FEATURES AND CONSEQUENCES OF TWO SCHOOL SCIENCE CURRICULA

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ABSTRACT
With the political change in 1994, South Africa entered a period of dramatic educational change. The former positivist school curriculum was replaced with an outcomes-based curriculum. In outcomes-based education (OBE) the process of learning is considered as important as the content, and both are aligned with the outcomes to be achieved at the end of the process. The new approach attends to deficiencies of the positivist approach, such as social and environmental aspects and responsibilities. This article reports on an analysis of the differences between the old and new natural sciences curricula in terms of instructional paradigms. The implementation of these curricula in natural sciences textbooks from both systems are investigated and compared. The results are complemented by an empirical study of the conceptual understanding of energy of 1211 Grade 9 and 10 learners and their science educators from 33 schools in the North-West province of South Africa. The results show a fundamental difference between the approaches, outcomes, teaching and assessment strategies of the two curricula before and after the educational reform. These differences give rise to inherently different results in terms of science knowledge learning. Contrary to the stated outcome of scientific literacy in the OBE curriculum, the learners' conceptual understanding of fundamental concepts of science is inadequate.

KEYWORDS
Curriculum, instructional paradigms, outcomes, textbooks, energy, science content knowledge

INTRODUCTION

Since 1994 much attention was paid to the compilation and implementation of National Curriculum Statements (NCS) for South African school curricula. Notwithstanding investment policies to enhance science education for all in South Africa through educating more science teachers, providing more access to students to study science at schools and supplying more science equipment to schools (Naidoo & Lewin, 1998), the desired results were not obtained (Pandor, 2006). Participation of African students in physical science subjects at school remained minimal with low pass rates and a low number of candidates reaching university entrance. The number of learners who passed higher grade physical science even declined from 2005 to 2006.

In two successive Trends in International Mathematics and Science Study (TIMMS) tests, South Africa performed lowest of the participating countries, some of them developing countries (Dempster & Reddy, 2007). Contributing factors included a weak base of science knowledge, skills and reasoning abilities as well as a lack of proficiency in English. Many science teachers also lack proper science knowledge and pedagogical content knowledge (Scholtz *et al.,* 2004).

The aim of this study was firstly to analyse the current reformed science curriculum in terms of the specified outcomes and prescribed knowledge and concepts in order to determine the paradigm on which it is based. Secondly, the curriculum analysis is complemented by an analysis of textbooks that implement the curriculum. The teaching and assessment approaches, content knowledge and skills presented as well as attention to context, integration, illustrations, etc. as applied in these textbooks are compared with that of a typical textbook used before educational reform. Thirdly, an empirical study was conducted with 1211 Grade 9 and 10 South African students in order to determine the influence of the OBE curriculum on their content knowledge base is. The same questionnaire was also completed by their science educators. This study reveals the features and consequences of the reformed curriculum as compared to the traditional positivist curriculum formerly implemented in South Africa.

INSTRUCTIONAL PARADIGMS

Educational goals for the 21st century differ much from the previous century. During the twentieth century three core instructional paradigms were practised (Farnham-Diggory, 1994; Heller, 1999; Potgieter, 2008), namely behaviourism, developmentalism (e.g. the contructivist theory) and the communal theory. The communal theory is a name chosen for a paradigm in which the needs and purposes of education are driven by the needs and aspirations of the community. It is also called cognitive apprenticeship (Heller, 1999), the critical theory (Potgieter, 2008) or the activity theory (Van Aalsvoort, 2004). The three different twentieth century paradigms and their influences on teaching and learning will be discussed briefly to provide a theoretical framework for the analysis of the former and new South African science curricula and textbooks.

Behaviorism

During the first half of the 20th century physics learning, teaching and assessment strategies in the classroom and laboratory were based on the behaviourist psychology that grew out of the classical empirist philosophy of science (Klassen, 2006). According to empirism knowledge is gained through the senses and the mind merely consists of representations of sensory stimuli. Consequently, knowledge can be transferred intact from teacher to student through the senses, i.e. the transmission model of learning.

