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High School Chemistry Teachers' Scientific Epistemologies and Laboratory Instructional Practices

Elaosi Vhurumuku

Marang Centre for Science and Maths Education, School of Education, University of Witwatersrand, Number 27 St Andrews Road, Parktown, 2050, Johannesburg, South Africa
E-mail: elaosi.vhurumuku@wits.ac.za

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ABSTRACT This qualitative study investigated the translation of two High School Chemistry teachers' scientific epistemologies into laboratory work instructional practices. The teachers' epistemologies on selected aspects of nature of science (NOS) and nature of scientific inquiry (NOSI) were elicited through semi-structured interviewing. Their laboratory instructional practices were obtained through observation of laboratory work sessions and reflective interviews. The findings reveal that the manifestation of a teacher's scientific epistemologies into laboratory work instructional practice is complex, and governed by factors in the instructional environment as well as other beliefs embedded within the teacher's conceptual ecological system. It is argued that the translation of a teacher's beliefs into practice is a conscious activity during which the teacher weighs and balances cognitive and epistemic factors and makes judgmental decisions about the merits and demerits of instructional action. It is concluded that teachers put their scientific epistemologies into practice, but only to a small extent.

INTRODUCTION

Understanding the nature of interaction between teacher beliefs and instructional practices is a major research issue in contemporary education (Borg 2015). Teacher beliefs comprise a complex, interrelated system of personal knowledge, assumptions, implicit theories, attitudes, and cognitive maps that are said to guide teacher instructional decision-making and action (Pajares 1992). The many beliefs that teachers hold have been identified and classified (Lumpe et al. 2000; Nespor 1987; Schraw and Olafson 2002). They include beliefs about the nature of knowledge and the processes of knowledge development and validation (epistemological beliefs), teaching effectiveness, teacher-efficacy, students and student learning, and the purpose of laboratory work.

During the last four decades, research into the interaction between teachers' beliefs and classroom instructional practices has produced contradicting findings with some results showing that relationships exist (for example, Brickhouse 1989; Gwimbi and Monk 2002; Hashweh 1996; Kang and Wallace 2005; Schraw and Olafson 2002; Tsai 2007) and others showing that teacher beliefs are not related to classroom practices (for example, Abd-El-Khalick et al. 1998; King et al. 2001; Lederman and Ziedler 1987; Mellado 1997). A recent study by Shi et al. (2014) found that the classroom practices of novice teachers are not always consistent with their espoused beliefs. It appears that the relationship between teacher beliefs and instructional practices is still both contentious and not clearly understood. For that reason, it remains an important research issue (Shi et al. 2014; Kim et al. 2013; Borg 2015). The study being reported in this paper is an attempt to understand the relationship between teacher scientific epistemologies and instructional practices utilizing a fusion of teacher beliefs and instructional practices theory with the interactionist conceptual ecology model. This fusion provides an interpretive lens for understanding the manifestation of teachers' beliefs into Chemistry laboratory instructional practices.

Sandoval (2005) defines scientific epistemologies as the constellation of beliefs, images, preconceptions, dispositions, views, perceptions and convictions concerning the nature of scientific knowledge and the nature of scientific inquiry, harbored by an individual. Scientific inquiry is the process of development and validation of scientific knowledge (Schwartz et al. 2004). Essentially, the present study investigates the interaction between the teachers' beliefs about nature of science (NOS) and nature of scientific inquiry (NOSI) (Bartos and Lederman 2014) and teacher instructional practices. For this study, these beliefs are collectively called scientific epistemologies. According to Bartos and Lederman (2014: 1153), some of the understandings of NOS secondary school teachers and learners are expected to have are:

1. Scientific knowledge is empirically based;
2. Observations and inferences are qualitatively distinct, in that the former are directly accessible to the senses, while the latter is only identified through its manifestation or effects;
3. Scientific theories and scientific laws are different types of knowledge;
4. The generation of scientific knowledge requires, and is a partly a product of, human imagination and creativity, from generating questions to inventing explanations;
5. Scientific knowledge is theory-laden (that is, influenced by scientists' prior knowledge, beliefs, training, and expectations);
6. Scientific knowledge both affects and is affected by the society and culture in which it is embedded; and
7. Scientific knowledge, while reliable and durable, changes (From Bartos and Lederman 2014: 1153).

Some aspects of NOSI secondary school teachers and learners are expected to understand are:

1. Scientific investigations always begin with a question;
2. There is no single set or sequence of steps in a scientific investigation;
3. The procedures followed in an investigation are invariably guided by the question(s) asked;
4. Scientists following the same procedures will not necessarily arrive at the same results;
5. The procedures undertaken in an investigation influence the subsequent results;
6. Conclusions drawn must be consistent with collected data;
7. Data is not the same as evidence; and
8. Scientific explanations are developed through a combination of evidence and what is already known (From Bartos and Lederman 2014:1153-1154).

