educative curriculum material (toys), in the restricted case of a single class group. While taking note of this caveat it seems probable that the design of the intervention, the method of constructing and validating data generating instruments, and the methods used to analyse the data in this study, might be used as an exemplar when constructing similar investigations using different educative curriculum materials in different topic areas.

Confidence in teaching and pedagogical content knowledge presented the least convincing results from the data, and it is recognised that they are in actual fact practice-based constructs, that is, they are best learnt by actually teaching. As such, the lack of authentic classroom practice presents a major limitation in this study in that the intervention had no practice-based component. While this might be a limitation in this particular study in its present format, it is not such a leap to introduce a practice-based component into future interventions of this nature.
4. RECOMMENDATIONS FOR FURTHER RESEARCH

As noted in the above section, the limitations of this study, such as the single topic and limited sample could be considered as a response to Davis and Krajcik (2005, p. 10) who “…urge researchers to continue to explore the ways that educative curriculum materials can promote teacher learning and how their effects can be measured, on small and large scale.”

As has been shown in the above sections, the strategy used in this study can, with minor adaptations, such as the introduction of a practical teaching component, may be used by using any number of educative curriculum materials and in any number of school science topics. Another area of further research is the whole idea of expanding the intervention, not only in terms of time, but also with respect to the form and structure of the intervention, such as additional data generating instruments (e.g. interviews and observation of the workshops). Also, while the issue of ethics will have to be addressed, it might be useful to adapt the study into a classical empirical study involving an experimental and control group, where the experimental group is treated to an intervention, such as in this study, and the control group follows a traditional lecture-based programme.

5. CONCLUDING REMARKS

The study took place within the broader context of a set of three science modules residing within an integrated BEd programme that is focused on the training of pre-service Intermediate Phase teachers who specialise in the teaching of science and mathematics. It takes one particular science topic, namely energy, and investigates the impact of an innovative educative curriculum material, namely toys, on these students’ subject content knowledge, pedagogical content knowledge, self-efficacy and confidence. In other words, it focuses on
what Fishman et al. (2000) call teacher learning, that is, changes in knowledge, beliefs and attitudes, and teaching skills. As noted by a number of researchers over the years (Arends & Phurutse, 2009; Borko, 2004; Flecknoe, 2000), these sorts of changes in teachers are crucial because their learners’ success in science is closely linked to these teachers’ competence.

The usefulness of this particular study can be seen in that it is an example of real pre-service teachers in real classroom situations (Cohen et al., 2007). In the final paragraph of the assignment one student wrote: “Hereby I conclude that energy is not such a difficult concept in science to teach (S036).” A number of researchers (Bleicher, 2004; Khwaja, 2006; Mulholland & Wallace, 2001) have all suggested that if the teaching of science, particularly in the primary school, is not to be compromised, science teachers need to have a positive attitude towards science and sufficient confidence in their ability to teach it, plus they need a high degree of confidence in their own content knowledge and understanding.

A student, writing at the end of the final activity in the series on energy wrote:

In conclusion, there are many ways to aid teachers in the effective teaching of energy. Some of these ways include: An increase of the teacher’s SCK and PCK; using an effective model of teaching; and the correct and effective use of aids such as the Sankey diagram and mechanical toys. By using these strategies, teaching and learning energy need not be so difficult. (S041)

This student’s perception is one that appears to sum up the essence of the study and encompasses most of what was attempted to be achieved during the intervention. Although anecdotal or qualitative responses may be challenged, the overall findings of this study suggest that the use of toys to teach energy, within the context of this study’s sample of pre-service students, has the capacity to promote gains in pre-service teacher’s subject content
knowledge and confidence, requirements that are essential for the effective teaching of science.
REFERENCES


APPENDICES

Appendix A: Identification and interaction between data collection sources

- **Questionnaire**
  - Pre-toys workshop
  - Post-toys workshop
  - Self-Efficacy
  - Science Teacher Self-efficacy Beliefs Instrument for pre-service teachers (STEBI-B)
  - Includes **Confidence** items

- **Questionnaire**
  - Pre-toys workshop
  - Post-toys workshop
  - Subject **Content** Knowledge
  - Questionnaire for Energy (SCK-EC)
  - Includes **Confidence** items

- **Questionnaire**
  - Pre-toys workshop
  - Post-toys workshop
  - **Pedagogical Content** Knowledge for teaching Energy (PCK-EC)
  - Includes **Confidence** items

- **Participant Writing**
  - Pre-toys workshop
  - Includes school science experience and **Confidence**

- **Toys workshops**
  - Includes **Confidence**
  - SCK
  - PCK

- **Web-based Assessment**
  - Post-toys workshop
  - Includes **Content** items
  - Includes **Confidence** items

- **Written Test**
  - Post-toys workshop
  - Include **Pedagogical Content** Knowledge items
  - Includes **Confidence** items
  - Includes **Content** items

- **Written Assignment**
  - Post-toys workshop
  - **Pedagogical Content** Knowledge
  - **Confidence** items
Appendix B1: Descriptive and inferential statistics summary

All mean values were standardised to a scale of 0 (minimum) and 10 (maximum)

### Descriptive Statistics

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### Inferential Statistics

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Appendix B2: Summary of Cronbach’s alpha

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Appendix C1: Questionnaire: subject content knowledge – energy concept (SCK-EC)

Subject Content Knowledge – Energy (SCK-E)

Notes:
- Comments in bold italics were not seen by respondents to the questionnaire – they have been added later to clarify the scoring of SCK-EC
- Item 1, seeking permission, was included with all the questionnaires. It may have varied slightly in wording with each questionnaire but the gist of the question remained the same.
- An * denotes items used in the calculation of SCK.

1. I hereby agree to participate in a study of the Energy concept in the science modules in the IP programmes. I understand that I am participating freely and without my being coerced in any way to do so. I also understand that I can stop completing the questionnaire at any time and withdraw as a participant in the research.

I have received the details of a person to contact should I need to speak about any issues which may arise from this questionnaire (leslie.meiring@nmmu.ac.za).

I understand that while my answers will not be anonymous, they will remain entirely confidential.

   o I agree to participate in this questionnaire
   o I do not agree to participate

2. Please indicate whether you are a male or a female

   O Male       Female

3. Indicate the highest level to which you did school science (natural or physical science - biology or life sciences will be asked in the next question)

   O Grade 6   O Grade 7   O Grade 8   O Grade 9   O Grade 10   O Grade 11   O Grade 12

4. Indicate the highest level to which you did school biology or life sciences.

   O Grade 6   O Grade 7   O Grade 8   O Grade 9   O Grade 10   O Grade 11   O Grade 12

You may feel like these guys in this and the PCK pre-questionnaires - That's okay you still have to work through all this stuff in our lectures so the post-tests should be better.

5. Write down the first three things that you associate with the term "energy". You may also like to expand on your associations in a sentence.