Two central assumptions of the behaviourist view of learning are decomposability and decontextualization (Farnham-Diggory, 1994; Heller, 1999; Klassen 2006). Knowledge is structured in the brain in the order that it is received and should therefore be broken into small, simple steps that are easy to consume by the learners. Learning is thus a linear, sequential process in which the primary difference between experts and novices is the amount of knowledge they possess. Experts are just further up the ladder of knowledge than novices. Education is therefore quantifiable and learning objectives can be specified and measured. Any contextual factors are perceived as irrelevant or even interfering with the learning of knowledge.

In the behaviourist paradigm all investigations, whether by students or scientists, should commence with objective observation of "facts" (Driver & Easley, 1978). Generalisations made from such facts can then induce hypotheses or theories. Consequently, experiments in the laboratory manual are given in a recipe format, telling the student exactly what to do and what is expected (Trumper, 2003). From this view, alternative interpretations of events imply either incorrect observations or faulty logic and are therefore considered to be wrong.

The logical positivism emphasizes the formal, logical building up of physics. The emphasis is on mathematical logic and the order of increased mathematical complexity. Applications of operationally defined quantities are formal and without context. A typical application is: “A force of 20 N gives an object an acceleration of 5 m/s^2. What force would be needed to give the same object an acceleration of 1 m/s^2?” (Beiser, 1978). Even if some of the problems replaced “an object” with “a brick” or another real-life object, it remained formal.

Today both empirism and behaviourism have been discredited (Klassen, 2006) and the associated learning process is depicted as *traditional*. The two more recent learning theories, the developmental and communal theories, both recognize that individuals acquire knowledge in different ways under their existing framework of understanding.

Developmental instructional paradigm

Developments in the neurosciences informed the cognitive model of learning, according to which learners construct their own cognitive knowledge structures. Learners build these cognitive structures from early childhood's interactions with their environment. (Klassen, 2006). This is the premise of developmental theories such as the constructivist learning theory. Unfortunately, physics education researchers found that students' ideas and explanations of events and phenomena often do not agree with that of physics. Consequently, conceptual change of these so-called alternative conceptions became a dominant part of physics education research.

In developmental theories novices and experts are distinguished on the basis of their personal theories and explanations, sometimes called qualitative models of events or experiences (Farnham-Diggory, 1994). Pedagogy based on this theory takes students through a carefully constructed sequence of situations, e.g. the so-called learning cycle (Heller, 1999). Interactive demonstrations, peer learning and tutorials are examples of changes in introductory pedagogy that are based on the developmental learning theory (Heller, 1999).

Although some of the contemporary purposes for laboratory work may be similar to traditional purposes, aspects such as the learning of scientific concepts, understanding of the nature of science and the development of positive attitudes are added (Trumper, 2003). Constructivist laboratory strategies (e.g. inquiry) differ completely from those of traditional laboratories. Traditional recipe laboratories have been replaced with open materials that point to areas in which problems can be found, to problems themselves, to viable but alternative procedures, etc.

The social constructivist theory recognizes the influence of students' environment (e.g. classroom atmosphere and peers) on their learning (Vygotsky, 1986). Vygotsky studied the role of the social environment as agents in developing students' thinking. His idea of the zone of proximal development particularly influenced developmental psychology (Bransford *et al.*, 2000). In cooperative learning capable peers and teachers all play a role in extending students' efforts to understand.

Communal theory

During the last decades instructional theories emerged that *focused on social context and relevance of science learning.* Three examples are the critical theory (Potgieter, 2008), the activity theory (Van Aalsvoort, 2004) and cognitive apprenticeship (Farnham-Diggory, 1994).

