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Reflections on Teaching Periodic Table Concepts: A Case Study of Selected Schools in South Africa

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ABSTRACT
The Periodic Table of Elements is central to the study of modern Physics and Chemistry. It is however, considered by teachers as difficult to teach. This paper reports on a case study exploring reflections on teaching periodic table concepts in five secondary schools from South Africa. Qualitative methodology of interviews and document analysis were used to collect data from five participants that were purposively selected. One specific research question was addressed: what practices inform Physical Sciences teachers when teaching periodic table of elements? Results showed that all participants were able to describe specific teaching and learning difficulties, such as relating the properties of substances to characteristics of the constituent particles. They further, recognised the importance of using models of atoms and molecules to promote understanding. These findings have implications for science teaching, learning and teacher education.
Keywords: periodic table, science goals, nature of science, inquiry teaching, scientific models

INTRODUCTION

The Periodic Table of Elements (PTE) forms part of high school and tertiary level chemistry hence, central to the study of modern science. It has influenced the development of quantum theory and continues to influence the quantum–mechanical calculations on molecules (Nelson, 2015).

The periodic table which was originally developed as a list of elements and later the Russian inventor and chemist, Dimitri Mendeleev, developed it into a list of atoms of the elements in the 1860s (Brooks, 2002). Mendeleev was able to use physical and chemical properties of elements to predict or recall the particles that constitute atoms: the number of protons and the arrangement of electrons (particle level). Since then, the PTE has been influencing theories in Physics and Chemistry. Today, any element symbol in the PTE refers to an atom of an element (Schmidt, 1998). The modern periodic table shows the arrangement of elements in order of their increasing atomic number. The atomic number is the number of protons in the nucleus of an atom. An atom comprises a nucleus, shells of inner or core

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State of the literature

- Most teachers experience difficulties when teaching science content at secondary school level, despite its practicality as a conceptual tool for organization of the chemical elements and understanding their properties.
- Successful teaching is influenced by sufficient expertise and content knowledge in the subject matter with a conducive teaching and learning environment.
- Insufficient facilities in schools that hinders the development of conceptual understanding of the MST subjects.

Contribution of this paper to the literature

- This paper provides a critical review on the teaching of a periodic table concepts.
- It highlights challenges faced by teachers of science to develop conceptual knowledge for the MST subjects.
- The paper makes a significant contribution to the literature and debate in the science education reform.

electrons, and a shell of outer or valence electrons (Nelson, 2015). Though a shift of meaning occurred from a periodic table listing substances to a periodic table of atoms of the elements, the current interpretation of the PTE has not completely replaced the original one. Both interpretations are used in parallel (Schmidt, 1998).

In South Africa, the PTE is a topic to which students are introduced at the secondary level. However, for many Physical Sciences teachers, this topic is considered difficult to teach where several studies reported that the majority of teachers experience difficulties when teaching science content at secondary school level (Mokiwa 2014a; 2014b; Mudau, 2013; Ejiwale, 2013; Jita & Ndlalane, 2009). In the South African context, Physical Sciences is a subject that investigate physical and chemical phenomenon and it is taught from grades 9 to 12. The newly introduced Curriculum and Assessment Policy Statements (CAPS) asserts that the teaching of Physical Sciences should be done through inquiry, application of scientific models, theories and laws in order to explain and predict events in the physical environment. The specific aims of Physical Sciences as described in the CAPS document include three outcomes. Outcome number one focuses on the development of practical scientific inquiry and problem solving skills. Constructing and applying scientific knowledge is learning outcomes two; whereas outcome three focuses on the Nature of Science (NOS) and its relationship to technology, society and the environment (DBE, 2011).

Physical Sciences has four strands; namely, matter and materials; life and living; energy and change; earth and beyond (DBE, 2011). The topic PTE is introduced superficially to students in grade 9 under the strand of *energy and change* where the focus is on the first twenty elements (see **Table 1**), and can be used as such in atomic structure. It displays the elements in increasing atomic number and shows how periodicity of the physical and chemical properties of the elements relates to atomic structure.