6. Which of the following statements do you associate with energy. Tick all the statements that you agree with or believe to be true or accurate. You may tick as many boxes as you like.
6.1* energy is always linked to human beings
6.2* all objects have energy that they can use
6.3 all our energy comes from the sun
6.4* energy is something possessed by a body and can be released by some event or trigger
6.5 energy is always defined as the ability to do work
6.6* energy is a type of fuel
6.7 work = force x distance moved
6.8* energy can be seen as a type of fluid that is transferred in certain processes
6.9* energy is a result of some event
6.10* energy cannot be created or destroyed
6.11* energy is transformed during certain processes e.g. potential to kinetic when a stone falls
6.12 there are many forms of energy e.g. sound, kinetic, heat, light
6.13 energy and force are the same thing
6.17** energy is the result of an event or process (this statement only appeared in the post-test)
6.14* energy must always involve movement
6.15* energy is transferred during certain processes e.g. potential to kinetic when a stone falls
6.16 energy has always been confusing for me

For the next 27 items you will be given a statement and then asked to respond as to whether the statement is TRUE or FALSE. I would like to also gauge your confidence in your response so I have given you a few more options besides simply 'TRUE' or FALSE'. These options will be interpreted by me as follows:

I know this is TRUE (You have absolute confidence you know the statement is true).
I think this is TRUE (You somehow think the statement is true, but you are not 100% confident it is true).
I have no idea (Choose this option if you understand the statement and context, but that you really do not know the correct answer, or that at best, your answer would be a 'wild' guess).
I think this is FALSE (You somehow think that the statement is false, but you are not 100% confident it is false).
I know this is FALSE (You have absolute confidence you know the statement is false).

NOTE: The order of the options: "I have no idea" is in the middle between "true" and "false". This is to help me to code your responses.

7* STATEMENT: Energy is a kind of 'stuff' that is transferred from place to place when something happens.
   o I know this is TRUE
   o I think this is TRUE
   o I have no idea
   o I think this is FALSE
   o I know this is FALSE

8* STATEMENT: Energy causes events to happen.
9* STATEMENT: Heating is a process of energy transfer.
10* STATEMENT: Electricity is an energy resource.
11* STATEMENT: An electric current transfers energy.
12* STATEMENT: Energy is lost when appliances such as light bulbs, heaters are used.
13* STATEMENT: Sound energy is transferred to the surroundings by vibrations.
14* STATEMENT: Light is a process of energy transfer.
15 STATEMENT: Respiration uses energy.
16 STATEMENT: Photosynthesis makes energy
17* STATEMENT: Chemical reactions cause energy to be transferred.
18* STATEMENT: Energy is lost when doing exercise.
19* STATEMENT: Energy from gravity makes a ball fall down when dropped from a height.
20* STATEMENT: Energy and force are interchangeable terms.
21* STATEMENT: Fuel and energy are interchangeable

The picture below shows a toy 'jumping bug'. The person compresses the spring so that the suction cups stick together and places the bug on the table. After a short time the suction cups come apart, releasing the spring, and the bug pops up into the air and then falls back onto the table.

This diagram must be used for the next EIGHT (8) items.

22* STATEMENT: When the bug's spring is compressed, but before it 'pops' up, the toy has energy.
23* STATEMENT: When it's moving upwards, after the spring has uncoiled, the bug has energy.
24* STATEMENT: The spring's energy is a hidden force within it.
25* STATEMENT: The bug has no energy when it is moving upwards.
26* STATEMENT: At the top of its flight, when the bug is moving neither up nor down, it has no energy
27* STATEMENT: If you ignore air resistance, the bug's energy remains the same throughout the flight.
28* STATEMENT: The bug has no energy when it is moving downwards.
29* STATEMENT: When it is above the floor and at rest on the table, the bug has energy.

The picture shows an electric heater plugged into the wall near the electricity meter of a home. The heater is switched on and the bars are glowing. Please respond to the next FOUR (4) items using the same criteria for the responses as in the toy 'jumping bug' items.

30* STATEMENT: The energy from the power station which supplies this heater did not exist before it was generated at the station.
31* STATEMENT: Not all the energy from the heater goes into heating the room.
32* STATEMENT: Unlike force, which you can feel, energy has no physical existence since it is merely an abstract idea.
STATEMENT: Then energy from the heater goes into the room and disappears.

If you would like to make any comment about the above questions, please make them here. I am interested to see how you understand energy and/or experienced it at school.

The figure below shows a sketch of a frictionless roller-coaster track with a ball being held in position A. The ball is then simply released at position A.

![Roller Coaster Track Diagram]

Predict to which maximum height the ball will reach after it is released.
- Position B
- Position C
- Position D
- Position E
- Position F
- Position G

How confident are you that your response to the above item is correct?
- Very confident
- Confident
- Not confident
- Just guessing

Explain your choice of the height reached by the ball in the roller coaster item.

Below are eight pictures (Labelled A to H) all involving energy. Choose any TWO and explain your choice in a sentence or two using the word ‘energy’. Write down the letter of the picture you are writing about before you start your explanation. Use the next two items to give us your response.
38 Explain your choice

39 Explain your choice

40* Sipho is pushing his bicycle up a hill. Where does Sipho get the energy to push his bicycle?

- From the food he has eaten
- From the exercise he did earlier
- From the ground he is walking on
- From the bicycle he is pushing

41 How confident are you that your response to the above item is correct?

- Very confident
- Confident
- Not confident
- Just guessing

42* Spring 1 and Spring 2 are identical. Then Spring 1 was squashed/compressed together a little and clamped in place. Spring 2 was squashed/compressed together a lot and clamped.

Which spring has the more stored energy?

- Spring 1
- Spring 2
- Both springs have the same energy
- You cannot tell unless you know what the springs are made of
43 How confident are you that your response to the above item is correct?

44* If you are burning wood, the reaction will
   - release energy
   - absorb energy
   - neither absorb nor release energy

45 How confident are you that your response to the above item is correct?

46* Which group of energy resources are all renewable?
   - coal, oil and natural gas
   - solar, oil and geothermal
   - wind, solar and tidal
   - natural gas, solar and tidal

47 How confident are you that your response to the above item is correct?

48 Comment on the following statement: If energy is conserved, why are we 'running' out of energy?

49 If you would like to make any more observations about the teaching and learning of energy in the primary school please make them here. Thank you for completing this questionnaire for me. Les Meiring
Appendix C2: Categorisation and Sources of items used in the development of SCK-EC.

<table>
<thead>
<tr>
<th>Energy ‘ideas’</th>
<th>Relevant questions in SCK-E questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration</td>
<td>#1, #2, #3, #4</td>
</tr>
<tr>
<td>General energy questions</td>
<td>#5, 6.16, #34, #37, #38, #39, #49</td>
</tr>
<tr>
<td>Specific Confidence questions</td>
<td>36, #41, #43, #45, #47</td>
</tr>
<tr>
<td>Energy as an abstract concept</td>
<td>#6.4, #6.6*, #6.8, #7, #22, #32, #33, #44#</td>
</tr>
<tr>
<td>* Misconception that energy is a “stuff”, ‘liquid’ or ‘thing’</td>
<td></td>
</tr>
<tr>
<td>Relationship between the scientific and everyday understanding of energy</td>
<td>#6.10, #12, #18, #27, #30, #31, #38, #39, #48</td>
</tr>
<tr>
<td>* Misconception that energy is not conserved, wasting energy, running out etc.</td>
<td></td>
</tr>
<tr>
<td>* Misconception that things ‘use up’ energy</td>
<td></td>
</tr>
<tr>
<td>Energy sources and resources</td>
<td>#6.3, #6.9, #8, #10, #13, #14, #22, #29, #35??, #38, #39, #40, #41, #44, #46</td>
</tr>
<tr>
<td>‘Definitions’ of energy</td>
<td>#6.5, #6.7, #6.12</td>
</tr>
<tr>
<td>Energy transferred and transformed</td>
<td>#6.11, #6.15, #12, #13, #14, #17</td>
</tr>
<tr>
<td>* Misconception that energy is found only in living things</td>
<td>#6.1, #22, #22</td>
</tr>
<tr>
<td>* Misconception that energy is associated only with movement or objects at rest have no energy</td>
<td>#6.2, #6.9, #6.14, #15, #16, #17, #22, #23, #25, #26, #28</td>
</tr>
<tr>
<td>* Misconception that energy is created as a result of an activity</td>
<td></td>
</tr>
<tr>
<td>* Misconception that energy and fuel are interchangeable concepts</td>
<td>#6.6, #21</td>
</tr>
<tr>
<td>* Misconception that terms energy and force are interchangeable</td>
<td>#6.13, #19, #20, #24</td>
</tr>
<tr>
<td>* Misconception that heat and temperature are the same thing</td>
<td>#9</td>
</tr>
<tr>
<td>* shaded question numbers are duplicated</td>
<td></td>
</tr>
</tbody>
</table>