Teachers and learners who do not harbor such understandings can be described as having inadequate knowledge, naive and traditional (Wallace and Kang 2004; Lederman et al. 2014; Pomeroy 1993).

To achieve the goals of developing desirable learners' understandings of both NOS and NOSI, Duschl and Grandy (2012) advocate that explicit teaching and learning about NOS and NOSI should not be separated from the practice of science as inquiry. This entails teaching laboratory work. Rudolph (2003) argues that the laboratory is the best place for developing and nurturing the learners' ideas about NOS and NOSI. This is supported by Van Dijk (2014) who alludes to the fact that the process of developing the learners' scientific epistemologies should not be separated from their studying science as inquiry including what happens in the school science laboratory. Wong and Hodson (2008) suggest that the best way of developing learners' understanding of scientific inquiry is involving them in authentic laboratory inquiry. Vhurumuku (2004) concurs and mentions that the Chemistry laboratory could be one of the best places for teaching about NOS. Aydin (2015) alludes to this fact and alludes to Chemistry teaching as a conduit through which teaching about NOS and NOSI can be done. This is especially so when Chemistry subject matter knowledge and teacher NOS understandings support each other. This is further supported by the findings of Demirdögen et al. (2015), which reveal that in order for a teacher to explicitly or implicitly teach about NOS that teacher must have adequate understanding of NOS. A teacher's understanding of NOS and NOSI is part of his/her scientific epistemology. The reform of Chemistry laboratory teaching practices is a priority on the agenda for science education in many parts of the world. Consequently, it is important to understand and explain how exactly Chemistry teachers' scientific epistemologies translate into instructional practices so as to inform both the practice and theory of Chemistry education. It is against this background that the study being reported here contributes to the understanding of the interface between teachers' beliefs and teaching practices.

Study Objectives

Given the contentious nature of the interaction between teacher beliefs and their instructional practices, the present study sets out to explain the process by which teachers' scientific epistemologies translate into classroom instructional practice, within the context of Advanced Level Chemistry laboratory work. Additionally, it seeks to unravel some of the factors that come into play at the teacher belief and instructional practice interface. Understanding these factors can be particularly valuable to those involved in curriculum development and innovation for both Chemistry teacher training and secondary school Chemistry teaching. In order to achieve the study objectives the following research questions are posed:

1. What are the A-level Chemistry teachers' scientific epistemologies?
2. What is the nature of the teachers' laboratory work instructional practices?
3. To what extent do teachers' scientific epistemologies influence laboratory instructional practices?

Theoretical Framework

Interactionist Conceptual Ecology Model and Teacher Instructional Practice

From an interactionist conceptual ecology perspective (Strike and Posner 1992; Southerland et al. 2006), scientific epistemologies are part of an individual's conceptual ecological system. The conceptual ecological system encompasses metacognitive, motivational and affective attributes, including scientific epistemologies, beliefs about teaching and learning, teacher attitudes towards students' capabilities and teacher perceptions of the teaching and learning environment, all of which influence teaching (Posner et al. 1982). Beliefs are part of an individual's conceptual ecology. Verjovsk and Waldegg (2005) define beliefs as those cognitive constructs, with episodic roots based on personal experience, which the individual accepts as true. This is in line with Nespor (1987) who describes beliefs as existential presumptions or personal truths generally unaffected by persuasion and tilted more heavily towards the affective and evaluative side. Beliefs are inseparable from human existence, personal experience and action.

Although teachers' experiences and actions belong to the social and are physical, they are actually part of the belief system as a whole (Wallace and Kang 2004). Teaching experiences and actions are part of episodic memories, knowledge and feelings, which feed into, and interact with, the teacher's belief system. Teachers' knowledge and experiences based on actual classroom practice form part of what has been referred to as "practical theories of teaching" or practical knowledge (Lotter et al. 2007). In addition to this contextualized knowledge of the classroom, the teacher also utilizes constructed knowledge of the subject matter. As human beings who experience phenomena, teachers also make use of incoming perceptual data. Audi (1998) is of the view that perceptual data is linked to and feeds directly into the belief system of an individual.

Within the teacher's conceptual ecology, beliefs relate to each other and can influence one another. This relationship can lead teachers to perceive, and act on information in different ways (Lotter et al. 2007), influencing classroom decisions, and instructional actions. As part of the belief system, instructional environment factors (time, resources, administrative requirements) can also influence teacher decision-making and instructional practice (Tobin et al. 1990). Tobin et al. (1990) use the term "constraints" to refer to this. Along the same lines, Lumpe et al. (2000) describe how teachers' perceptions of responsiveness of their teaching environment for their effective practice as 'context beliefs'. Context beliefs are about how the entire environment in which instruction occurs influences teaching behavior and action. This environment includes students, other teachers, administrators, "institutions, organizations and the physical environment" (Lumpe et al. 2000: 278). The various types of teacher beliefs are said to compete with or against each other in mediating instructional practice, behavior and action (Kang and Wallace 2005). There is also the possibility that different beliefs could interrelate in such ways as to reinforce or favor certain classroom behaviors and actions by the teacher.