The critical theory is concerned with the critical meaning of experiences as they relate to gender, race, class and other social aspects (Potgieter, 2008). Conflict (such as class conflict in Marxism) and inequality are crucial in understanding the dynamics of human relations. Reality is perceived to be shaped by historical, social, political, economic, etc. values. Events are understood within social and economic contexts with emphasis on ideological critique and praxis.

The activity theory proposed by Van Aalsvoort (2004) is in reaction to the positivist theory that ignores the relevance of science to society. In the activity theory, society is conceived of as a whole of social practices that are somehow related. Social practices manifest differently in various cultures. Results of activities should provide for a personal need. Examples of personal needs are the need for food, protection, a career, etc. The execution of an action is usually a combination of several operations that depend on objective conditions. Knowledge is considered to be grounded in a social practice. An activity stresses the functional nature of concepts rather than their descriptive nature as in logical positivism. Concepts are multiperspective and their meanings are determined by the social practice in which it functions. Concepts are therefore situational instead of universal and evolve with the development of social practice. Van Aalsvoort (2004) interpreted these ideas in terms of chemical or chemical-related social practices. Such practices are meant to provide for human needs by making products from raw materials, e.g. the production of food, medicines, clothing, etc. These practices are characterized by a number of motives because different parties are involved, like consumers and producers. Chemical or chemical-related practices include the chemical researcher, analyst and engineer, each with a different motive-goal. Operations concern the techniques and routines that are characteristic for the profession. Reflection has the function of bringing about improvements in a practice. Amongst others, reflections may use chemical concepts as tools.

In this approach the learner is considered an apprentice (Van Aalsvoort, 2004). Consequently, the school learner should get assigned tasks that are characteristic for a profession in a social practice. Language is considered an important tool of a profession. When carrying out these tasks, the learner gets acquainted with the material as well as the skills. A novice becomes an expert through the mechanism of acculturation (Farnham-Diggory, 1994). An expert (e.g. the teacher) should guide learners through a task by actions of modelling (showing how it looks), coaching (doing it with guidance) and fading (slowly withdrawing structure) (Heller, 1999).

CURRICULUM ANALYSIS

The National Curriculum Statement (NCS, Department of Education, 2003) specifies the principles, outcomes and core knowledge for school learning in general, and science learning in particular. This information indicates the instructional paradigm on which learning should be based. The *principles of learning* given in the NCS are:
- Social justice, a healthy environment, human rights and inclusivity.
- A high level of skills and knowledge for all.
- Clarity and accessibility of learning outcomes and assessment standards.
- Progression and integration in learning areas from grade to grade.

The *critical outcomes* of the OBE curriculum envisage learners who will be able to (Department of education, 2003):
- identify and solve problems and make decisions using critical and creative thinking
- work effectively with others as members of a team, group, organisation and community
- organise and manage themselves and their activities responsibly and effectively
- collect, analyse, organise and critically evaluate information
- communicate effectively using visual, symbolic and/or language skills

According to the *developmental outcomes* learners should also be able to:
- reflect on and explore a variety of strategies to learn more effectively.
- participate as responsible citizens in the lives of local, national and global communities
- be culturally and aesthetically sensitive across a range of social contexts
- explore education and career opportunities
- develop entrepreneurial opportunities.

The critical and developmental outcomes describe the kind of citizen the education and training system should aim to create. The curriculum seeks to create a lifelong-learner who is confident and independent, literate, numerate, multi-skilled, compassionate, with a respect for the environment and the ability to participate in society as a critical and active citizen (Department of Education, 2003).

Learning outcomes and assessment standards are designed from the critical and developmental outcomes. The three *learning outcomes* for the natural sciences grades R to 9 relate to (Department of Education, 2003):
1. Scientific investigations: The learner will be able to act confidently on curiosity about natural phenomena, and to investigate relationships and solve problems in scientific, technological and environmental contexts.
2. Scientific knowledge: The learner will know and be able to interpret and apply scientific, technological and environmental knowledge.
3. Science, society and the environment: The learner will be able to demonstrate an understanding of the interrelationships between science and technology, society and the environment.