Reference for items in SCK-EC Questionnaire

<table>
<thead>
<tr>
<th>Item Numbers</th>
<th>Sources and consequently validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items #1-#4</td>
<td>Administrative and demographical items</td>
</tr>
<tr>
<td>Item #5</td>
<td>Developed and validated by Finegold and Trumper (1989)</td>
</tr>
<tr>
<td>Items #6 - #21</td>
<td>Department for Children Schools and Families (2003, 2009)</td>
</tr>
<tr>
<td>Item #35</td>
<td>Finegold and Trumper (1989)</td>
</tr>
<tr>
<td>Item #38 &amp; #39</td>
<td>Finegold and Trumper (1989)</td>
</tr>
<tr>
<td>Items #40 - #48</td>
<td>TIMSS &amp; PIRLS International Study Centre (2009)</td>
</tr>
</tbody>
</table>

Note: Items not specifically mentioned above were items specifically asking about the student’s confidence in their response to the previous questions.
Appendix C3: Comments on items in the SCK-EC questionnaire.

Item 6

It should be noted that ‘FALSE’ statements were not added into the total as ‘ticking’ a box meant that the respondent thought that the statement was correct, true or accurate. Only ‘TRUE’ statement were scored when calculating the total score for SCK-EC.

Which of the following statements do you associate with energy. Tick all the statements that you agree with or believe to be true or accurate. You may tick as many boxes as you like.

□ 6.1 energy is always linked to human beings (FALSE)
□ 6.2 ✓ all objects have energy that they can use (TRUE)
□ 6.3 all our energy comes from the sun (TRUE – this statement was not used as it while technically true was confusing to the respondents who mentioned things such as what about nuclear energy etc. in the general comments)
□ 6.4 energy is something possessed by a body and can be released by some event or trigger (FALSE)
□ 6.5 energy is always defined as the ability to do work (TRUE/FALSE? This statement was ignored because, while it is a commonly used statement at schools at the FET level it has been questioned by some researchers for it accuracy as it addresses the misconception that ‘energy can cause something to happen’ - Millar, 2005; Watts, 1983)
□ 6.6 energy is a type of fuel (FALSE)
□ 6.7 work = force x distance moved (TRUE – this statement was not used as formulas such as this were not required of the respondent group for their understanding an detaching of energy)
□ 6.8 energy can be seen as a type of fluid that is transferred in certain processes (FALSE)
□ 6.9 energy is a result of some event (FALSE)
□ 6.10 ✓ energy cannot be created or destroyed (TRUE)
□ 6.11 energy is transformed during certain processes e.g. potential to kinetic when a stone falls (FALSE/TRUE? If one chooses to reject the transform model then this is a problematic statement – to avoid trying to determine the respondent’s reason for choosing true or false this statement was rejected)
□ 6.12 there are many forms of energy e.g. sound, kinetic, heat, light (FALSE – this statement was also rejected because of the focus on the acceptance or rejection of a particular model, viz. transfer or transform)
□ 6.13 energy and force are the same thing (FALSE)
6.17 energy is the result of an event or process (*FALSE this statement only appeared in the post-test and for this reason was not used*)

6.14 energy must always involve movement (*FALSE*)

6.15 ✓ energy is transferred during certain processes e.g. potential to kinetic when a stone falls (*TRUE and while it may be problematic – for similar reasons as 6.11 & 6.12 it was used to calculate SCK-EC. It is a correct statement*)

6.16 energy has always been confusing for me (*This statement speaks to confidence and it was used in this context – if ‘ticked’ then not confident in content knowledge – scored with a ‘1’ and if not ‘ticked’ then confidence assumed and scored with a ‘5’)*)

**Items 7 through to 33**

Items 15 and 16 were not used because the concepts of ‘breathing’ and ‘respiration’ were not addressed during the course.

Items that were considered to be FALSE were: #7, #8, #12, #18, #19, #20, #21, #24, #25, #26, #28, #30, #31 and #33 (total of 13 items).

Items that were considered to be TRUE were: #9, #10, #11, #13, #14, #17, #22, #23, #27, #29 and #32 (total of 11 items).
# Appendix C4: Web-based content knowledge assessment

<table>
<thead>
<tr>
<th>Questions</th>
<th>Possible Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Statements 1</strong>&lt;br&gt;Energy is an abstract concept. This causes problems in teaching and learning about energy because many learners see energy as “something”.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statements 2</strong>&lt;br&gt;The terms “energy”, “force” and “momentum” are all really just mean the same thing.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 3</strong>&lt;br&gt;An object at rest has no energy.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 4</strong>&lt;br&gt;The Law of Conservation of Energy applies only to machines and living things. It does not apply to natural things such as coal and oil. So we can say that the world is ‘running’ out of energy.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statements 5</strong>&lt;br&gt;Heating is a process of energy transfer.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 6</strong>&lt;br&gt;Energy is created as a result of an activity or event.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 7</strong>&lt;br&gt;Electricity is an energy resource.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 8</strong>&lt;br&gt;An electric current transfers energy&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 9</strong>&lt;br&gt;Energy is 'lost' when appliances such as bulbs, heaters etc. are used.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 10</strong>&lt;br&gt;Sound energy is transferred to the surroundings by vibrations.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 11</strong>&lt;br&gt;Light is a process of energy transfer&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 12</strong>&lt;br&gt;Chemical reactions cause energy to be transferred.&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 13</strong>&lt;br&gt;Energy is lost when doing exercise&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Energy Statement 14</strong>&lt;br&gt;The terms ‘fuel’ and ‘energy’ are interchangeable&lt;br&gt;</td>
<td>True ✓</td>
</tr>
<tr>
<td><strong>Denis the Menace</strong>&lt;br&gt;The story of Dennis appeared in your module. This story is used to…&lt;br&gt;</td>
<td>Illustrate (show) that you can use stories to teach about energy&lt;br&gt; Explain the “law of conservation” - in this case energy&lt;br&gt; show that science appears in everything we do, including playing with blocks&lt;br&gt; show that if parents (in this case a mother) are very observant they can help their children</td>
</tr>
</tbody>
</table>
learn about science

Strange diagram:

What is the name given to the following diagram:

Sankey ✓
Dennis’ picture
Energy Accounting Diagram
Joule Diagram
Feynmann Diagram

Angry Man 1:
When the ‘angry’ man's skirt was compressed, but before he jumped, he possessed energy.
True ✓
False

Angry Man 2:
When he was moving up into the air, after the spring uncoiled, he had energy.
True ✓
False

Angry Man 3:
The spring's energy is a hidden force within it.
True ✓
False

Angry Man 4:
At the top of his flight, when he was moving neither up nor down, he had no energy.
True ✓
False

Energy Terms:
Match the following energy terms and ideas.