In line with the above described interactionist perspective, Tsai (2002) describes teachers' scientific epistemologies as being "nested", meaning that teachers beliefs about scientific knowledge and scientific inquiry are related to and interact with other beliefs within the ecological system (Southerland et al. 2006). These include beliefs about teaching, learning and student abilities. A logical consequence of the interactionist conceptual ecology model is that components of the ecological system act on each other. The action can be part of a rational process during which individuals account for their perceptions, compare competing ideas and make evaluative decisions about preexisting conceptions (Southerland et al. 2006). For practicing teachers this implies an ecologically embedded belief driven decision-making process, and a socio-cognitive process that includes problem identification, reflection and action. Duschl and Wright (1989) are of the view that teacher decision-making determines their instructional behavior consciously or unconsciously.

Some studies have shown that other than scientific epistemologies, teacher classroom decision-making, behavior and actions are mediated by a plethora of other factors including the nature of the curriculum, the nature of students, school administrative requirements and the availability of teaching and learning resources (Demirdögen et al. 2015; Gess-Newsome and Lederman 1995; Southerland et al. 2003). It is also known that in their classroom practices, teachers might act in ways, which are contrary to their espoused beliefs (Shi et al. 2014; Southerland et al. 2003; Wallace and Kang 2004).

As already noted, this study advances an explanation of the interaction between Advanced Level Chemistry teachers' scientific epistemologies and their classroom actions. Empirical data is drawn from a combination of interviews and Chemistry laboratory class observations.

METHODOLOGY

Participants

The participants were two Zimbabwean teachers of Advanced-level (A-level) Chemistry teaching for the last two years in a high school in Zimbabwe. For ethical reasons, the teachers are presented here under the pseudonyms, Zivanai and Abongile.

Zivanai was a 33-year-old male who had been teaching A-level Chemistry for six years. He held a Bachelor of Science Education degree equivalent (Lic. Cert Enrique, Jose Varona University, Cuba). Zivanai is a product of the Zimbabwe-Cuba Teacher Training Program and was qualified to teach both Mathematics and Chemistry at Advanced level (A-level). His teaching load also included classes in O-level Physical Science and Mathematics for younger students.

Abongile was a 23-year-old female and a professional neophyte. She had just graduated from the Bindura University of Science Education (Zimbabwe), with a Bachelor of Science Education degree majoring in Chemistry and Mathematics. Like Zivanai she was qualified to teach both Chemistry and Mathematics up to A-level. This was her first year of experience as a qualified science teacher and of handling an A-level Chemistry class. Abongile was interested in proving herself as an effective teacher. She is a strict disciplinarian as revealed by the manner in which she emphasized accuracy of students' experimental results and punctuality to laboratory sessions.

Data Collection

For the current study, the scientific epistemologies explored included the purpose of experiments in science, the nature of scientific observations, the source of scientific knowledge, the validation of scientific knowledge, the tentative nature of scientific knowledge, and the cultural 'contextuality' of scientific knowledge. These aspects were chosen because of their relevance to Zimbabwe A-level Chemistry education. In order to get information about teachers' beliefs about NOS and NOSI, that is, their scientific epistemologies, each teacher was asked a set of core questions around which probing for clarification and deeper understanding was done. The semi-structured interview questions (see Appendix A) were drawn and synthesized from the literature (Ryder et al. 1999; Vhurumuku et al. 2006). All interviews were audiotaped and transcribed verbatim.

Teacher laboratory instructional practices were investigated through laboratory class observations and in-depth reflective interviews. Teaching materials, such as, laboratory manuals, exercises and assessments guides were also examined. Semi-structured, non-participatory observation (Cohen et al. 2000) was done (see Appendix B for observation guide). The aim was to capture as much as possible of the laboratory class events. Each teacher was observed for four consecutive laboratory sessions, teaching different laboratory work content areas. About one week before each laboratory session observation, the teacher was asked to avail a copy of the laboratory work task that was to be done. The teacher also briefed the observer (researcher) on the approach he/she was going to use and provided the marking guide by which he/she was going to assess the students' reports.

At the end of each laboratory class observation, the teacher was interviewed based on his/her lesson delivery. The purpose of questioning was to get clarifications and further understand the teacher's actions and reasons and justifications for those actions. Probing was also done with the aim of making the teachers reflect on both their scientific epistemologies and instructional practices. Additionally, each teacher was asked to provide responses to the following questions: 1. Can you briefly describe your teaching of A-level Chemistry laboratory work? 2. Do you think the way you teach Chemistry laboratory work helps students understand what science is all about? All interviews were audiotaped and transcribed verbatim.