Table 1. Periodic table of the first 20 elements *(Source: American Chemical Society (ACS), 2014)*

PERIODIC TABLE
ELEMENTS 1–20

HYDROGEN 1 H 1.01							HELIUM 2 He 4.00
LITHIUM 3 Li 6.94	BERYLLIUM 4 Be 9.01	BORON 5 B 10.81	CARBON 6 C 12.01	NITROGEN 7 N 14.01	OXYGEN 8 O 16.00	FLUORINE 9 F 19.00	NEON 10 Ne 20.18
SODIUM 11 Na 22.99	MAGNESIUM 12 Mg 24.31	ALUMINUM 13 Al 26.98	SILICON 14 Si 28.09	PHOSPHORUS 15 P 30.97	SULFUR 16 S 32.07	CHLORINE 17 Cl 35.45	ARGON 18 Ar 39.95
POTASSIUM 19 K 39.10	CALCIUM 20 Ca 40.08						

However, in grade 10 the PTE is taught under the theme *Chemical change* focusing more on the position of the elements, similarities in chemical properties in groups, and electron configuration in groups (DBE, 2011). The time allocated for the teaching of the whole PTE section is 4 hours. Students are expected to develop an understanding about the importance of the periodic table in Chemistry. This of course is not an automatic pursuit. Teachers of Physical Sciences are expected to possess a sound knowledge of concepts about the periodic trends of physical properties of elements. From a constructivist perspective, teachers facilitate the learning process and guide students in their meaning making (Luera & Otto, 2005).

Despite its practicality as a conceptual tool for organization of the chemical elements and understanding their properties, most teachers experience difficulties when teaching science content at secondary school level (Mokiwa 2014a; 2014b; Mudau, 2013; Ejiwale, 2013; Jita & Ndlalane, 2009). The issues of what kind of knowledge is adequate for making effective instructional decisions or designing appropriate learning environments are on the agenda of current research world-wide (Malcolm & Alant, 2004). For South Africa, the unsatisfactory teaching competencies of the majority of science teachers is attributed to weak content knowledge arising from poor teacher education programmes offered in the former colleges of education prior to 1999. In 2014 the Mpumalanga Department of Basic Education (MDBE) established a mathematics, science and technology (MST) academy so as to address this problem. The academy is mandated to provide environment for innovation and change in the MST education through creative research and teaching by teachers and students. The academy has one school (also known as an MST school) in the each of the four districts of the Province that enrol MSTE students only from grades 8-12. The specific challenges to be addressed by the academy includes:

- inadequate capacity of teachers to develop conceptual knowledge for the MST subjects,
- insufficient facilities in schools that hinders the development of conceptual understanding of the MST subjects.

The argument here is that successful teaching is influenced by sufficient expertise and content knowledge in the subject matter with a conducive teaching and learning environment. Focusing on classroom practice of participants, teacher knowledge and the kinds of instructional strategies they use while teaching the PTE, this paper reports on a qualitative case study that was carried out in the Mpumalanga Province, South Africa. The main research question was *what practices inform Physical Sciences teachers when teaching the periodic table of elements?* In essence, I wanted to know how these teachers teach the periodic table concepts. The purpose of the study was for the participants to reflect on their teaching, hence create an awareness of their perspectives about their teaching of the PTE.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

This study is underpinned by the social constructivism theory (Vygotsky, 1978). As a theory of knowledge and learning, social constructivism views the teaching and learning context, students' prior knowledge and the interaction between student and the context as vital in informing teacher practice (Luera & Otto, 2005). Social constructivists believe that *knowledge* is a human product, and is socially and culturally constructed (Gredler, 2008). Members of a society create meaning through their interactions with each other and with the environment they live in. The emphasis is on the collaborative nature of learning. In school, students interact with teachers, peers, technology and the environment. Students in a social constructivist classroom are considered active agents, responsible for their own learning, enhanced by their interactions with peers, family, and their environment. Classrooms and have less teacher autonomy and are more student centred (Christensen, 2003). Students are also encouraged to use their prior knowledge and experiences, answer questions formulated by them or posed to them for learning to occur. A student, therefore, requires deliberate effort to relate new knowledge to relevant concepts he/she already possess (Luera & Otto, 2005). To achieve this, students work collaboratively to ask questions, explore and assess what they already know. On the side of the teacher, Leach and Scott (2003) posit that teachers' role is "to introduce and support the use of new knowledge on the social plane" (p.102).

