Science education in South Africa for the 21st century: Mutualism between knowledge domains

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Abstract
‘Science has assumed an important role in the contemporary economy’, especially in the 21st century (Watters and Watters 2007). It also is a well-known fact that the quality of teaching and science teachers has a significant impact on the quality of learning. Science is a challenging subject; therefore the work of the teachers involved in science education can also be very challenging, taking into account the varieties of knowledge required for teaching complex and abstract science concepts. Science education and teaching rely upon more than just science content as a school subject and topic-specific knowledge, instructional strategies and assessments (Lankford 2010). Teachers of science need to understand science as a discipline, and this includes understanding the nature of science and the integration of the various knowledge domains. The argument for mutualistic possibilities among these knowledge domains for ‘better’ science education in the twenty-first century is investigated. This article reports on a theoretical study in which a pool of concepts and principles were examined to provide an overview of the potential mutualism of a variety of knowledges that a successful and effective science teacher should acquire/have.

INTRODUCTION/BACKGROUND
Science and technology have taken on greater significance in education since the national democratic elections in 1994 [20th century] in South Africa. According to the TIMMS Science Framework (2011), ‘... understanding of science is imperative if citizens are to make informed decisions about themselves and the world they live in’. Science is becoming increasingly important nowadays, as science education is often seen as a gateway subject for development and scientific excellence globally, as well as for understanding the natural world we live in. According to the National Framework for Teacher Education (NFTE) (DoE 2006), shortages are being experienced in scarce skills areas such as Mathematics, Science and Technology. This is mirrored in the United States (US) as ‘we desperately need more qualified ... science and math teachers’ (Physics forums 2011). The importance of school science is indicated in the quote below:

“As biological sciences have assumed an important role in the contemporary economy ...,” students (learners) choosing these subjects (sciences) as a career path need
to develop complex problem-solving skills; develop an ability to adapt to various disciplines; develop conceptual understanding of different topics; and develop lifelong learning skills to ensure their success in a post-education life (Watters and Watters 2007).

Mathematics and science are challenging subjects; therefore, the work of the teachers can also be very challenging. Learners need qualified and competent teachers as early as possible during the years of training; they need to be taught by specialist teachers (Kind 2009; Physics forums 2011). According to Kind (2009, 169), having a ‘Bachelor’s degree in a science subject does not guarantee effective teaching’. As teachers are the primary agents in science education, the development of a quality teaching corps is a primary condition for educational excellence, as noted by McGrath (2008) who states that: ‘The quality of teaching and teachers has a significant impact on the quality of learning.’ It is well documented that teaching of this quality in science is linked to teachers’ understanding of the nature of science, their beliefs about teaching science and about learning science (Tsai 2006), which ties in with the outcry for ‘more teachers, better teachers’ (DoE 2006).

Science teachers differ from scientists in the way in which science content knowledge is transformed to support teaching and make complex and abstract science concepts understandable for learners (Cochran 1997). According to Magnusson, Krajcik and Borko (1999, 95), ‘effective science teachers know best how to design and guide learning experiences ... to help ... students [learners] develop scientific knowledge and an understanding of the scientific enterprise’.

Knowledge required for teaching complex and abstract science concepts relies upon more than just science content as a school subject and topic-specific knowledge, instructional strategies and assessments (Lankford 2010). Teachers need to understand science as a discipline, as well as the nature of science; they need to know the science school curriculum, understand learners and their misconceptions about science, and potential barriers to learning science. Most of all, they need to understand that there is a variety of approaches towards science teaching and education. Many of these factors, or knowledge domains (see Figures 1 and 2), need to be considered for quality education, especially in science education. Thus, the argument for mutualistic possibilities among these knowledge domains for ‘better’ science education in the twenty-first century is investigated.