These learning outcomes have to be achieved to accomplish the purpose of natural sciences learning, i.e. scientific literate citizens. The learning area Natural Sciences consists of four themes, namely

- Energy and change (physics)
- Matter and materials (chemistry)
- Life and living (biology)
- The earth and beyond (geography)

Core knowledge and concepts are given for three school phases, namely from grades R to 3 (Foundation phase), grades 4 to 6 (Intermediate phase) and Grades 7 to 9 (Senior phase). The empirical study reported here focussed on the Senior phase, as the one that forms the foundation for the highest school phase (Grades 10 to 12). The core knowledge and concepts in the physics part (energy and change) of the senior phase entails the following topics (Department of Education, 2003):

- Potential energy as stored energy
- Release of potential energy as kinetic energy in the motion of systems, its parts or particles
- Unlimited number of systems in which energy can be stored, or transferred, including electrical, mechanical, chemical, gravitational, optical, etc.
- Energy is degraded when used
- Heat and ways of heat transfer
- Energy transfer in ecosystems
- Light energy
- Objects exert forces through which a system is formed that can store or transfer energy.

From the stated principles and outcomes, it follows that the emphasis of the NCS is not on the attainment of a logical sequence of knowledge, but rather on the acquiring and applying of skills and knowledge in context. Social aspects such as social justice and environmental responsibility are principles guiding the learning process. Skills, e.g. problem-solving, creative thinking, responsible decision-making and communication are prominent in the critical outcomes. The kind of learner that is envisaged is one that will acquire the values and will act in the interest of the South African society. According to Ramsuran (2005), the NCS fit in a framework that is essentially humanistic, constructivistic and socially critical. The principles, outcomes and views stated in the NCS therefore supports the communal theory.

In order to verify this deduction from the information given in the NCS, natural sciences textbooks were analysed to determine how they implemented the philosophy of the NCS.

ANALYSIS OF TEXTBOOKS

Textbooks are interpretations of curricula used by teachers to guide them in what to teach, how to teach it, and in what order it can be taught (Leite, 1999; Stoffels 2005; Lemmer et al., 2008). Learners use the textbooks to do the experiments or activities in the class, do homework assignments and to study for tests and examinations. Textbooks are often the most-used aid for classrooms.

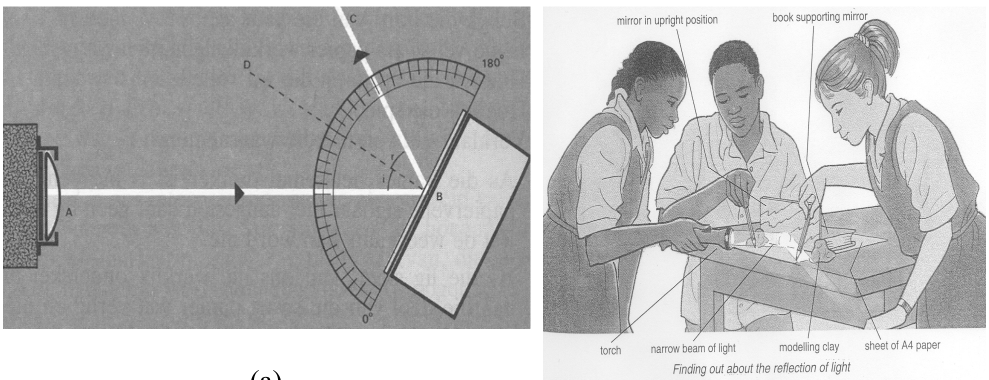
Three recent grade 9 natural sciences textbooks were analysed (Ayerst *et al.,* 2006; Cherub & Govender, 2006; Trust *et al.,* 2006). The analysis examined the presentation of the prescribed content knowledge, a summary of the types of instructional and assessment activities as well as the role played by context and textbook illustrations. These aspects are compared with the positivist approach of a traditional textbook (Brink & Jones, 1984), i.e. a typical textbook used before the introduction of OBE.