Within social constructivism theory, I adopted a *Pedagogical Content Knowledge* (PCK) model that would enable me focus on specific classroom practice aspects of participants especially content knowledge (CK) and Pedagogical knowledge (PK) they use while teaching the PTE. Shulman (1987) defined PCK as the knowledge that includes “an understanding of what makes the learning of a specific topic easy or difficult” (p.9). This is the knowledge that encompasses teachers’ knowledge of representations and instructional strategies in relation to knowledge of student learning, with respect to a specified content area.

Various scholars (e.g. Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Mulholland & Wallace, 2005; Park & Oliver, 2008; Rollnick et al., 2008) have proposed different conceptualizations of PCK, in terms of the features they include or integrate. So far, two elements are central in any conceptualization of PCK, i.e. knowledge of representations of subject matter and instructional strategies incorporating these representations; and understanding of specific student conceptions and learning difficulties with respect to a specified content area. Other scholars (e.g. Mudau, 2013; Roohan, Taconis & Jochems, 2011) contends that PCK is not only about the knowledge of various domains which amalgamate to result in the PCK, but the teacher’s craft is the ultimate variable in the classroom practice for students’ learning.

There seems to be consensus amongst researchers regarding the nature of PCK. Firstly, since PCK is *topic based*, in general sense it is to be distinguished from knowledge of pedagogy, of educational purposes, and of student characteristics. Secondly, since PCK has a focus on the *teaching* of a particular topic, it is likely to differ considerably from subject matter knowledge as such.

METHODOLOGICAL ORIENTATION

This is a qualitative case study. The choice of qualitative approach has been influenced by orientation that I needed to immerse myself into the data in the pursuit to understand what participants see as being significant and important (Creswell, 2014).

The participants’ reflections of teaching PTE was informed by data from five teachers, it can be thought as a collective case study (Stake, 2013). The rationale for using a multiple participant design was to inform the case by generating contrasting results for predicable reasons (Yin, 2015). A purposive sample of five teachers from five MST schools in Mpumalanga Province was used. Of these, two were from urban, two from rural and the remaining one from semi-urban school. These schools were selected purposively to the extent that they were regarded as rich sources of information I intended to gather (Punch, 2013).

All the participants teach Physical Sciences at the Further Education and Training (FET) Band. Within the context of South African education the FET Band includes grades 10 to 12. It also include career-oriented education and training offered in other FET institutions i.e. technical colleges; Vocational, Education and Training (VET) and private colleges. **Table 2** illustrates the characteristics of the participants. I was aware that this sample could not be regarded as a representative of all the Physical Sciences teachers in Mpumalanga Province.

The findings may nevertheless be substantively applicable to other teachers in similar settings.

Table 2. Characteristics of teachers in the study

Teacher	Gender	Highest qualification	Teaching experience	School type	Class size
T1	Female	B.Ed	6	Urban	35
T2	Male	B.Ed	14	Urban	35
T3	Male	M.Ed	12	Rural	37
T4	Male	B.Ed	9	Semi-Urban	37
T5	Male	M.Ed	13	Rural	36

B.Ed : Bachelor of Education
M.Ed : Master of Education

Data collection

The collection of data was done in two phases. Phase one comprised of individual interviews with participants. These interviews took place in participants' respective schools as it was deemed a convenient point for researchers and participants. The interviews sought to elicit information on participants' instructional practices with a specific focus on the teaching of the PTE. Interviews were audio recorded and transcribed verbatim. The duration of the interviews was between 45-60 minutes. Phase two entailed the analysis of documents specifically, the lesson plans, scheme of work and text books used. Document analysis sought to elicit data on participants' readiness to teach the PTE.

