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Exploring the Teaching of Physical Science through Inquiry

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ABSTRACT Inquiry-based instruction has not been widely adopted by secondary school science teachers, inspite of decades for research and curriculum design. This paper aimed at contributing to the documentation of the use of inquiry in Physical Science classrooms. In this case study, the data from the four participants about their classroom practice was gathered using qualitative research methods of observation protocol and individual interviews. Analysis of results showed that majority of these teachers held fairly limited views of inquiry making them use teacher-centered approaches. Elements and essential features of inquiry were observed in less than half their lessons. The remaining teacher used a combination of both traditional classroom activities and inquiry-based activities with more abilities to do inquiry and essential features of inquiry in their lessons, leading to a guided type of inquiry. This paper documents that even the experienced teachers struggle to enact inquiry-based teaching and therefore recommends professional development programmes (PDPs) that will enrich teachers' knowledge of inquiry.

INTRODUCTION

The current trend in science education worldwide focuses on inquiry-based instructions. South Africa is no exception in this reform. The South African Department of Basic Education (DBE) asserts that the teaching of Physical Science should be done through scientific inquiry and the application of scientific models, theories and laws in order to explain and predict events in the physical environment (DBE 2011). Both, National Curriculum Statements (NCS) and the Curriculum and Assessment Policy Statement (CAPS) advocate the use of inquiry-based instruction during teaching as opposed to the traditional science teaching. The problems however exist as many Physical Science Teachers (PSTs) in South Africa are struggling to teach the curriculum they have not been taught. This lack of experience is true for both experience and novice teachers. Since the majority of Physical Science teachers do not frequently employ inquiry instruction, it is helpful to understand who use them and how.

According to the DBE (2011), the newly introduced curriculum; CAPS, will be implemented in three phases. The year 2012 has seen the implementation of CAPS for grades R - 3 and grade 10, while in 2013 it has been implemented in grades 4 - 6 and grade 11. The last phase is scheduled for 2014 for grades 7 - 9 and grade 12. CAPS support the importance of science teachers possessing understanding of inquiry-based instruction and the assumptions inherent in the process for both teaching and assessment purposes. Although closely related to science processes, inquiry-based instruction extends beyond the mere development of science process skills, such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data. Inquiry-based instruction includes the traditional science processes such as discussion but it also refers to the combination of these processes with general science process skills (Lederman 2009; Lederman et al. 2014). The National Research Council (NRC) (2011) describes five *essential features* of classroom inquiry that apply across all grade levels. These are:

- Learner engages in scientifically oriented questions,
- Learner gives priority to evidence in responding to questions,
- Learner formulates explanations from evidence,
- Learner connects explanations to scientific knowledge, and
- Learner communicates and justifies explanations.

These five features are central to leaners' developing knowledge of any science concept and becoming a critical thinker. Depending on the amount of teacher or learner involvement, one can determine whether an experience is categorized as structured or guided inquiry. A case in point, learners in an inquiry classroom should be able to formulate their own questions about the natural world. However, this is not an automatic pursuit as they will need to be supported while constructing their own understanding of a phenomenon. Their pursuit will be achieved when science is taught through the process of inquiry because learners will be able to pose questions and seek answers based on observation, exploration and evidence they have gathered. On the side of the teachers, this inquiry approach affords them an opportunity to become facilitators while learners become more self-directed. This results in a shift from a more teacher-centered classroom to a more learner-centered classroom. To achieve this, it requires PSTs to possess the art of teaching their learners to develop problem solving and inquiry skills for meaningful learning to occur (Lederman 2009). At a nutshell, within any classroom, a lesson may be more or less learner directed, depending on the variation of the features implemented.

Although there is no clear cut definition of scientific inquiry, for the purpose of this research, the definitions used by the NRC (2011) will be used. This definition draws upon the essential features of classroom inquiry as the essence of inquiry, particularly the notion of giving priority to evidence and explanation. The following research question guided the study: *What practices inform Physical Science teachers search for scientific knowledge?* My proposition as a researcher is that PSTs with conceptions reflective of reformed views of Nature of Science (NOS) will also incorporate opportunities for inquiry-based instruction in their classes provided they value or understand this method of instruction. Conceptions are taken here as PSTs' views and ideas of the processes and products of science knowledge and how learners' acquire them.

Objective of the Study

The following objectives guided the study:

- To investigate Physical Science teachers understanding of scientific inquiry
- To examine Physical Science teachers classroom practice

Literature Review

Classroom inquiry as described in the NCS and CAPS documents includes 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 NOS and its relationship to technology, society and the environment (DoE 2007; DBE 2011). Apart from being learning outcomes, they are also teaching and learning strategy-embedded. Firstly, inquiry can be thought of as a content area of study in that learners should come to understand how scientists operate. Learners should understand that scientists observe, ask questions, conduct investigations, and provide explanations about a phenomenon (NRC 2011). As noted by Lederman (2009), understanding about inquiry reflects the philosophical and historical nature of scientific inquiry and NOS. To Lederman (2009) scientific inquiry refers to the methods and activities that lead to the development of scientific knowledge. Therefore, the intercept of these domains of knowledge (NOS, scientific inquiry and science concepts) coupled with ability to apply that knowledge, forms the conceptual basis of a scientifically literate individual (Lederman 2009).