Fuels: Energy that is stored in a concentrated form ✓
Kinetic Energy: Energy that is linked to movement ✓
Potential energy: Energy that is linked to position ✓
Heat: Energy that is moving from a region of high energy to region of low energy ✓
Temperature: A measure of the average kinetic energy of particles ✓

Energy Movement:
Energy is able to be transferred from one place to another by means of either: conduction, convection or radiation. Match up the energy transfer in certain "things" with the mode of transferance.

Movement of energy through a piece of metal: conduction ✓
Movement of energy through a liquid: convection ✓
Movement of energy from the Sun to the Earth: radiation ✓
When a room gets heated by a panel heater (or any heater for that matter): radiation and convection ✓
Movement of energy through the air: convection ✓
Movement of energy up the spoon while it is in a hot cup of tea: conduction ✓
<table>
<thead>
<tr>
<th>Kreepy Crawlie 1</th>
<th>True</th>
</tr>
</thead>
<tbody>
<tr>
<td>You 'played' with this toy in your Toys Workshop.</td>
<td>The adjacent Sankey Diagram could be used to represent the energy flow in this toy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kreepy Crawlie 2</th>
<th>True</th>
</tr>
</thead>
<tbody>
<tr>
<td>You 'played' with this toy in your Toys Workshop.</td>
<td>The adjacent Sankey Diagram could be used to represent the energy flow in this toy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kreepy Crawlie</th>
<th>True</th>
</tr>
</thead>
<tbody>
<tr>
<td>You 'played' with this toy in your Toys Workshop.</td>
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</tr>
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</table>

False

<table>
<thead>
<tr>
<th>Kreepy Crawlie</th>
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</thead>
<tbody>
<tr>
<td>You 'played' with this toy in your Toys Workshop.</td>
<td>The adjacent Sankey Diagram could be used to represent the energy flow in this toy.</td>
</tr>
</tbody>
</table>

False
Appendix D1: Questionnaire: Pedagogical Content Knowledge - Energy Concept (PCK-EC)

Pedagogical Content Knowledge (PCK) Pre-Test

1  I hereby agree to participate in a study of the science modules in the IP and FP programmes. I understand that I am participating freely and without my being coerced in any way to do so. I also understand that I can stop completing the questionnaire at any time and withdraw as a participant in the research. I have received the details of a person to contact should I need to speak about any issues that may arise from this questionnaire (leslie.meiring@nmmu.ac.za). I understand that while my answers will not be anonymous, they will remain entirely confidential

   O I agree to participate   O Thank you, but I don't want to participate

2  Two models are proposed for the teaching of the energy concept in schools, namely the transformation model and the transfer model. Briefly describe the transformation model by giving an example of the words that a teacher might use if they are using this model while teaching the energy concept.

3  How confident are you that your response to the above question is correct?

   O Very confident   O Confident   O Not confident   O Just guessing

4  Two models have been proposed for the teaching of the energy concept in schools, namely the transformation model and the transfer model. Briefly describe the transfer model by giving an example of the words that a teacher might use if they are using this model while teaching the energy concept.

5  How confident are you that your response to the above question is correct?

   O Very confident   O Confident   O Not confident   O Just guessing

6  Two models are proposed for the teaching of the energy concept at schools. These are the ‘transformation’ model and the ‘transfer’ model. In South African schools it is recommended that when teaching the energy concept teachers should...

   o Use both models interchangeably
   o Use only the transfer model
   o Use only the transformation model
   o Start with the transformation model and then follow with the transfer model
   o Start with the transfer model and then follow with the transformation model

7  How confident are you that your response to the above question is correct?

   O Very confident   O Confident   O Not confident   O Just guessing
Possible reasons for your choice of teaching model/s for the teaching of the energy concept are suggested below. Which of them could be used to motivate your response to the question above? You may tick more than one box.

☐ Both models add a great deal of value in the teaching of the energy concept.
☐ The RNCS document (syllabus) only talks about ‘transferring’
☐ The RNCS document (syllabus) only talks about ‘transformation’
☐ The RNCS document requires that the learners be exposed to both models.
☐ There are many types (or forms) of energy and this makes the transformation model the most appropriate to use
☐ It is scientifically more correct to use the transfer model
☐ Energy is an abstract concept and the use of forms or types of energy is inappropriate

How confident are you that your response to the above question is correct?

☐ Very confident ☐ Confident ☐ Not confident ☐ Just guessing

If you were consistently to see the following words used in a textbook:

heat, light, sound, electrical, kinetic, chemical, potential (elastic and gravitational) nuclear

Which model would the textbook be using?

☐ Transfer
☐ Transform

Explain your response to the question above.

Suggest a possible advantage for teaching the energy concept by using the transform model.

Suggest possible disadvantages for teaching the energy concept by using the transform model.

A picture of a wind-up mouse was shown to learners by three teachers.

The following explanations of the energy concept were given to the learners by three different teachers.

Teacher A: Potential energy stored in the person's muscles is changed to elastic potential energy in the spring. Potential energy in the spring is changed to kinetic (moving) energy and some sound energy when the mouse is moving.
**Teacher B:** Energy from the person is transferred to the spring when it is wound up. Energy is then transferred from the spring to the mouse while it is moving. Some of the energy stored in the spring is transferred to the surroundings by sound.

**Teacher C:** Potential energy from the person's muscles is transferred to the spring when it is wound up. When the mouse is released the energy stored in the spring is changed into kinetic energy (moving energy and some sound energy).

Which teacher is using a transform model to explain the wind-up mouse in terms of the energy concept?

- Teacher A
- Teacher B
- Teacher C

15 Which teacher is using a mixture of both models?

- Teacher A
- Teacher B
- Teacher C

16 You give the learners a picture of a torch.

You as a teacher wish to describe energy concept for this torch. Use the transfer model and write a similar explanation as is used above for the wind-up mouse.

17 It has been suggested that it is better to introduce the energy concept in Grade 6/7 by associating it with fuels and food. What do you know about the teaching and learning of the energy concept that would support the above suggestion?

18 How confident are you that your response to the above question is correct?

- Very confident
- Confident
- Not confident
- Just guessing

19 A number of barriers have been identified that prevent the learning and understanding of energy. These barriers need to be addressed when one is teaching the energy concept. The following six questions each highlight such a barrier. In a few sentences describe what you could do in your teaching to address the barrier that is highlighted.

**Barrier Statement:** Energy causes events to happen

20 Barrier Statement: A car uses petrol energy to make it go

21 Barrier Statement: Energy is used up when doing exercises
22 Barrier Statement: **Energy is fuel**

23 Barrier Statement: **Energy and force are interchangeable**

24 Barrier Statement: **The world is running out of energy**

25 Each of the following eight items is a statement that could have been made by learners with respect to the energy concept. For each statement you must considered whether it illustrates (shows)

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

Statement: **There are many ways of transferring energy, e.g. food, wires, plugs, springs and sunlight.**

26 **If** the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

- [ ] energy is used up or created
- [ ] energy is a kind of stuff
- [ ] fuels are energy
- [ ] energy makes things happen
- [ ] energy and force are similar ideas
- [ ] It is a misconception but none of these
- [ ] It just sounds like a misconception to me.
- [ ] It is not a misconception

27 Statement: **A car uses petrol energy to make it go.**

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

28 **If** the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

- [ ] energy is used up or created
- [ ] energy is a kind of stuff
- [ ] fuels are energy
- [ ] energy makes things happen
- [ ] energy and force are similar ideas
- [ ] It is a misconception but none of these
- [ ] It just sounds like a misconception to me.
- [ ] It is not a misconception
29 Statement: As the clockwork car (i.e. one where a spring is wound up) moves, it uses up the energy in the spring. When all the energy is used up, it stops going.