Data analysis

The analysis of data was subjected to open, axial and selective coding (De Vos et al., 2011) Open coding was done line by line, followed by axial coding where paragraphs were compared to give precision to a category. Lastly, core categories were selected during selective coding. The analysis was done in two phases. The first phase involved, transcribing the audio-recorded data i.e. individual interviews. Then the transcripts were coded, after having been read several times to get familiar with them. This being a case study of the reflections of five teachers, my emphasis was on the discussion and classification of their views rather than on the teachers themselves. In the second phase data from the document analysis were grouped into categories.

FINDINGS AND DISCUSSION

Management of teaching and learning

The analysis of data revealed that teachers use the scheme of work from the Department of Basic Education (DBE). They get scheme of work through their respective school heads of science department who get it from the senior education specialist in their respective districts. Although most teachers are able to breakdown these schemes of work to suite their planning, they all tend to recycle them each year with minimal or no change at all.

Regarding lesson plans, the majority of teachers in the study plan their lessons weekly with the exception of T1 who indicated that she plans her lessons in a cycle system. T1's school has eight days in a cycle that enables her to see her two grade 9 classes six times in eight days. More interestingly, she uses two different languages i.e. English and Afrikaans; to teach the two classes. The Language of Learning and Teaching (LoLT) in T1's school is both English and Afrikaans. She basically uses one lesson plan that is in English and Afrikaans. When asked about how she manages to balance between the two LoLTs, T1 expressed her dilemma with the science register which sometimes pose threats to teaching and learning of the PTE concepts. She said:

> *"Aaagh... Sometimes I can't find equivalent terminology in Afrikaans, so I use English. To help my students I ask them to make a rhyme using first letters of elements in the periodic table. In this way they are able to remember the elements".*

Like schemes of work, lesson plans are also being recycled from one academic year to another. Regarding text books used to teach the PTE, teachers in the study indicated that they use a combination of at least two text books. The rationale behind this choice is that the two books complement each other. Interestingly, all five teachers in the study used at least one similar text book in spite the fact that the choice of which text book to be used is entirely on a teacher in consultation with the head of science department in the school. All participants indicated that their students have at least a copy of the text book used in class. This was possible because the management of teaching and learning i.e. learning programmes, lesson plans, assessment, moderation, examination etc. in the participating schools is under the MST academy.

Specific teaching and learning difficulties

The abstract nature of the topic

The Majority of the teachers in the study consider teaching the PTE concepts as difficult since the teachers themselves have never seen number of elements in real life. They pointed out that many students struggle to understand the relationship between the numbers of particles in the nuclei. Hydrogen nucleus for example, contains only one proton. However, in the nuclei of all other atoms both, neutrons and protons are present. This abstract nature of the topic poses a threat to teachers' confidence hence they opt for rote learning. Teachers simply ask their students to memorize the periodic table trends and expectations. For instance, some teachers said:

> *"In most cases students assume that nuclei contain as many protons as neutrons, and they memorize this but they get confused when realizing that the nuclei of standard Chlorine atoms cannot have equal numbers of protons and*

neutrons…they [students] connect neutrons with neutralization and they conclude that neutrons have neutralized protons" (T5).

This teacher admit that he finds it difficult to clear this misconception on his students. One could question his content knowledge considering his 13 years of teaching experience. He does not know that the nuclei of atoms with lower atomic numbers such as carbon are composed of equal numbers of protons and neutrons; and that as the atomic number increases; the number of neutrons exceeds the number of protons.

"The majority of them have difficult with the periods and groups in the table [PTE]; even if you tell them that the groups explain the number of electrons in the outer shell…the period determines the number of shells, they don't understand. Then I have to either use division or use some concrete items [models] to explain which is not easy because we don't have a lab and resources (T3).

When asked about measures he takes to respond to the situation, T3 said:

"I sometime improvise though it is not easy. I bring my laptop and let them watch online documents and videos to support the teaching and learning of these concepts. I use my own internet facilities even for other school activities…I also use PhET interactive simulations… a white board or interactive board in my teaching".