A mutualistic approach to the knowledge and understanding of science should enable/support teachers and learners to take part in discussions or make decisions relating to diverse issues and topics, such as the use of technology, environmental issues and health issues. Pedagogical content knowledge (PCK), therefore, is a necessary knowledge base for effective teaching (Lankford 2010) and the mutualism (integration) of a variety of knowledge from various domains during teaching is crucial for effective science teaching and learning to take place (Watters and Watters 2007; Botha and Reddy 2011). The knowledge domains mentioned in this article link together a variety of skills, attitudes and knowledge including that of learners and
also knowledge about the teacher him/herself.

The article reports on a normative theoretical study whereby a pool of concepts and principles were examined to provide an overview of the mutualism of a variety of knowledge that a successful and effective science teacher should acquire/have. This theoretical study is non-empirical and is not based on observation or experience but on theories or logic. The normative theory is based on the ideals and obligations we should accept – things that are intrinsically valuable (Thatcher 2006), normative in the sense of identifying concepts, and principles that are of value in effective science teaching and learning.

During this theoretical study, it became clear that the variety of knowledge domains is ever increasing as education develops, adapts and changes; it is clear that the interactions between these domains could become complex over a period of time and that emergence happens at different points of the process.

In this article I review the importance of PCK in science education in South Africa for the twenty-first century. The roles of the various domains of knowledge required for effective teaching will be highlighted and considered in relation to and supported by the different viewpoints of researchers such as Shulman (1986; 1987), Grossman (1990), Carlsen (1999), Magnusson, Krajcik and Borko (1999), Kind (2009), Etkina (2010) and Lankford (2010). An integrated perspective is developed and presented as a proposition towards effective science teaching. This could lead to an empirical study of how these knowledge domains could contribute to effective science teaching in the science classroom.

SCIENCE EDUCATION AND KNOWLEDGE

According to Gough (2002), the goals of science education include:

• Learners’ understanding and appreciation of the evolutionary nature of scientific knowledge and the nature of science as a human endeavour and its contribution to society; and

• Learners’ abilities to make decisions that include ethical consideration of the impact on people and the likely products of science.

Gough (2002) argues that ‘traditional science education is becoming a threatened species as students [learners] are increasingly more involved in technology and the social world’. According to her, the content of science curricula has a ‘strong negative influence’ on learners who are rapidly losing interest in pursuing their studies in science beyond the compulsory school years. Learners today behave differently to the way in which faculty members (lecturers) behaved in the ‘good old days’ when they (we) were students. These differences could have an impact on the way that learners learn and how they respond to science education (Stears 2009; Twenge 2009).

It is, therefore, imperative that a successful science teacher should develop a variety of skills and competencies to address these differences and to build a
science ‘teacher repertoire’ (Saunders 2007) to respond to the various needs of science education in the twenty-first century. Such a repertoire would include general pedagogical knowledge, specific subject matter knowledge and PCK, which includes a variety of knowledge domains as depicted in Figure 2. PCK is more than just the ‘sum’ of all the categories (components) (Abell 2008) comprising PCK; it is the integration thereof that is important in the professional development of science teachers. ‘Teachers do not only possess PCK, they employ [and integrate] the different components in planning and executing their instruction’ (Abell 2008).

*Mutualism* in science is a symbiotic relationship from which all role players/stakeholders benefit. The relationship between the various knowledge domains in science teaching and education could well be mutualistic, or integrating, in order to meet the need for effective science teaching in a changing world. In this case, the variety of knowledge domains plays an important role in professional development in science teaching and education. With learners revealing a declining interest in science, mutualism among the various knowledge domains, in addressing the teachers’ needs and meeting the demands of effective teaching in this changing educational environment, could enhance the survival of science education. These domains should be mutualistically linked by means of PCK, a theoretical construct that was introduced by Shulman (1986/87) as a means of describing the particular form of content knowledge, its teachability and ways of presenting it (Loughran, MulHall and Berry 2008). PCK also provides a particular way of thinking about science teaching (Mulhall, Berry and Loughran in Loughran, MulHall and Berry 2008) and is a transformation of other types of knowledge into a viable construction (Abell 2008).