Teacher interviews and laboratory class observations were done during the first term of the A-level Chemistry Upper Sixth year. In Zimbabwe, A-level is studied over a two-year period. The first year is called Form 5 or Lower Sixth and the second year is called Form 6 or Upper Sixth. Students write their final examination at the end of the second year. Schools run for three terms a year. The duration of each term is about 90 days.

Data Analysis

Data was qualitatively analyzed through a combination of analytic induction (Murcia and Schibecci 1999; Lincoln and Guba 1985) and interpretive analysis (Thorne et al. 1997; Gall et al. 1996). In analyzing the teachers' scientific epistemologies, each respondent's responses to all the questions were repeatedly read and emerging themes/units of meaning coded and recoded. Data from the post laboratory session interviews was similarly read and reread and units of meaning coded and recoded. The objective here was to get insights into the teacher's decision-making process and instructional practice at the conceptual ecological level. For each teacher, all the data, that is, from scientific epistemologies interviews, laboratory session observation notes, and post laboratory session interviews were also read and reread with the objective of getting a holistic picture of the teachers' scientific epistemologies and instructional practices as well as look for patterns that might suggest links or associations between scientific epistemologies, decision-making and instructional action. At the bottom of the data interpretation was an effort to answer the questions: What could have driven the teacher to teach in the way he did? What could have been going on in the mind of the teacher? What factors could have influenced the teacher's decision-making and instructional action? How can the data be given meaning from the point of view of interactionist conceptual ecology theory? What could have been happening in the conceptual ecological system of the teacher? In what ways were the teacher's scientific epistemologies influencing teacher behavior and action? There was a deliberate effort to isolate the scientific epistemological issue in question and make inferences concerning it being reflected in teacher laboratory instructional actions. This meant going back to listen to the audiotaped interviews and reading and rereading the transcribed texts. Thorne et al. (1997) advise that the major focus of this kind of analysis and interpretation should not be simply sorting and coding but synthesizing, reconceptualizing and theorizing. In line with this, there was a deliberate effort to search for patterns and strands of linkage between or among the various pieces of information. Meaning making was done, and reasonable inferences made based on action, behavior and speech. The researcher and an experienced science educator in the same University with the researcher carried out coding and recoding of the responses independently. All the final meanings and interpretations were a result of consensual agreement.

RESULTS AND DISCUSSION

The findings are presented under the headings teachers' scientific epistemologies, teachers' instructional practices, and the manifestation of teachers' scientific epistemologies into laboratory work instructional practices.

Teachers' Scientific Epistemologies

Zivanai

On the issue of the purpose of experiments in science, Zivanai gave a response, which could be described as having taints of both realism and constructivism. To realists science is done for purposes of discovering new knowledge for knowledge's sake, so as to quench human curiosity. Constructivists are of the view that science should be pursued to solve human problems of needs and wants, for example, curing of diseases and producing more food (see, Matthews 2015). When asked, "Why do scientists do experiments?" his reply was:

Z: *The reason why scientists do experiments is out of curiosity or to find why certain things happen and for development purposes, for example produce a new product like polymers or a new drug, which can be of use to man.*

Zivanai was also of the view that scientists' theoretical backgrounds affect their observations and interpretation of evidence. This is illustrated in the interview extract below:

Z: If you have a theory, observations maybe biased towards the theoretical background. There are instances where you can do away with that through experience.

I: Are scientific observations objective?

Z: I think there are instances where they can be objective but we can't get rid of our beliefs when carrying out observations. There is a certain percentage of objectivity but there is always that subjectivity.

According to Bartos and Lederman (2014), such an understanding of the nature of scientific observations by teachers is desirable. To Zivanai, scientific knowledge could come from a variety of sources including experiments and observations. He acknowledged the role of imagination and creativity in the generation of scientific knowledge. His thinking about the role of culture and how scientific knowledge is validated is reflected in the interview extract below:

Z: Usually its beliefs which are cultural, for example the cold war between Soviets and Americans. When scientists work together, without cultural conflicts, consensus is usually arrived at. To a large extent our science in Africa is considered inferior. The chemicals we produce are not considered to be of scientific value.

I: How do the scientists arrive at consensus?

Z: I think they sit down and talk and come to one point like Americans coming together with the Russians.

These responses point towards a generally acceptable understanding regarding NOSI, namely the influence of culture and political nature of the development of scientific knowledge as well as how disputes are settled within the scientific community. On whether scientific knowledge was static or dynamic, Zivanai was of the view that scientific knowledge changes, was tentative and revisionary. He went on to explain that advances in technology bring about a better understanding of nature and leading to abandonment of old theories and the generation of new ones. Consistent with the expected desirable understandings (Bartos and Lederman 2014), he had the idea that scientific knowledge was both tentative and durable. This is part of what he said:

Z: What we can call a theory can be untrue in future. Some theories can stand the test of time but in many areas there is a lot to learn. For example, the Periodic Table is one area in Chemistry where… We are still synthesizing elements maybe one day someone will rearrange the elements.