"I don't have many problems in teaching Periodic table. Only some lazy students they don't by heart remember symbols of elements (T2).

When asked about measures he takes to respond to the situation, T2 said:

"I use that chart [pointing at it on the class wall] as you can see everything is coloured so they can see metals, non-metals and gases. I sometimes give them the names and I ask them to write the symbols or the other way round. Then slowly I introduce them to balancing equations and writing formulas".

The extracts above show that translating abstract concepts into understandable ideas is one of the major challenges for these teachers of science. Their responses raise questions of their PCK, and of relevance of science learning. The strategies used by these teachers to enhance students' conceptual understanding as well as their skill of transforming the subject content in order to make it teachable, is also in question. Though teacher T3's school is rural, he indicated the use of models and the Physics Educational Technology (PhET) simulations to enhance understanding of the PTE concepts. Other teachers regardless of their school locations being urban or semi-urban emphasized *memorization*. This finding does not support Deal and Peterson's (1999) study which found students from rural communities lack academic ability and that this negative discourse exists among rural school teachers.

All the five participating schools were MST schools equipped with white boards and internet connection, but teachers T1, T2, T4 and T5 were not competent enough in teaching the PTE concepts using either PhET simulations, white board technology or any model in their teaching. They are technologically challenged. In fact, their teaching relied heavily on the text books and sometimes on the PTE charts that were too old and untidy. Such practices may pose threats to the current notion of reform science teaching.

Furthermore, participants' teaching of PTE concepts was not linked with students' everyday life. Although students interact with many elements (e.g. Aluminium, copper, iron, carbon, silver, oxygen, fluorine, chlorine, etc.) in their everyday life, none of the participants spoke of linking school science and everyday life. It is like the elements in the PTE exist in a different planet. This failure of the teachers to link school science with students' everyday life may hinder students from developing interest in studying the topic and science in general. This teaching approach raise questions on teacher education, their PCK and teacher readiness to embrace change.

Students' progression

CAPS encourage the incorporation of prior knowledge in science teaching and learning. For the science teachers this requires them to consider the elicitation of prior knowledge and learning preferably when introducing a new lesson to encourage continuity and progression of concepts.

> *"My students have difficulties with identifying chemical symbols, writing electronic configurations, identifying positions of elements in the PTE. Since they start learning about atoms and symbols in grade 8, but you find that when they come to grade 10 they don't even recognize most of the common symbols taught in grade 8. If you look at the CAPS document it goes back up to primary school, so it makes me wonder what is happening lower grades" (T3)*

CONCLUSION

Reflecting on the teaching of the PTE helped to identify difficulties, deficiencies and gaps on the delivery of Physical Sciences curriculum. It further provided some information regarding measures needed to promote understanding of science concepts more especially the PTE concepts. Teachers in the study generally held positive attitudes about teaching the PTE. However, their positive attitudes are challenged by reforms in the teaching professional. These includes use of technology for teaching science and teaching approaches that are more student-centred. They were also concerned about the level of support from the DBE and that scheme of work given to them not being in line with the pace setter. These are matter of concern not for the teaching of the PTE, but for the teaching and learning of science in general.

I also noted that, teachers are struggling to link PTE concepts with students' everyday life. Mpumalanga Province has a number of mines. One would expect teachers to refer to mines and mining activities in the region as a way to enhance understanding. In contrast, students are forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks for the sake of passing tests and examinations. This could be one factor that many students are repelled to take MST subjects.

RECOMMENDATIONS

This study has shown that, despite the fact that most elements in the PTE are common in everyday life; teachers have limited knowledge about them. If South Africa is to make significant advancements in science education, the study recommends new strategies to address the needs of thousands of science teachers. Professional Development Programmes (PDPs) for science teachers have little impact in giving teachers the specific content knowledge they need. Both, facilitators and teachers need a deeper understanding of CAPS content. I argue that, although an understanding of teaching and learning is crucial, teachers cannot teach what they do not know. These PDPs need not to be to be tailor-made; instead they should be structured in such a way to address specific challenges faced by the teachers.

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