In the traditional Grade 9 textbook (Brink & Jones, 1984) chapters are divided into traditional topics, i.e. electrostatics (Chapter 1), current electricity (Chapter 2), force, work and energy (Chapter 3), etc. In each chapter, the content is presented in a logical, sequential way. Alternative conceptions are not attended to. At the end of each chapter a summary of the content and a large number of "Test your knowledge" questions are given. Formal and conceptual knowledge are tested.

Experiments in Brink and Jones (1984) are recipe-like with questions added to guide learners' thinking about what they are doing. Learners' attention is directed to specific observations. Each experiment is preceded by physics theory and followed by an explanation of the obtained observations and results. Typical textbooks used before educational reform in South Africa can be considered as behavioristic. The NCS-based textbooks, however, deviated much from this paradigm. Traditional experiments aimed to teach basic science principles and concepts, were replaced with activities that integrate science, technology and society. Instead of the traditional standard syllabus, the topics presented in the three NCS books differed because the NCS prescribes core knowledge and concepts per phase (e.g. grades 7 to 9) and not per grade. Only one of the three books referred to alternative conceptions and only for some of the topics.

In many of the activities learners have to predict the outcomes of an investigation, make observations and afterwards discuss their findings and own ideas with their peers. Most of the "instructions" consist of questions urging the students to think or talk about it. No answers to the activity questions are given in the Learners' Books, and only one book explains some results after the activities. The answers to these questions are given in the Teacher Guides. Stoffels (2005) found that many teachers, especially from African schools, follow rote learning strategies. They give the learners the answers to the questions without explaining it. Learners write down the correct answers and often repeat it verbally a number of times.

An important difference with traditional books is that laboratory safety measures (e.g. safety glasses and shielding) are attended to in NCS books, even in some sketches. Sketches in the traditional books are diagrammatic and used to illustrate the experimental set-up, the theory or application. Only essential information, e.g. the apparatus used or a circuit diagram, is given (Fig 1(a)). At most, a hand or eye is shown. However, sketches in NCS textbooks often illustrate students doing the activity while the apparatus are often not central (Fig 1 (b)). In Trust *et al* (2006) the conversation of the students (complete with their face expressions) is added to some sketches. Gender and race equality as well as disabilities are emphasized in all NCS books (e.g. Fig 1 (b)). Although these may be important issues to address, it is ideological and can cause cognitive noise in the learning of physics concepts and principles. The activities and sketches take up most of the space, while the theory (usually given before the activity) generally takes up only a few lines per page.



(a) (b)

Figure 1: Sketches from (a) Brink & Jones (1984) and (b) Ayerst *et al.* (2006)

The percentage occurrence of type of activities (whether perceptive, conceptive or formal) were compared for the traditional and NCS books. The presentation of light was chosen, because it is a topic in three of the four books that were analysed. Other topics, such as electricity, are not presented in all of the books in Grade 9. Table 1 compares the type of activities. The table shows the average occurrence of each type of activity in the two NCS books, because the percentages differed only by a few percent. Perceptive activities are considered as activities in which the learners have to observe an everyday-life event of phenomena. Examples are the observation of the order of rainbow colours caused by the spray of a garden hose or how the pupils of the eyes change from dim to bright light. Conceptual activities aim to accomplish learners' conceptual understanding of a phenomenon, while formal activities involve measurement and data analysis.