Abongile

When answering the question: "Why do scientists do experiments?" Abongile gave a response, which can be described as inadequate, naïve, traditional or verificationistic (Wallace and Kang 2004; Matthews 2015; Pomeroy 1993). She said:

A: To verify some concepts, to show that what is said is really true. Vanenge vachida kutaridza kuti ruzivo nderwe chokwadi [Shona for "They would want to show that knowledge is really true"] *or maybe to explain some phenomenon*.

Unlike Zivanai, Abongile was of the opinion that scientific observations were objective. Her meaning of the term objective however appeared to be the same as that for the term real:

A: They [observations] *are objective because eee... what you observe and what actually happens is one and the same thing.*

I: Can different scientists make different observations on the same thing?

A: They should see the same things if they all observe carefully.

Her views on the source of scientific knowledge can be described as inductivist and positivist. According to her, experiments and observations were the key sources of scientific knowledge. Scientists performed experiments and came to valid conclusions. Contrary to contemporary understandings of NOSI and NOSI, she saw little roles for dream and imagination in the generation of scientific knowledge (Bartos and Lederman 2014)

A: At times you get reactions, but at times you get some result and you have to explain *why you get those results. So by observing, they may be doing some experiment with a control of some sort and then they come to make a conclusion and say it's like this.*

I: What about just imagining?

A: Even dreaming, but all the same you have to back what you say by doing experiments…so really it's experiments that matter.

Although she agreed that scientific knowledge could change in the light of new evidence, she did not believe in the role of consensus in the authentication and legitimization of scientific knowledge. To her, experiments and observations were the cornerstones in the validation and legitimization of scientific knowledge. She further argued that scientific truths were universally and culturally free, because they were based on experimental evidence.

Teachers' Laboratory Work Instructional Practices

Results from the laboratory session observations and interviews capturing the instructional practices of the two teachers are summarized in Table 1. The Table was constructed from the analysis of data from the post laboratory session interviews and laboratory session observations. It captures the main strategies used by the teacher in executing laboratory work, such as, starting with laboratory work and following it with discussion of theory, using teacher demonstrations, organizing problem-solving activities, verificationistic laboratory activities and organizing group or individual practical activities, the level of student-student interaction, the level of inquiry, and what the teacher mentioned to be the major constraints to teaching.

In the next sections, the teachers' instructional practices are further described.

Zivanai

Zivanai had been teaching A-level Chemistry for six years. He said that he would enjoy his teaching, as he loves the profession, but that the acute shortage of essential reagents and chemicals for the effective teaching of A-level Chemistry was increasingly frustrating him. As is the case in many of Zimbabwe's high schools the country's economic problems are inevitably bearing on the teachers' classroom practices. Zivanai succinctly captured the sad scenario:

Z: A hundred grams of silver nitrate can cost the equivalent of my monthly salary. So you see, most of the time you really don't teach the way you want. Some practical experiments you simply avoid because they are unaffordable, especially for a school like this one. You do the best you can but hey…

Zivanai believed that laboratory work should train students to become scientists in their own right. When asked: *"What is the aim of school Chemistry laboratory work?"* he replied:

Z: To boost the understanding of scientific concepts and also train them for life so that they are able to solve problems so that they can find solutions. They can actually solve problems of a scientific nature because they have learnt skills of a scientific nature.

His general strategy in teaching A-level laboratory work was that he started by demonstrat-

Table 1: A summary of the teachers' instructional practices determined from laboratory work sessions observations and interviews

Teacher	*Most important objective of*	*Main strategies*	*Level of interaction*	*Level of inquiry*	*Mentioned constraints*
Zivanai	- Develop students' and understanding of theory Examination preparation	- laboratory work then theory - group -practicals -teacher demonstrations - problem solving	High student -student interaction	low inquiry	-Examinations -Syllabus content -Resources
Abongile	Examination preparation	- Verificationistic - Guided discovery - practical to theory - Individualized practical work	Low student -student interaction	VeryLow inquiry	-Syllabus content -Examinations -Resources

ing the use of equipment including manipulations of apparatus. Students were then assigned to work on practical activities in small groups with the teacher moving from group to group giving assistance where required. After a few laboratory sessions and when he was satisfied that the requisite laboratory skills had been mastered by the students, he gave the students individual practical work. He gave his rationale:

I: What methods do you normally employ in teaching laboratory work?