PCK is not an independent category of knowledge but a special ‘amalgam’ of content and pedagogy that sets teaching apart from other professions (Shulman 1987; Abell 2008; Kind 2009) and is considered as one of the goals in teacher education (Borko and Putnam 1996 in Loughran, MulHall and Berry 2008). The concept of PCK is integral to teaching as a profession and is often considered to be an important aspect of a teacher’s lived experience (Botha and Reddy 2011). It is described as a transformation of teacher knowledge from a variety of domains of knowledge that include subject matter knowledge, pedagogical knowledge and knowledge about content (Carlsen 1999; Magnusson Krajcik and Borko 1999). According to Kind (2009), the literature points to a more integrative-type (mutualistic-type) of PCK model as it tends to offer a wide-ranging general picture of the teacher’s skills and knowledge developed over time (Abell 2008; Nilsson 2008; Kind 2009) in science teachers through continuous professional development.

The *Nature of Science* (see Figure 1) involves the professional practice of science teachers which requires applicable knowledge for educating students and learners through inquiry towards understanding and application; it is a way of knowing about the natural world. The nature of science also reflects PCK, the science curriculum and assessment. Science is characterised by the systematic gathering of information through various forms of direct and indirect observation and the testing of this
information by methods including, but not limited to, experimentation. The principle product of science is knowledge in the form of naturalistic concepts and the laws and theories related to those concepts. All those involved in teaching and learning science should have a common, accurate view of the nature of science (NSTA 2011).

Science is a way of knowing, a process of producing knowledge based on evidence. This evidence is gained by different methods of doing science: the ‘Scientific method’ and ‘Scientific inquiry’. Science is subject to change; there is no single correct answer. Science connects the past with the present. Science is not authoritarian. Learners should be aware that science is both a way of knowing about the natural world and a body of knowledge that is characterised by certain standards of analysis and peer review, and that it is a distinctly human endeavour. However, the school curriculum only presents a sub-set of science disciplinary knowledge and is presented in particular ways; knowledge is hierarchical and sequenced for school-level groups.

However, the reality is that teachers often hold inadequate conceptions of the nature of science, which may be translated as being positivist in the sense that they believe the substantive content of science is fixed and unchangeable rather than tentative (Van Driel, Verloop and De Vos 1998). In order to attain an understanding of science and the development of scientific knowledge, teachers need to consider the needs of diverse groups of learners (Botha and Reddy 2011) linking to the array of knowledge domains needed for effective science teaching.

*Education* is given the task of providing ‘comprehensive knowledge’ providing insights into the interaction between the various knowledge domains (Gough 2002). While Shulman (1986) originally conceptualised PCK as an educational construct, various knowledge domains have since been identified from PCK by various authors.
as having an impact on education. Researchers have chopped and changed their viewpoints regarding PCK for just over a decade.

Shulman (1986) conceptualised PCK to include knowledge of representations of subject matter; an understanding of specific learning difficulties; and student conceptions of science. Grossman elaborated on Shulman’s conceptualisation of PCK in 1990 and identified the following five categories: knowledge and beliefs for teaching subject matter; knowledge of students’ understanding; conceptions and misconceptions of particular topics in a discipline; knowledge of the curriculum; and knowledge of instructional strategies and representations. Magnusson, Krajcik and Borko (1999) introduced more detail into these categories in 1999. These included the orientations towards teaching science; knowledge and beliefs of the science curriculum; knowledge of students’ understanding of science; knowledge of assessment in science; and knowledge of instructional strategies.

Carlsen (1999) then integrated the previous views of PCK as depicted in Figure 2. PCK is a form of teacher knowledge and it includes five general knowledge domains, namely: the general education context; the specific education context; the general pedagogical knowledge; subject matter knowledge; and PCK. All five of these domains are further detailed as shown in Figure 2 (Botha and Reddy 2011).