Table 1: Comparison of the activities in the traditional and NCS books

Type of activity	**Traditional book**	**Average of two NCS books**
Perceptive activities (%)	10	31
Conceptive activities (%)	60	57
Formal activities (%)	30	12

The majority of all the activities in the books are conceptual. The percentage of the perceptive and formal activities differ significantly. While the traditional book has only 10 % perceptive activities and 30 % formal activities, these percentages are approximately reversed in the NCS books. It should also be pointed out that the depth and width of conceptualization or formalization differed. For example, in a formal experiment about image formation by a concave lens in the NCS books, the learners compared the distances of the object in front of and the image behind the mirror. Apart from these distances, the traditional book also prescribed the measurements of the object and image heights as well as calculations of the magnification. The conceptual activities of the NCS books also do not have the depth of the traditional book. This is the reason why some of the teachers still use activities from the traditional books as an addition to the NCS books (Lemmer *et al*., 2008).

The difference in emphasis on the understanding of concepts and formalization of concepts was also evident from the presentations of energy and related concepts in the traditional and NCS books. Traditionally energy is defined as the ability to do work. Kinetic and potential energy are then defined and relationships between concepts established. Calculations are done for different situations of energy transfer. In response to this formal way of doing, neither definitions nor calculations are given in the NCS books. A variety of energy transfers in everyday-life and technological contexts are discussed qualitatively. In accord with the prescribed core knowledge, potential energy is described as energy stored in systems, that can be released as kinetic energy. No formal relationships are given, e.g. the dependence of kinetic energy on the mass and velocity of an object. Kinetic energy is only associated with "movement". Movement is not described, neither in general terms nor in terms of a reference system. Although examples are given for energy transfers to less useful forms during conversions (as prescribed), none of the NCS books even mentioned the principle of conservation of energy. This principle is a cornerstone in physics (Lemmer & Lemmer, 2006).

The first learning outcome for natural sciences teaching (NCS) prescribes two teaching strategies, namely inquiry and problem solving. Inquiry skills such as writing a hypothesis, compiling an investigation, compilation of tables and graphs and communicating of results, are required in many of the activities in the NCS books. Although a very low level of accomplishment is expected, the learners at least get a feeling of what it is about. Problem solving is however not much attended to, neither as a skill nor as a means for concept understanding in physics (Gaigher *et al.*, 2006).

Environmental and social issues are considered important by the NCS textbooks. In one of the activities two newspaper reports are given, one in favour of and one against the use of nuclear energy as alternative energy source in South Africa. Learners had to summarize the reasons given by the two writers and debate the matter. The learners were not required to find any additional information. Unfortunately, one of the two reports was particularly biased and gave misleading statistics. Anyway, the learners do not as yet have the necessary scientific or technical knowledge to judge the issue. The high level of knowledge and reasoning skills needed by such activities stand in great contrast to the little knowledge that learners can acquire from preceding activities in the books.

Something else found in the NCS books are cultural (mostly mythical) explanations for natural phenomena such as lightning. Such explanations are given together with the scientific explanation of the phenomenon. The idea seems to be that learners should recognize that different ways of explaining natural phenomena exist. Choosing which one to accept is left open.

Cooperative learning is promoted in the activities. The textbooks specify which activities have to be done in pairs or groups. Summative assessment focuses on self-, peer and group assessment. Rubrics are used to evaluate the effectiveness of the group or reflect on learning. The assessment criteria in the rubrics are not specific, but broad and general. The same rubric is used for assessment of different activities.

The structure of concept presentation in the NCS textbooks is neither linear nor in the form of concept maps. While concept maps (e.g. Novak, 2004) shows *relations* between concepts, the OBE curriculum is built on *relatedness* between concepts, societal issues, technological applications, etc. Instead of propositions, it consists of hyperlinks. Therefore it can be called a hyperlinked system. The result is comparable with what may be obtained when going to a web address and then following the one link after the other that seems relevant, occasionally returning to the home page to follow yet another path.

Table 2 summarises the results of the analysis of the traditional and NCS grade 9 science books. These features confirm that the traditional curriculum is behaviourist in nature, while the NCS curriculum is communal.