Z: It depends on the stage, for example when they are in Lower Sixth they need lots of assistance from the teacher. I demonstrate the use of equipment, they work in small groups and this is not for evaluative purposes…we change stages in Form 6 we gradually get to the individual. We expect them to be scientists in their own right. They must learn to have their own results.

For all the four observed lessons, Zivanai's pattern of instruction was basically the same. Typically, he would start by introducing the day's laboratory task. Almost always these tasks were sourced from past examination papers. During the pre-laboratory talk the students listened and wrote notes. They took the form of going through the laboratory worksheet with the students, with the teacher explaining the distribution of apparatus and reagents. Although the laboratory exercises were to be done individually, the students were told that they were free to exchange information and discuss their results during the practical. Students asked questions pertaining to aspects of the practical as they read about it from the worksheet. Students started working on the laboratory activity. The laboratory assistant was present all the time and assisting students with manipulations of apparatus when appropriate. In one of the laboratory sessions, the assistant was seen to spend some time with a student who was struggling with using the pipette filler. In all the sessions, students were observed to work quietly at first but the laboratory became noisy as the laboratory session progressed. Meanwhile, the teacher would disappear into his office, which was adjacent to the laboratory. The noise level would rise. Occasionally the lab assistant shouted at the students "Hey guys too much noise". Students were seen to share ideas and ask each other questions. The girls generally appeared to be less talkative and more self-centered and individualistic than the boys. They also appeared to be less confident in following the procedures of the laboratory exercise. During the first observed laboratory session, students were seen checking on each other's titers. One student whose volume was much different from the others went back to repeat a titration. The teacher would occasionally pop in from his office to check on the students' progress. He would move around the class making stops here and there. Students would be reminded that their laboratory reports should be handed in by the end of the following day. After collecting and marking the students reports the teacher would then discuss the practical during one of the theory lessons.

Abongile

As already mentioned, Abongile had just come out of university (1 year experience) and was handling her first A-level class. Abongile was interested in proving herself as an effective teacher. When asked what she thought was the main purpose of school Chemistry laboratory work, she earnestly replied that it was to prepare students for examinations. The development of the students' understanding of the subject matter was only important if it aided the examination preparation goal. She always emphasized accuracy of experimental results and following of instructions. During one of the observed laboratory sessions, a student raised a complaint about the mark he had been given by the teacher for one of the answers to the post laboratory questions. Abongile had this to say to the student:

A: Robert [not the student's real name]…eee you are one of those who failed to follow instructions. Now if you don't read the instructions carefully you mess up. I always say first read and understand the instructions then go on to do the practical. It's mistakes like yours, which can lead to inaccurate results. By the way your question again?

During the fourth observed laboratory session, one of the problems of investigation was the separation of magnesium and copper ions from a solution labeled FA7 (a mixture of magnesium nitrate and copper (II) nitrate) using sodium hydroxide, sulphuric acid, distilled water, test tubes, filter funnel and filter paper. Students were required to design an experiment to achieve the separation and go on to identify the ions in the separated precipitates or solutions. Students were given a handout outlining the problem for investigation. The problem in question was from a past examination. Students were asked to do the practical individually. The teacher emphasized that it was to be individual work and no exchange of ideas or any form of unnecessary interaction was going to be tolerated. Each student was provided with a set of core reagents and apparatus. Chemicals to be shared were made known to the students and their place of source indicated. The laboratory assistant was in attendance.

Students went on to do the laboratory task. The teacher moved around the class whispering assistance to some students. When one of the students was making a serious error, the teacher stopped the class and boomed at the students:

A: Now you people, what did I say about adding reagents in qualitative analysis. I said little by little not a whole bucket at a time. If you don't follow instructions your results will always be inaccurate or wrong.

The students continued with the practical still with not much interaction. At the end of the session, Abongile collected the completed worksheets. She was going to mark them putting a lot of emphasis on accuracy of observations. If the marking showed that the students had problems with the practical she would come back the following session and start by performing a demonstration. She said she always wanted the students to do the laboratory exercise first then she could follow it up with class discussions or demonstration or both. When she had marked the students' scripts, she came back in the following laboratory session and started by reviewing the students' answers. She reported that one quarter of the students had done well. Most had failed to follow instructions. The teacher went on to propose and demonstrate her own method for separating copper ions from magnesium ions. The students said the teacher's method for separation of ions was good. Abongile challenged students who thought their method was good to come forward and share it with the class. None of the students volunteered. Instructions for the day's laboratory exercise were given and students went on to do the laboratory exercise. As usual this was strictly individual work. The problem had again been sourced from a past examination paper and no student-student cooperation was encouraged.