Figure 2: Domains of teacher knowledge (Carlsen 1999)

Two major contributions from the work of all these authors were the acknowledgement of the importance of subject-specific knowledge in effective teaching, and the identification of a type of knowledge known as pedagogical content knowledge which was seen to be unique to the teaching profession. These could be seen as developing from a teacher’s knowledge of content and knowledge of pedagogy (Botha and Reddy 2011).
According to the research review by Abell (2008), researchers identified important characteristics of PCK, namely: it includes ‘discrete’ categories of knowledge; it is dynamic – not static; the content is central to PCK; and it involves the transformation of other types of knowledge (Henze, Van Driel and Verloop; Lee and Luft; Loughran, Mulhall, and Berry; Rollnick et al.; Padilla et al., all cited in Abell 2008, in a special edition of IJSE).

Teachers’ knowledge, beliefs and attitudes about education (natural science teaching) have a profound effect on all aspects of their teaching (Dobey and Schafer 1984; Nespor 1987; Smith and Neale 1991; Carlsen 1993; Koster, Brekelmans, Korthagen and Wubbels 2005). Some of this research was framed by the conceptualisations developed by Shulman and his colleagues concerning the diverse domains that teachers use when planning and teaching (Shulman 1986; Grossman 1990). Teachers should incorporate these diverse domains of knowledge into their teaching repertoire and their teaching, in order to ensure effective science teaching.

The concept of knowledge domains (including PCK) has been used in education as a vehicle to understand how teachers conceptualise and organise their teachings. Many authors have placed knowledge in various categories such as domain knowledge (Carlsen 1999; Hong, Horng, Lin and ChanLin 2008); teacher competencies (Barnes and Nobles 1999; Casey 1999; Koster et al. 2005), which Stoof, Martens and Merrienboer (2000) define as the levels of integration of knowledge, skills and attitudes, which further define a good (natural science) teacher; academic knowledge and skills (Barnes and Nobles 1999); and subject-oriented, methodological, communicative and organisational competencies (Korthagen 2004).

Knowledge of subject matter and pedagogical skills are necessary for successful teaching but they are not sufficient. It is, therefore, clear that the acquisition of PCK should start in the pre-service training phase of teachers (Lankford 2010). If their roles and competencies as teachers are not adequately developed, teachers will be ill prepared to pursue their roles as competent teachers as well as to build on their teacher/teaching repertoire. Therefore, science education should be ‘mutually respectful’ (Gough 2002) of the various knowledge domains, recognising the need for broadening the already extended list of knowledge domains as discussed in the following section and depicted in Figure 3.

SCIENCE AND SOCIETY – EXTENDING THE DOMAINS

Technological content knowledge
Changes in science education goals over the last decade induced new orientations towards science education globally (Mansour 2009). Mansour (2009) further argues that the science-technology-society (STS) approach is an ‘interdisciplinary field of study that seeks to explore and understand the many ways that modern science and technology shape modern culture and values’. This would mean that learners would engage in science and technology with different viewpoints on issues concerning
everyday life (Fensham 1985). Therefore, science learners are encouraged to make responsible decisions within society regarding the impact of modern science in their everyday life situations (Aikenhead 1994).

According to the Ubiquitous Learning Institute (ULI 2011) at the University of Illinois, teaching and learning need to be reconsidered in an ‘era when people can carry the Internet in their pocket’, and structured learning opportunities therefore become an ‘anytime, anywhere’ enterprise.

As science is a ‘living’ subject, content needs to be up to date and linked with real time, real world situations/issues/problems, as learners need to become informed adults and citizens in their country upon leaving the school environment and continuing their professional development. Technology affords teachers and learners the opportunity to be life-long learners, as envisaged by the educational policy documents (DoE 2000).

According to Burbules (2011), teachers and learners cannot be left out of the digital world of the twenty-first century, better known as the information age or computer age, in which individuals have the ability to transfer information freely and have instant access to knowledge, which was impossible only a couple of years ago. This is linked to the idea of a Digital Revolution characterised by the change from analogue, mechanical and electronic technology to digital technology (Information age, Wikipedia).