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

30 If the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

- energy is used up or created
- energy is a kind of stuff
- fuels are energy
- energy makes things happen
- energy and force are similar ideas
- It is a misconception but none of these
- It just sounds like a misconception to me.
- It is not a misconception

31 Statement: Plants make energy from the sun.

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

32 If the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

- energy is used up or created
- energy is a kind of stuff
- fuels are energy
- energy makes things happen
- energy and force are similar ideas
- It is a misconception but none of these
- It just sounds like a misconception to me.
- It is not a misconception.

33 Statement: I burnt up the energy from the chocolate when I ran home.

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

34 If the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.
☐ energy is used up or created
☐ energy is a kind of stuff
☐ fuels are energy
☐ energy makes things happen
☐ energy and force are similar ideas
☐ It is a misconception but none of these
☐ It just sounds like a misconception to me
☐ It is not a misconception.

35 Statement: **Energy from gravity makes the ball fall down.**

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

36 If the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

☐ energy is used up or created
☐ energy is a kind of stuff
☐ fuels are energy
☐ energy makes things happen
☐ energy and force are similar ideas
☐ It is a misconception but none of these
☐ It just sounds like a misconception to me
☐ It is not a misconception.

37 Statement: **Energy makes the rocket go up.**

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

38 If the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

☐ energy is used up or created
☐ energy is a kind of stuff
☐ fuels are energy
☐ energy makes things happen
☐ energy and force are similar ideas
☐ It is a misconception but none of these
☐ It just sounds like a misconception to me
☐ It is not a misconception.
Statement: As you get further from the torch the light gets dimmer because the light energy is running out.

- A lack of precision (accuracy) in the terminology (words) used
- an underlying misconception about the scientific idea
- both (of the above)

If the learner's statement consists of a misconception (or misconceptions) which are they? You may tick as many of the boxes as you like.

- energy is used up or created
- energy is a kind of stuff
- fuels are energy
- energy makes things happen
- energy and force are similar ideas
- It is a misconception but none of these
- It just sounds like a misconception to me
- It is not a misconception

A well-known teaching tool for the teaching of the conservation of energy is the accounting model (or the story of Dennis). Briefly suggest why this is such a good model to use.

Thank you for doing this questionnaire for me. Any other comments that you would like to bring to my attention about the teaching of energy in the primary school. Thanks Les Meiring
Appendix D2: Assignment: Teaching energy in the Intermediate Phase

Student Number:
Name:

Teaching the Energy Concept in the Intermediate Phase

Introduction:

This introduction must be between three and five lines long and tell the reader why energy is difficult to learn and teach (at least one reference).

Background:

This background must be between 10 and 15 lines long and explain the concepts of subject content knowledge and pedagogical content knowledge with respect to an IP teacher of Natural Sciences (i.e. you) (at least two references).

Energy alternate conceptions:

This section, in which you name at least three common energy misconceptions, must be about 15 lines long. You need to suggest how these misconceptions might have arisen and suggest possible ways to ‘fix’ them (two references).

Transfer/Transform debate:

This section must be at least 20 lines long in which you outline each of the two sides of the debate. You need to say which one is suggested by the SA curriculum and reflect on your own standpoint with respect to this debate (two references).

Educative Curriculum Materials that could be used to teach energy at IP level:

Sankey Diagrams:

You need to describe Sankey diagrams and discuss their possible advantages and disadvantages (5 lines and one reference).

Mechanical Toys:

You need to discuss possible advantages and disadvantages of using toys to teach the energy concept. You must also state your position on using this ECM (5 lines).
Conclusion:

Here you must write a five-line paragraph that summarises the teaching of energy in the primary school.

References:

This reference list must be in an acceptable format (we suggest Chicago or APA) and must have at least four references. You need to use at least eight references in the text above, but of course you may need to use the same reference more than once. BUT you need at least four unique references.

Marking Rubric:

<table>
<thead>
<tr>
<th>Section</th>
<th>Max</th>
<th>Mark</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intro</td>
<td>10</td>
<td></td>
<td>This paragraph must make the reader interested in reading further.</td>
</tr>
<tr>
<td>Background</td>
<td>10</td>
<td></td>
<td>After reading this, I want to be able know what PCK is all about.</td>
</tr>
<tr>
<td>Alt Concept</td>
<td>10</td>
<td></td>
<td>There are many energy misconceptions – choose three that you find interesting (you may have had them yourself).</td>
</tr>
<tr>
<td>Debate</td>
<td>10</td>
<td></td>
<td>This is an important one for any science teacher, so make sure that the reader can identify each side of the debate and clearly identify your personal position in the debate.</td>
</tr>
<tr>
<td>ECM (Sankey)</td>
<td>10</td>
<td></td>
<td>Clear explanation – you might want to include a diagram or picture.</td>
</tr>
<tr>
<td>ECM (Toys)</td>
<td>10</td>
<td></td>
<td>Here I want to know what you think about using toys to teach energy. I would like to use some of your comments in my own research.</td>
</tr>
<tr>
<td>Conclusion</td>
<td>10</td>
<td></td>
<td>This must summarise the state of teaching and learning of the energy concept in the primary school.</td>
</tr>
<tr>
<td>Reference</td>
<td>10</td>
<td></td>
<td>This must be in an acceptable format (Use MSWord’s referencing system).</td>
</tr>
<tr>
<td>Overall</td>
<td>20</td>
<td></td>
<td>Here we are looking for correct grammar and spelling (you must use either the SA or UK grammar and spell checker). If you plagiarise (cut and paste from internet or books or other people’s work without acknowledging it) you will get zero for this section.</td>
</tr>
</tbody>
</table>

Total 100
Appendix D3: Post-course written assessment

The lecture group consisted of too many students to be accommodated in one venue, and as such, they could not answer the assessment simultaneously. Consequently, the students were divided into two groups for this assessment and this resulted in two slightly different assessments being constructed. In order to save space in this report, the two assessments have been combined in this appendix (questions that were common to both assessments are in bold font).

1. A Sankey Diagram is used as teaching tool to teach about the conservation of energy.

A small toy gets its energy transferred to it when it is wound up by a learner. Once released on the table it moves making a scratching noise (50% of the energy), and at the same time it slightly heats the table (10% of the energy).

OR

An incandescent (i.e. an old type bulb NOT an ‘energy-saver’) gets energy transferred to from the electricity supply of a house. When the light bulb is switched on some energy is transferred to the surroundings by heat (80% of the energy) and the light bulb makes a buzzing sound (10% of the energy).