Table 2: Summary of features of traditional and NCS Grade 9 science textbooks

Aspect	Traditional curriculum	NCS curriculum
Focus	Formal theory	Social aspects
Purpose	Scientific knowledge and applications	Scientific literacy Development of potential of individual and uplifting of society
Relevancy	Only in some of the formal applications	Learners' and social needs
Science for …	scientists	all
Learning is ….	individualistic	communal
Motivation for learning science	Knowledge and understanding of scientific theory.	Science is relevant and functional
Experiments / Activities	Experimental observations lead to formal theory	Activities to educate through physics
Assessment	Formal testing of content knowledge	General, reflective; Form without much substance
Sketches	Diagrammatic sketches of apparatus; show only what is relevant	Picture-like sketches showing group or context. Apparatus small and not central.
Experiential learning	Structured laboratories	Activities & Case studies
Responsibility of science	Not attended to	Important for society

EMPIRICAL STUDY OF CONCEPT KNOWLEDGE OF LEARNERS AND EDUCATORS

In an empirical study, a questionnaire was drafted and completed by 1211 Grade 9 or 10 learners and their science teachers from 33 schools in the North-West Province, South Africa. The concept under investigation was energy since it is the focus of the physics part (called Energy and Change) of the natural sciences curriculum from Grade R to 9 (Department of Education, 2003). An understanding of the energy concept can consequently be expected.

The questions of the questionnaire all refer to the context of a boy named Peter who pulls a heavy cart along a road up a hill, holds the cart at rest on the top of the hill and then by accident let go of the handle and the cart runs down the hill. The percentages of correct answers are given in Table 3. These percentages only reflect the number of students who chose the correct option to each question. Some of these students, however, gave incorrect reasons for choosing these answers. The reasons that they provided revealed alternative and misconceptions held by the learners.

Table 3: Results of questionnaire

No	Question	% correct	
		Learners	**Teachers**
1	Does Peter do work when pulling the cart uphill?	96	96
2	While Peter is pulling the cart uphill, the following has/have energy *[list of items]*	42	64
3	While Peter is pulling the cart uphill, the following exert(s) forces *[list of items]*	40	61
4	Suppose Peter pushed the cart uphill instead of pulling it. When reaching the top of the hill he would have used (less/more/as much) energy	15	42
5	Does Peter exert a force when he holds the cart stationary on the top of the hill?	69	75
6	Where does the cart have the largest total amount of energy? *[list of options]*	13	30
	AVERAGE	39	61

Question 1 was best answered with 96 % of the students who said that Peter does work. Most of the reasons supplied related to energy or force. Only a few of the Grade 10 learners used the operational definition of work as the product of force and distance. Everyday-life answers were also obtained, e.g. “I think he (is) going to sell this thing that is in the cart”. Many of the learners marked the same option in questions 2 and 3 indicating a confusion of force and energy. The reasons given confirm such confusion, which has also been reported by Rankhumise & Lemmer (2008). The majority of learners are of the opinion that Peter would have used more energy when pushing the cart than when pulling it. This indicates that they consider the means instead of the change in energy for the work done. None of the learners referred to the difference in energy of the cart at the bottom and on the top of the hill. Notwithstanding nine years of education in the theme Energy and Change, they do not use this concept in questions on energy. This is confirmed by the learners’ answers to question 6.

The results show that the learners do not have a proper conceptual understanding of energy. Alternative conceptions such as the anthropocentric (human-centered) view, energy as an activity and energy as an ingredient (Watts, 1983) occurred in reasons given by students. Their science education was consequently neither effective in addressing these alternative conceptions, nor in establishing the scientific concept. This result is confirmed by the case study of Rankhumise and Lemmer (2008) in which Grade 10 learners’ low conceptual knowledge of energy showed an average normalised learning gain of 50 % after a constructivist intervention.

From Grades 10 to 12 a more formal physical science curriculum is followed in order to prepare the learners for tertiary education. The results of the Grades 9 and 10 learners in the study were similar, showing a minimal increase in the grade 10's conceptual understanding of energy. This explains the weak Grade 12 examination and TIMSS results for South Africa mentioned earlier.