Younger people are more likely to use technology than ‘older’ people who, in some cases, display resistance to using technology in the classroom (Burbules 2011). Teachers, therefore, need to become more informed and skilled regarding information technology and to use it in innovative and creative ways to enhance their teaching, thereby changing the role of the teacher as mere knowledge provider to knowledge broker or facilitator. Technology has consistently improved education and human knowledge: the printing press offered the rapid distribution of knowledge and the engine made travel possible, concentrating education increasingly in schools and universities, and disseminating information more efficiently.

Technological pedagogical content knowledge (TPACK) is a framework for understanding and describing the kinds of knowledge needed by a teacher for effective pedagogical practice in a technology-enhanced learning environment. The TPACK framework argues that effective technology integration for teaching specific content or subject matter requires understanding and negotiating the relationships among these three components: Technology, Pedagogy and Content. A teacher capable of negotiating these relationships represents a form of expertise.

Examples of courses offered by other Higher Education Institutes include: Technology Across the Curriculum and Instructional Media & Technology, graduate level courses taught at the University of Missouri-Columbia and the College of Education at Kansas State University alternatively. The purpose of these courses is to support teachers as they learn to integrate technology into meaningful learning experiences for their learners and to ensure that each undergraduate teacher entering their professional course work has a fundamental grasp of digital technologies.
and how they are used to instruct young people in their content (KITE in action – University of Missouri 1).

The impact of technology is hampered by not everyone having access to this portable form of knowledge and learning, thus widening the gap between those that have the knowledge and support and those who do not.

**Affective knowledge**

The affective domain has not received as much attention as the cognitive domain, as it is difficult to measure/categorise/characterise the affective competencies (Olsen and Wyett 2000). Bloom (1956) describes the affective as a growth in feelings or emotional areas; it includes the manner in which we deal with things emotionally, such as revealed through feelings, values, appreciation, enthusiasm, motivation and attitude. It is also concerned with the *perception* of value issues, as well as the *awareness* and *growth* in attitudes and feelings. Bloom categorised the affective competencies into receiving, responding, valuing, organisation and characterisation (Bloom 1956).

According to Semensky (2009, 444), ‘Affective knowledge serves as the necessary condition for effective and successful learning’, and to quote Krathwohl, Bloom and Masia (1964):

> The taxonomy is ordered according to the principle of internalization. Internalization refers to the process whereby a person’s affect toward an object passes from a general awareness level to a point where the affect is internalized and consistently guides or controls the person’s behavior.

Internalising affectiveness in science and science education will determine the attitude and behaviour of teachers towards science teaching and learning. The latest effort to define what teachers need to know and be able to do tends to overemphasise the cognitive (and physical) skills of teachers; the affective domain is easily neglected but should not be left to chance; it should be made explicit in any teacher education (Olson and Wyett 2000). ‘Educators should be chosen not merely for their special qualifications, but more for their personality and their character, because we teach more by what we are than by what we teach’ (Durant in Olson and Wyett 2000).

Teacher’s affective competencies impact learners’ learning directly. An ineffective teacher-learner relationship leads to ineffective learning by learners; therefore, teachers’ personalities and attitudes are just as important as their knowledge of subject matter and pedagogical skills (Olson and Wyett 2000). There needs to be a balance between the ‘know, be able to do and be’.

**KNOWLEDGE OF THE SELF: A BIOGRAPHY**

As is well known, any teacher, by association, has a multitude of roles and seldom just teaches (DoE 2002). Most teachers act as mediators, specialists, leaders,
administrators, and providers of support, among others (DoE 2002). Teachers need to know their own strengths and weaknesses: What teaching-learning and organisational skills do I have? What knowledge do I have of science content, pedagogies and methodologies? What do I know about the learners and their conceptions and misconceptions in science? Do I know the content of the policy documents? Am I motivated, enthusiastic, dedicated, competent and scientifically literate? In answering these questions the teacher starts to build a science teacher repertoire – a biography of the self.