1.1 Using the following grid given, draw the Sankey diagram to showing this process.

```
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
|   |   |   |   |   |   |   |   |
+---+---+---+---+---+---+---+---+
```

1.2 What is the significance (importance) of:
   A. the length of the arrows. (2)
   B. the thickness of the arrows. (2)

OR

1.2 Why do we say that this type of bulb is very inefficient? (2)

1.3 How would your diagram be different if you used an energy saver bulb instead? (2)

2. Give the two most important things that make energy difficult to teach and to learn. (4)

3. A learner complains that she is confused, you as the teacher have told her that energy is conserved and that we cannot create or destroy it. On the other hand her parents are telling her to switch off her light off when she is not in the room as she is wasting energy: Briefly explain the main points that you will make to her to assist her to get clarity on these two contradicting ideas. (6)

OR

3 Explain why the world is trying to move away from, or limit the use of, fossil fuels (oil, coal etc.) towards renewable energy resources (e.g. wind, solar etc.). (6)

4. Children (and some adults) have misconceptions concerning energy. You must identify ANY two possible misconceptions concerning energy that an IP learner may have. You must write down the misconception, explain its possible origin and finally suggest a teaching strategy to deal with the misconception. (8)
Appendix E1: Science Teaching Efficacy Belief Instrument - Pre-service Primary Teachers (STEBI-B)

This questionnaire was embedded in the self-efficacy questionnaire that was on LEARN

<table>
<thead>
<tr>
<th>Number</th>
<th>Scale</th>
<th>P/N</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>STOE 18</td>
<td>P</td>
<td>When a learner does better than usual in science it is often because the teacher exerted a little extra effort.</td>
</tr>
<tr>
<td>Q2</td>
<td>PSTEB 19</td>
<td>P</td>
<td>I will continually find better ways to teach science</td>
</tr>
<tr>
<td>Q3*</td>
<td>PSTEB</td>
<td>N 20</td>
<td>Even if I try very hard, I will not teach science as well as I will most subjects.</td>
</tr>
<tr>
<td>Q4</td>
<td>STOE</td>
<td>P</td>
<td>When the science marks of learners improve, it is often due to their teacher having found a more effective teaching approach.</td>
</tr>
<tr>
<td>Q5</td>
<td>PSTEB</td>
<td>P</td>
<td>I know the steps necessary to teach science concepts effectively</td>
</tr>
<tr>
<td>Q6*</td>
<td>PSTEB</td>
<td>N</td>
<td>I will not be very effective in monitoring (managing) science experiments (investigations).</td>
</tr>
<tr>
<td>Q7</td>
<td>STOE</td>
<td>P</td>
<td>If learners are underachieving in science it is most likely due to ineffective science teaching</td>
</tr>
<tr>
<td>Q8*</td>
<td>PSTEB</td>
<td>N</td>
<td>I will generally teach science ineffectively</td>
</tr>
<tr>
<td>Q9</td>
<td>STOE</td>
<td>P</td>
<td>The inadequacy (short-comings) of a learner’s science background can be overcome by good teaching.</td>
</tr>
<tr>
<td>Q10*</td>
<td>STOE</td>
<td>N</td>
<td>The low science achievement of some learners cannot generally be blamed on their teachers.</td>
</tr>
<tr>
<td>Q11</td>
<td>STOE</td>
<td>P</td>
<td>When a low achieving child improves in science, it is usually due to extra attention given by the teacher.</td>
</tr>
<tr>
<td>Q12</td>
<td>PSTEB</td>
<td>P</td>
<td>I understand science concepts well enough to be effective in teaching primary school science.</td>
</tr>
<tr>
<td>Q13*</td>
<td>STOE</td>
<td>N</td>
<td>Increased effort in science teaching produces little change in some learners’ science achievement.</td>
</tr>
<tr>
<td>Q14</td>
<td>STOE</td>
<td>P</td>
<td>The teacher is generally responsible for the</td>
</tr>
</tbody>
</table>

18 Science teaching Outcomes Efficacy factor
19 Personal Science Teacher Efficacy Belief factor
20 All these items have their scores reversed
21 See (Bleicher, 2004, p. 387 where he had a problem with the qualifier ‘some’ students in Q 10 and 13. It seemed to affect how some students interpreted these two statements. The word ‘some’ confounded their responses. This was changed on LEARN for respondents 191 and onwards. These changes increases the reliability of the questionnaire.)
| Q15 | STOE | P | Learners' achievement in science is directly related to their teacher's effectiveness in science teaching. |
| Q16 | STOE | P | If parents comment that their child is showing more interest in science at school it is probably due to the performance of the child's teacher. |
| Q17* | PSTEB | N | I will find it difficult to explain to learners why science experiments do not work. |
| Q18 | PSTEB | P | I will typically be able to answer learner's science questions. |
| Q19* | PSTEB | N | I wonder if I will have the necessary skills to teach science. |
| Q20* | PSTEB | N | Given the choice I will not allow the principal (or HoD) to evaluate my science teaching. |
| Q21* | PSTEB | N | When a learner has difficulty understanding a science concept I will usually be at a loss as to how to help the learner understand it better. |
| Q22 | PSTEB | P | When teaching science I will usually welcome learner questions. |
| Q23* | PSTEB | N | I do not know what to do to turn (motivate) learners in science |

* Items reversed before scoring
Appendix E2: Questionnaire: Self-efficacy (STEB-I)

Self-efficacy questionnaire

This questionnaire is not reproduced here in full.

Items 1 – 3 Permission and demographic details

Items 4 – 26 were the STEBI-B items (see Appendix E1)

27 If you have the choice, will you choose to be the one to teach science to your IP class?
   - Definitely NO
   - Probably NO
   - Not sure
   - Probably YES
   - Definitely YES

28 The major part of my time in science teaching should be spent on:
   - Textbook-based instruction only
   - More textbook-based instruction than anything else
   - An equal amount of textbook-based instruction and activity-based instruction
   - More activity-based than textbook-based instruction
   - Activity-based instruction only

29 How would you rate yourself right now with respect to your effectiveness to teach IP science?
   - Superior - I could be one of the most outstanding teachers of elementary science
   - Above average
   - Average - A typical primary school teacher of science
   - Below average
   - Low - I would probably be one of the least effective teachers of elementary science in the school

30 Please rate your experience of science in your primary school.
   - Did not do any science
   - It was great - my favourite subject (learning area)
   - It was okay - I tolerated it
   - I did it but seldom enjoyed doing science
   - I hated it

31 Please rate your junior high school experience of science
   - Did not do any science
32 Please rate your senior high school experience of science

- Did not do any science
- It was great - my favourite subject (learning area)
- It was okay - I tolerated it
- I did it but seldom enjoyed doing science
- I hated it

33 Please rate your experience of the science modules that you have done at university so far.

- Have not done any yet
- They have been great - I have more knowledge and confidence
- They have been great - I have more confidence but I need more content knowledge
- They have been okay - bit boring at times but I have still learnt a great deal
- They have not been motivating - I have learnt something and I am more confident but...
- I have hated them and given a choice would not have done them

34 Briefly comment on your overall science experience (at school and university) I am interested in how confident you feel to teach science and how confident you are about your science knowledge.
## Appendix F: Identification of item-groupings in the questionnaires used for quantitative analysis

<table>
<thead>
<tr>
<th>Factors</th>
<th>Questionnaires</th>
<th>STOE 10 – Items</th>
<th>PSTEB 13 – Items</th>
<th>SCK 33 - Items</th>
<th>PCK 31 - Items</th>
<th>Conf-C 31 - Items</th>
<th>Conf-P 3 - Items</th>
<th>Conf-T 2 - Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEBI</td>
<td>(Appendix E2)</td>
<td>#4 - #13</td>
<td>#14 - #26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>#27; #29</td>
</tr>
<tr>
<td>SCK-EC</td>
<td>(Appendix C1)</td>
<td>#6.2; #6.10;</td>
<td>#6.15</td>
<td>#7 - #14</td>
<td></td>
<td></td>
<td></td>
<td>#6.16;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>#17 - #33</td>
<td></td>
<td>#35; #40; #42;</td>
<td></td>
<td></td>
<td></td>
<td>#7 - #14;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>#36; #41; #43;</td>
<td></td>
<td></td>
<td>#36; #41; #43;</td>
<td></td>
<td></td>
<td>#17 - #33</td>
</tr>
<tr>
<td>PCK-EC</td>
<td>(Appendix D1)</td>
<td>#2; #4; #6; #8.2;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>#3; #5; #7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>#8.6; #8.7; #9;</td>
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<tr>
<td></td>
<td></td>
<td>#12 - #15; #17;</td>
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<td></td>
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<td>#19 - #22;</td>
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<tr>
<td></td>
<td></td>
<td>#23.1; #24.4;</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>#24.7; #25.4;</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>#25.5; #25.7;</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>#26.4; #27.2;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>#27.4; #27.5;</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>#28.8; #29.9;</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>#30.4; #30.5;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>#31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix G1: Worksheets completed at the two ‘Toys Workshops’.