The Translation of Teachers' Scientific Epistemologies into Laboratory Work Instructional Practices

Zivanai held strong beliefs about science as progressing through consensus and that scientists are creative. In his practice however, Zivanai is seen to struggle against an "unfriendly" instructional environment and still make decisions and do practices he believes can bring about students' understanding of science and how it is practiced. In line with the findings of Shi et al. (2014) and contrary to his beliefs, he is observed to organize group activities and encouraged students to engage in scientific discourse. Overall, however, there appeared to be some link between some of his scientific epistemologies and his instructional decision-making and instructional practices (Borg 2015). Zivanai explained his instructional actions identifying some constraining variables responsible for him not teaching exactly according to all his beliefs as suggested by Shi et al. (2014) and as found from results of Demirdögen et al. (2015).

Z: We repeat experiments whose results are known rarely do we ask students to be creative. Our education system is examination oriented there is little room for students to be creative…to act like real scientists.

Zivanai's actual practice, when teaching laboratory work, can be described as a balance between what he believes in and what the instructional environment allows him to do. In his instructional practice he attempts to develop the students' manipulative skills and allow students to be creative but, the extent to which he can do so appears to be limited by factors in the instructional environment, the syllabus content, lack of resources and examinations (Shi et al. 2014; Demirdögen and Hanuscin 2015). When asked whether the way he was teaching laboratory work made students understand scientific inquiry as he understood it he replied:

Z: You don't always teach the way you want science to be like because of these examinations and the syllabus, and also sometimes you don't have resources. It's not always about what you believe, not in our system.

This is in line with the findings of Shi et al. (2014) that teachers can practice contrary to their espoused beliefs. His actual practice appears to be guided by effort to balance the realities of the instructional environment (the curriculum, resources, examination) and his own beliefs and orientations about what science is and how it should be taught. He is seen to be trying to give students a feel of inquiry, as he understands it. This supports assertions (Abd-El- Khalick and Lederman 2000; Lotter et al. 2007) that the translation of teachers' scientific epistemologies into instructional practices is difficult because of intervening variables or barriers (Tobin et al. 1990). From what Zivanai is saying and watching him teach, it appeared that some factors in the instructional environment inhibited the translation of some of Zivanai's scientific epistemologies into laboratory instructional practice. In this case, the translation of teacher scientific epistemologies into laboratory instructional practices is determined by what the teacher sees as the reality in the instructional environment.

In the case of Abongile, the translation of a teacher's scientific epistemologies into instructional decision-making and practice also appears to suffer from the influence of factors embedded within the teacher's conceptual ecology. There was an association between her beliefs about inquiry and her instructional practices (Borg 2015). When asked to explain what she understood by laboratory inquiry Abongile had this to say:

A: I think eee…it is how scientists gather information or can I say discover things. It's how scientists show that or obtain new knowledge and showing by experiments that that knowledge is actually true.

I: You are talking about what scientists do but what about here in your laboratory with your students?

A: Here we want students to learn by doing experiments so that they pass the examination.

There is an apparent link between believing that scientific inquiry is about scientists "showing by experiments that knowledge is actually true", that school laboratory inquiry helps students "learn by doing experiments" and Abongile's practice of instruction, which is mainly verificationistic and examination focused (as witnessed during the laboratory session observations—individualistic and very low student-student interaction). This also appears to be in line with her belief in one method of science. Her beliefs about what makes a good teacher that is one whose students pass the exam, appears also to have a great influence on how she teaches. Abongile's beliefs about the purpose of experiments in professional science and what makes a good teacher also appears to be linked to her beliefs about the purpose of experiments in school Chemistry. This is not surprising, since the teachers' epistemological beliefs have been shown to be related to teachers' beliefs about teaching (Borg 2015).

What appears to be the case with the teachers studied here is that the extent to which the teacher's scientific epistemologies filter onto the laboratory instructional practice is reduced by the factors in the instructional environment such as examination demands and availability of resources. The effect of these factors is to make the teachers not to teach science "the way you want" or not always to teach, "what you believe". As the teachers' instructional practices and the interview transcripts suggest their practices appear to be in reconciliation between their scientific epistemologies and their perceptions of the environmental factors in which they operate, that is, the contextual factors or barriers or constraints (Demirdögen et al. 2015). Interestingly, in the case Abongile, so-called constraining variables appear to actually foster filtration of verificationistic scientific epistemologies into laboratory practices, which are teacher centered. In this case, the examination-focused curriculum actually promotes manifestation of a teacher's traditional scientific epistemologies into practice. In this case, it is not exactly a constraint. The influence of instructional environment factors appears not to always discourage the translation of scientific epistemologies into instructional practice.