Olsen and Wyett (2000) are convinced that teachers’ personalities and attitudes are just as important as their pedagogical skills and specific content knowledge of subject matter. They suggest that teachers should consider additional competencies in order to achieve a balance, including that a teacher is an authentic person; sees all people as worthy, treating them with respect and dignity; and is an empathetic person who understands learners’ feelings and responds appropriately. It could, therefore, be inferred that the affective knowledge domain forms the basis on which all other knowledge domains work together mutualistically (see Figure 3).

![Figure 3: Extended domains of teacher knowledge (Carlsen 1999; Botha and Reddy 2011)](image)

CONCLUSION

Learning to teach science is not about acquiring a bag of tricks based on a set of general pedagogical strategies, it is about developing a complex and contextualised set of knowledge to apply to specific problems of practice (Abell 2008).
The overarching goals of this study were to contextualise the importance of the different knowledge domains and the PCK development of science teachers. Learners engage with technology on a daily basis, applying their technological knowledge and skills to their everyday activities. An effective science teacher, therefore, should also be hands-on with these technology skills in order to support learners’ learning, especially in this technological age where ‘the internet is carried in the pocket’ and information is readily available anywhere, anytime. Teachers need to be sensitive to and address the needs of twenty-first century learners – ‘the generation me’.

Teachers should be aware of their own abilities and know themselves, if they want to be part of, and keep up with these ongoing changes. Teachers’ personalities and attitudes play an important role in an era of change. They cannot afford to resist the changes taking place in education and the world in general. Linked to these changes is an awareness of the newly gained/emerging knowledge domains accompanied by the related skills of an effective science teacher. Teachers are also chosen by schools regarding their personality and character; thus, teaching is often more dependant on who teachers are than by what they teach.

The mutualism of a variety of knowledge domains during science teacher education and teaching is necessary for effective teaching and learning to take place and to ensure that appropriately qualified teachers fill these positions in educational institutions. Science teachers differ from scientists in the way in which science content knowledge is transformed in order to support teaching and make complex and abstract science concepts understandable to their learners. It is not just about knowing the subject content, it extends into how it is taught, who is teaching and under what conditions teaching is taking place.

It could, therefore, be inferred that PCK in science education in South Africa for the twenty-first century is of high importance due to the enduring need for more and better science teachers (and scientists) as documented in the National Policy Framework For Teacher Education and Development in South Africa (2006) – ‘More teachers; Better teachers’. According to research done by Loughran, MulHall and Berry (2008), it is reported that PCK offers another way of thinking about learning and teaching science and helps teachers to go beyond the traditional gathering of ‘tips and tricks’ about teaching. PCK is not merely the amount of knowledge in a number of categories, it is also about the quality of that knowledge and how it is put into action; ‘it is not a free-standing type of knowledge, but is influenced by and influences other knowledge types’ (Abell 2008).

Therefore, PCK could be used as a conceptual framework in the teaching of science within a science teaching preparation programme (Loughran, MulHall and Berry 2008). Through PCK, and the other integrated knowledge domains, particularly technology, the affective and biography, science teachers might develop their own professional knowledge of practice (Loughran, MulHall and Berry 2008). What we seek is mutualism among cognitive, affective and physical skills in order to promote effective science teaching in South Africa in the twenty-first century. A great deal of time and effort is needed before understanding of PCK and the various
knowledge domains will become visible in teachers (Etkina 2010). These newly
emerged knowledge domains with related skills will not be gained overnight, it will
take some time for a teacher to accept and adapt to the change, acquiring extended
periods of practice and experience.

Although many other types of knowledge domains could be added to those already
mentioned, the body of knowledge that constitutes science as a discipline needs to
articulate more closely with human experiences. A mutualistic relationship between
technology, the affective domain and the self can go a long way to realising the goals
of science teaching in the twenty-first century. Closing words from Burbules (2011)
who declares, it is all about learning:

To know, to be able to do and to be!
To be is to learn!

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