**Educative Curriculum Materials: Toys Workshop (2010)**

Many children’s toys involve the energy concept. The aims of these two workshops are to:

- enable you to use the toys as educative curriculum materials to assist you in your understanding of the concept of energy, and to
- help you to develop ways in which you might use these, (or similar) toys, to teach the concept of energy to Intermediate Phase learners.
- generate data concerning IP students’ opinions on the usefulness of using toys to improve their subject content knowledge and pedagogical content knowledge with respect to the energy concept.

The toys are grouped according to certain criteria. You are required to ‘play’ with at least one toy from each group and complete the questions asked of each group of toys. The assessment of this part of the worksheet is based on two criteria:

- the completeness of your responses, and
- the ‘scientific’ correctness of your responses (see shaded boxes in the response tables)

As we will be using parts of this worksheet in research (with your permission) we will assess them and give you feedback, but we will keep the actual sheets until the end of the module.

This worksheet is divided into three parts:

**PART 1: Working with six toys (to be completed during the first workshop)**

**PART 2: Working with five toys (to be completed during the second workshop)**

**PART 3: Reflections that are to generate data for research (to be completed during second workshop of online on LEARN)**

I hereby give permission for my responses in this worksheet to be used for research on condition that my responses are confidential and anonymous in the research.

**Worksheet Part I**

(There are eight groups of toys and you must complete at least any SIX (of the eight)

**Group 1 (Roller Coasters)**

A number of different forms of roller coasters are given for you to select one from, viz. Short Run, Long Run, Train and Speed Track.
The toy from this group that I chose to work with is...

The energy transferences that I identified were... (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy. (See below this table for the key) | SA* | A | UN | D | SD

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

If you choose SHORT RUN - then answer the following questions:
- What is the minimum distance that the car has to be dragged backwards so that it can complete the loop?
- List a few factors that could affect your answer above (i.e. the distance dragged)

If you choose TRAIN - then answer the following questions:
- Name the energy sources.

* SA = Strongly Agree, A = Agree, UN = Uncertain, D = Disagree, SD = Strongly Disagree

Group 2 (Kreepy Crawlies and Friends)
The toy from this group that I chose to work with is...

The energy transferences that I identified were… (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy. (See key below group 1 table)

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

Group 3 (Jumping Jack Flash)

The toy from this group that I chose to work with is...

The energy transferences that I identified were… (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy. (See key below group 1 table)

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)
<table>
<thead>
<tr>
<th>I have learnt a great deal of science using this toy.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briefly explain what science is involved in this toy.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I think that this is a useful toy with which to teach energy to IP learners.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briefly explain your rating to the statement above.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class*? (This question will be assessed if relevant to the chosen toy).

**Group 4 (Checker Flag)**

<table>
<thead>
<tr>
<th>The toy from this group that I chose to work with is…</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The energy transferences that I identified were… (fill the transferences in the boxes below)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If possible, draw a Sankey Energy Diagram for this toy.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I liked ‘playing’ with this toy.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I have learnt a great deal of science using this toy.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briefly explain what science is involved in this toy.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I think that this is a useful toy with which to teach energy to IP learners.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briefly explain your rating to the statement above.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

In each of the cases above where is the potential energy “stored”?

Group 5 (Solar Panel)

You will play with this toy outside. If you decide to use this toy in your IP classroom, what plans will you have in place if it is a cloudy, rainy day? Solution:

Check whether your solution works. Your comment:

The energy transferences that I identified were… (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy. SA* A UN D SD

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy. SA* A UN D SD

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners. SA* A UN D SD

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

Why (how) could this toy be used in a lesson on Learning Outcome 3, viz. Science, Society and the Environment.
Group 6 (Toy Gun)

The toy from this group that I chose to work with is...

The energy transferences that I identified were... (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked 'playing' with this toy.

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

In light of the fact that we are trying to create a gun-free South Africa, would you use this toy in an IP classroom? Motivate your response.
In this exercise you need to play around with the burglar alarm. How does it all work? The Sankey diagram here will be useful. The second half of this exercise is deceptive as it is a toy that some teachers have suggested could be used when you want to get across the idea of “transformation”. (Hint: Bring your little brother with you when you need to transform the car into a robot – it requires nimble fingers and incredible skill – remember to transform it back into the car again before you leave).

The energy transferences that I identified in the burglar alarm were…

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If possible, draw a Sankey Energy Diagram for the burglar alarm.

I liked ‘playing’ with the burglar alarm.  

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Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

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</table>

Briefly explain what science is involved in this toy.

I liked ‘playing’ with the transformer toy

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Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I think that the transformer toy will be able to assist with the understanding of energy transformation.

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Briefly explain your rating for the above statement.
**Group 8 (Bouncing Ball)**

**Briefly describe how you could use these balls to teach two aspects of IP Science**

1. **Energy:**

2. **Investigations**

   **The energy transferences that I identified were...** (fill the transferences in the boxes below)

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</table>

**I liked ‘playing’ with this toy.**  
**Briefly explain your rating to the statement above.**  (What was it about the toy that you liked or disliked?)

**SA*  A  UN  D  SD**

**I have learnt a great deal of science using this toy.**  
**Briefly explain what science is involved in this toy.**

**SA*  A  UN  D  SD**

**I think that this is a useful toy with which to teach energy to IP learners.**  
**Briefly explain your rating to the statement above.**

**SA*  A  UN  D  SD**
Worksheet Part II

(There are SEVEN groups of toys and you must complete any FIVE of the seven)

Group 1 (2010 What A Noisy Extravaganza)

The vuvuzela has become a common sight at soccer games – but how does it work. Together with the vuvuzela you need to play with the gently sounding swinging tube (see group 2). Play around and get different sounds from different toys and then try to answer the questions below. Sound originates with a vibrating ‘something’. Often it is a vibrating column of air, vibrating string, skin (as in a drum) or a vibrating reed etc.

In each of the following toys you need to be able to identify what it is that is vibrating. You will also need to discuss how (and if) you are able to change the pitch and the loudness of the sound produced.

<table>
<thead>
<tr>
<th>I liked ‘playing’ with these ‘sound’ toys.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
<th>D</th>
<th>SD</th>
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<tbody>
<tr>
<td><strong>Briefly explain your rating to the statement above.</strong>  (What was it about the toy that you liked or disliked?)</td>
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<table>
<thead>
<tr>
<th>I have learnt a great deal of science using this toy.</th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
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<tr>
<td><strong>Briefly explain what science is involved in this toy.</strong></td>
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<table>
<thead>
<tr>
<th>I think that this is a useful toy with which to teach energy to IP learners.</th>
<th>SA*</th>
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<th>UN</th>
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<th>SD</th>
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<tr>
<td><strong>Briefly explain your rating to the statement above.</strong></td>
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</table>

| What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class?  (This question will be assessed if relevant to the chosen toy). |

| What is vibrating in each of the toys? Choose one toy and write its name here: ................................. |
Discuss the pitch
Discuss the frequency
Trumpets (horns) – what is similar between the two of them and what is different?