Previous studies (for example, Tsai 2002, 2007) have pointed towards the teachers' harboring of non-traditional (constructivist) beliefs as meaning engaging in teaching practices that are also constructivist or open-inquiry oriented. The actions of the teachers in this study fail to fully support that view. However, it appears that there was constant conflict between the teachers' beliefs and the realities of their teaching contexts. In deciding the nature of his/her practice, the teacher appears to strike a balance between those convictions embedded within his/her conceptual ecology and factors obtaining in the environment in which he/she is operating as a teacher. The expression of some of the teachers' scientific epistemologies appears to be both weakened (Zivanai) and in some cases strengthened (Abongile). It looks like what eventually filters from scientific epistemology into teacher laboratory instructional practice is determined by the effect or influence of both environmental factors and other beliefs already embedded in the teacher's conceptual ecology. Teacher instructional practices here appear to be governed by conscious effort to balance both environmental factors and the influence of other beliefs in the teacher's conceptual ecology. Judgmental decisions are made about the merits and demerits of instructional choices. The teacher appears to be constantly asking him or herself: *"Under these circumstances could this be the best approach to use?"* The teacher reflects on the nature of his/her instructional practice. They think about and continuously locate features of the instructional environment context into their conceptual ecosystem, an ecological system that is replete with interacting factors. The translation of a teacher's scientific epistemologies into practice is complex because all factors are interrelated. They all might have an influence on each other.

CONCLUSION

The teachers' perceptions of their instruction provide reflective and evaluative mirrors through which they can make judgments about the merits and demerits of instructional decisions that is, their scientific epistemologies. Because teachers continuously reflect on their instructional practices, the translation of scientific epistemologies into practice is not a subconscious activity but a conscious purposeful activity feeding into daily decision-making and instructional practice. Previous studies suggested that teachers with constructivist science epistemological beliefs tend to utilize student-centered pedagogies where the student-student interaction is high. The same studies link harboring naïve or empiricist or traditional scientific epistemologies with use of teacher centered pedagogies. The results of this study do not support such a direct linkage. While the teacher might hold naïve or constructivist scientific epistemologies, these epistemologies do not easily filter onto the teacher's instructional practices. As far as the teachers studied in this investigation are concerned, instructional behavior is a carefully considered activity, resulting from conscious balancing of a variety of factors and convictions. In deciding the nature of his/her practice, the teacher appears to strike a balance between those convictions embedded within his/her conceptual ecology and factors obtaining in the environment in which he/she is supposed to operate as a teacher. What filters from scientific epistemological beliefs into practice are only but trickles mediated by a plethora of factors.

RECOMMENDATIONS

In order for teachers to properly and explicitly teach learners about NOS and NOSI, it is necessary for policymakers, including curriculum designers to ensure that conditions are favorable for teachers to enact practices according to their convictions. Teachers might have all the noble intentions and right beliefs, but they may not teach what is right for learners to learn and know if the environment in which they operate is not socially, politically and materially conducive. At the same time, new assessment practices require to be fashioned out, so that teachers do not merely see teaching as serving the purpose of preparing learners or students for subject matter examinations. Significant latitude should be given to teachers to teach what they believe is the best for learners without the constraints of curricula and examinations. In the case of Zimbabwe, it is necessary to revise the current A-level Chemistry curriculum in order to encourage explicit teaching of the acceptable ideas about NOS and NOSI. Additionally, understanding and developing teacher beliefs should be part and parcel of in-service teacher training and educational research in teacher training institutes. This can greatly enhance understanding of the interaction between teacher beliefs and classroom practices.

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APPENDIX A

Interview Guide

The questions you will be asked require you to say what you think about science and how it is developed, basing your answers on your own thoughts. There is no right or wrong answers. Just say what you think.

1. Why do scientists do experiments?
2. Do experiments always tell us the truth about the nature of things? Explain your answer.
3. Are scientific observations theory- free? Explain your answer.
4. Do you think what you do in the Chemistry laboratory with your students is similar to what is done in scientific laboratories?
5. How are conflicts of ideas resolved in the scientific community?
6. Will the knowledge we know in Chemistry today one day change? Explain.
7. Comment on the issue of science and culture.
8. How do scientists arrive at conclusions in building scientific knowledge?

APPENDIX B

Laboratory Class Observation Guide

While the observations were done without the guidelines of an observation schedule (in the tradition of a checklist or adaptation of a schedule used elsewhere), the capture of lesson proceedings was guided by a deliberate effort to examine the following issues:

(i) source of problem for practical activity or activities
(ii) distribution of apparatus, chemicals, etc.
(iii) how the teacher gave out instructions and other information
(iv) the role of the laboratory assistant
(v) nature of student-student interactions
(vi) nature of teacher- student interactions
(vii) how students recorded information
(viii) group activities if any
(ix) pre and post laboratory activities
(x) what was expected of students' reports
(xi) how students made observations
(xii) how students interpreted data
(xiii) skills and techniques performed by the students
(xiv) students' performance of frequent experimental tasks e.g. transferring of aliquots, turning burette taps, controlling Bunsen flames, etc.
(xv) lesson introduction and lesson closure
(xvi) the open-endedness of tasks or activities (degrees of freedom given to students to make decisions)