Although the teachers performed better than the learners in all the items, the results are very disturbing. The questions asked test for such elementary knowledge that they should have had it 100 % correct. Percentages below 50 % were obtained for questions 4 and 6. It is interesting to note that the percentages of the teachers correspond to the profile of the learners, i.e. the sequence is the same from the best to the lowest mark. This indicates that teachers' poor knowledge is transferred to their students and that they have a tremendous effect on their students' learning. Given this result, it is even more important that textbooks present scientific concepts and principles in a clear, coherent way, so that the teachers can at least learn as they go. The implications of these results for training of new science teachers are self-evident. It is imperative that depth in content knowledge is ensured.

CONCLUSIONS

Following world-wide educational reform, physics education in South Africa changed from a positivist curriculum embedded in the behaviourist paradigm, to an Outcomes Based curriculum that supports the communal theory. This result is obtained from the analyses of curricula and textbooks, as well as an empirical study that probed the understanding of more than a thousand learners and their science teachers about the concept of energy.

In the former positivist curriculum scientific knowledge was presented in a sequential logical way with the aid of carefully selected experiments and emphasis on scientific explanation of the results. A major deficiency is that it lacked relevance to real-life situations. It neither attended to technological and career applications nor to environmental and social responsibilities. These deficiencies were addressed in Outcomes-Based Education (OBE), as is evident from the study.

The OBE curriculum can be described as "education through science" where the traditional curriculum aimed to achieve "science through education" (terms coined from Holbrook and Rannikmae, 2007). Consequently the OBE curriculum shares the same philosophy with the activity theory proposed by Van Aalsvoort (2004) as a remedy for lack of relevance of positivist curricula, as well as the critical theory built on social needs (Potgieter, 2008). These theories encompass the achievement of personal goals, stressing intellectual and communication skill development as well as the promotion of character and positive attitudes. They further advocate the achievement of social goals in the social education domain, stressing cooperative learning, socio-scientific decision-making and responsible citizenry.

Although scientific knowledge is one of the three learning outcomes of natural sciences education given in the NCS, the purpose is not to learn a structured body of knowledge, but to interpret and apply it in a variety of scientific, technological and environmental contexts. Consequently, the expected (prescribed) core knowledge and concepts that learners should acquire is little and shallow. The result is that the learners do not understand or internalize the scientific concepts and principles and gain little theoretical knowledge. This is confirmed by the empirical study of learners' conceptions of energy. Other factors, such as inadequately prepared teachers also contribute to learners' poor knowledge acquisition.

Unfortunately the OBE curriculum not only attended to deficiencies of the positivist curriculum, it also disposed of strong points such as focus on structured presentations and learning of formal scientific theory. According to the cognitive model of learning, learning to think scientifically commences with knowing the concepts and principles of science (Kirschner *et al*., 2006). Outcomes of the NCS such as critical thinking, responsible decision-making and effective communication all require a proper foundation of that knowledge. Inadequate school learning of scientific knowledge is expected to have a negative effect on South Africa's need for well-trained professionals with a profound scientific knowledge base such as doctors, engineers, pharmacists, geologists, scientists, etc. Notwithstanding the emphasis of the NCS on social aspects and responsibilities, they neglected the most important responsibility of science education, namely to produce scientists with sound scientific knowledge to form a basis for technological, economic and social development of the society and country.

Instead of making the curriculum more relevant, OBE only exposes learners to reality. What is required is a way to promote relevance that is in accord with the cognitive model of learning (Lemmer & Lemmer, 2008). Physics learning should commence with learners' experience of reality, progress to a conceptual understanding and culminate in formal physics. Such learning is partly communal and partly individual: Perceptive learning is promoted by interaction with the environment and peers, but every learner must internalize the conceptions and this can only be done individually.

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