Group 2 (2010: The Party Continues)

I have learnt a great deal of science using this toy.  
Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.  
Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

What is vibrating in each of the toys? Choose one toy and write its name here: .....................
Group 3 (Crazy Chemistry)

The toy from this group that I chose to work with is…

The energy transferences that I identified were... (fill the transferences in the boxes below)

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If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy.

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

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I have learnt a great deal of science using this toy.

Briefly explain what science is involved in this toy.

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I think that this is a useful toy with which to teach energy to IP learners.

Briefly explain your rating to the statement above.

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What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy.)

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</table>
**Group 4 (Generators)**

The toy from this group that I chose to work with is…

The energy transferences that I identified were… (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy. (See below this table for the key)

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).

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<th>Transference</th>
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</table>
The toy from this group that I chose to work with is…

The energy transferences that I identified were… (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy. (See below this table for the key)

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<th></th>
<th>SA*</th>
<th>A</th>
<th>UN</th>
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</table>

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

<table>
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<th></th>
<th>SA*</th>
<th>A</th>
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<th>SD</th>
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</table>

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

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<th></th>
<th>SA*</th>
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</table>

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy).
Group 6 (Farnborough Airshow)

The toy from this group that I chose to work with is...

The energy transferences that I identified were...
(fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

If I liked ‘playing’ with this toy. (See below this table for the key)

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<th>SA*</th>
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</table>

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

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<th></th>
<th>SA*</th>
<th>A</th>
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</table>

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

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<th></th>
<th>SA*</th>
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</table>

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy.)
**Group 7 (Tops)**

The toy from this group that I chose to work with is...

The energy transferences that I identified were... (fill the transferences in the boxes below)

If possible, draw a Sankey Energy Diagram for this toy.

I liked ‘playing’ with this toy.

Briefly explain your rating to the statement above. (What was it about the toy that you liked or disliked?)

I have learnt a great deal of science using this toy.

Briefly explain what science is involved in this toy.

I think that this is a useful toy with which to teach energy to IP learners.

Briefly explain your rating to the statement above.

What “teaching” tips would you give to someone who is intending to use this toy as an “educative curriculum material” in an IP NS class? (This question will be assessed if relevant to the chosen toy.)
**Worksheet Part III**

**Data for our Research**

(You may prefer to complete this part of the worksheet on LEARN)

(Your responses to these questions have no effect on your assessment for the above piece of work)

In all the questions below use a 1 to 5 scale. 1 means the lowest rating and 5 the highest rating. E.g. 1 could mean ‘no confidence’ and 5 ‘very confident’; or 1 means you haven’t got a clue while 5 would mean that you know a great deal about the topic etc.

<table>
<thead>
<tr>
<th>Rating</th>
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<table>
<thead>
<tr>
<th>Question</th>
<th>Rating</th>
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</thead>
<tbody>
<tr>
<td>1. How confident were you about your understanding of energy before the start of these two workshops using toys?</td>
<td></td>
</tr>
<tr>
<td>2. How confident are you now at the end of these two workshops using toys?</td>
<td></td>
</tr>
<tr>
<td>3. If your pre- and post-ratings above differ, comment on what influenced this change the most.</td>
<td></td>
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<tr>
<td>4. How much did you know about energy before the start of Unit 1?</td>
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</tr>
<tr>
<td>5. How much did you know about energy at the end of Unit 3?</td>
<td></td>
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<tr>
<td>6. If your pre- and post-ratings above differ, comment on what influenced this change the most.</td>
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<tr>
<td>7. Did ‘playing’ with toys have any impact on your understanding of energy.</td>
<td>Yes</td>
</tr>
<tr>
<td>8. Comment on your response to the question just above.</td>
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</tr>
<tr>
<td>9. Would you consider using toys to teach energy in an IP class?</td>
<td>YES</td>
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<tr>
<td>10. Comment on your response to the question just above.</td>
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</tbody>
</table>
11. Which toy did you enjoy playing with the most? Write down its “heading” name

12. Why do you think that you enjoyed this toy the most?

13. Which toy taught you the most about energy. What did the toy teach you?

14. Did playing with the toys motivate you to try to understand the energy consideration of the toy. [ ] YES [ ] NO

15. If you decided to use toys as teaching resource for energy in the IP. List briefly things that you believe are important considerations.

16. Any other comments?
Appendix G2: The most enjoyable toy and the toy that taught the most about energy

<table>
<thead>
<tr>
<th>Toy’s Name</th>
<th>Q11: The most Enjoyable Toy</th>
<th>Toy’s Name</th>
<th>Q13: The toy that taught the most about energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Angry Man/Smiley Face</td>
<td>29% (n=21)</td>
<td>The Angry Man/Smiley Face</td>
<td>12% (n=9)</td>
</tr>
<tr>
<td>The Roller Coaster</td>
<td>12% (n=9)</td>
<td>The Roller Coaster</td>
<td>10% (n=7)</td>
</tr>
<tr>
<td>Hand Warmer</td>
<td>10% (n=7)</td>
<td>Short Run</td>
<td>8% (n=6)</td>
</tr>
<tr>
<td>Kreepy Crawlie</td>
<td>8% (n=6)</td>
<td>Solar Panel</td>
<td>8% (n=6)</td>
</tr>
<tr>
<td>Helicopter</td>
<td>8% (n=6)</td>
<td>Shakey Torches</td>
<td>7% (n=5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wind Generator</td>
<td>7% (n=5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bouncing Balls</td>
<td>7% (n=5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Guns</td>
<td>7% (n=5)</td>
</tr>
</tbody>
</table>
Appendix H1: Ethics Clearance

FACULTY OF EDUCATION
Tel. +27 (0)41 504 2125
Fax. +27 (0)41 504 9383

6 May 2010

Mr L Meiring
Education Faculty
NMMU

Dear Mr Meiring

THE IMPACT OF TOYS, AS AN EDUCATIVE CURRICULUM MATERIAL, ON PRE-SERVICE PRIMARY SCHOOL NATURAL SCIENCES TEACHERS’ UNDERSTANDINGS OF ENERGY

Your above-entitled application for ethics approval served at the May meeting of the Faculty Research, Technology and Innovation Committee of Education (ERTIC).
We take pleasure in informing you that the application was approved by the Committee.
The ethics clearance reference number is H10-Edu-ITE-010.
We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

Ms J Elliott-Gentry
Secretary: ERTIC
Appendix H2: E-mail to students

Dear PICN301 Student,

I would like you to please to assist me with two questionnaires placed on the LEARN site in the module IP Science Evaluation.

These are quite long and you may not have too much knowledge about some of the questions at this stage but they form the basis for a large chunk of PICN301 (the science module that you will be doing next semester). I will ask you to do two similar questionnaires after you have completed the energy section in PICN301 next semester.

Please assist me with this as I need your opinions for my Doctoral Research.

The first questionnaire is in Unit 3 of the module IP Evaluation and it is about subject knowledge (energy). I also ask you in some of the questions to tell me how confident you are of your answer.

The second questionnaire is in Unit 4 and it is called pedagogical content knowledge.

Unfortunately they are quite long and may take a little time to complete - but please try and please encourage your friends to also do these two questionnaires.

Thanks (if you have any questions about this please email me)

Les Meiring

Faculty of Education
Ext 4044