A second element of inquiry is a learner's ability to do scientific inquiry (DBE 2011; NRC 2011). Here learners are expected to observe, ask and respond to question posed by them, plan and design investigations, collect and analyse data, and be able to explain based on their observations.

Thirdly, looking from a teacher's perspective, classroom inquiry can be viewed as a kind of pedagogy, that is, one's ability to use inquiry-based instruction in the classroom in order to address key science principles and concepts (NRC 2011). Teachers of science must be able to *do* science and be able to bring to the classroom the attitudes and views of scientists to effectively incorporate inquiry-based activities to their teaching (Flick and Lederman 2006; Lustick 2009). To achieve this, a basic understanding of philosophies of science is necessary. With a basic science content background and the ability to carry out the process of science, PSTs can teach science as conceptually oriented, hands-on, problem solving, and critical thinking, hence promoting science literacy amongst learners.

Though the definition of inquiry used in this research presents features of classroom inquiry from a learner's perspective, one can easily derive aspects of inquiry from the teacher's perspective. For instance, with regards to the teaching of Physical Science, teachers are required to design learning activities in such a way that there is less intervention from them; instead, there should be more learner self-regulation. This may include learners rising and responding to questions, share ideas, plan and design activities to answer questions, conduct experimental work, make predictions, and communicate their findings. At face value, one may think of these features as phases that follow one another in that order, but in practice this is not the case. As a non-linear process, the phases of inquiry are cyclic and iterative in nature and a learner may decide to revisit say, the original question or alter data collection procedures, at any stage or phase. The implication to the teaching is that a teacher can facilitate inquiry in the classroom by posing thoughtful questions and helping learners to do the same; by encouraging dialogue among learners and with the teacher; by keeping learners' curiosity alive; while a teacher remains a life-long learner (Binns and Popp 2013) and hence connecting their interests within a broader thematic framework. It can therefore be concluded that an inquiry-based classroom should focus on accomplishing two major goals: (a) learners should develop proficiency in using the investigative skills of science and (b) they should learn specific science concepts by actively engaging in lessons to answer questions they generate or posed to them.

Theoretical Underpinnings

This study is underpinned by the social constructivist theory (Vygotsky 1978). Social constructivists believe that there is no truth out there to be discovered. They further assert that reality is subjective and can only be *constructed* through social interaction and through the empathetic understanding of peoples' meanings of their life world. Reality can thus be known by those who experience it personally (Cohen et al. 2011).

As for *knowledge*, social constructivists believe that *knowledge* is also a human product, and is socially and culturally constructed (Gredler 2008). According to Fosnot (2005), knowledge is emergent, developmental, non-objective, viable, constructed explanations by humans in meaning making in cultural and social communities and discourse. Members of a society create meaning through their interactions with each other and with the environment they live in. The emphasis is on collaborative nature of much learning. In a school set up, learners interact with teachers, peers, technology and the environment. Learners in a social constructivist classroom are considered active agents, responsible for their own learning, enhanced by their interactions with peers, family and their environment and have less teacher autonomy (Gredler 2008). Learners are also encouraged to use their prior knowledge and experiences, answer questions formulated by them or posed to them for learning to occur; a learner, therefore, requires a deliberate effort to relate new knowledge to relevant concepts he/she already possess (Luera and Otto 2005). To achieve this, learners works collaboratively to ask questions, explore and assess what they already know.

Through collaborative learning methods, learners will develop teamwork skills and see individual learning as essentially related to the success of group learning. Collaborative learning should be seen as a process of peer interaction that is facilitated and structured by the teacher. Discussion can be promoted by the presentation of specific concepts, problems, or scenarios; it is guided by means of effectively directed questions, the introduction and clarification of concepts and information, and references to previously learned material. The teacher' role is to facilitate learning process while learners are trying to make their own meaning. To Fosnot (2005) and Mortimer and Scott (2003), meaning-making in a social constructivist class occurs in three phases, namely, the social plane, wherein the teacher provides new content; internalization, wherein the teacher helps learners make sense of the new knowledge; and, lastly, the application of the new knowledge.

Regarding teaching science through inquiry, Lederman et al. (2014) and Lederman (2009) posit that it is vital to take into consideration how teachers' understandings of inquiry have developed as a result of the social context in the classroom. For instance, in the process of construction, people develop patterns of belief, constructing knowledge in ways that are coherent and useful to them. Since the construction process is influenced by a variety of social experiences, the knowledge constructed by each individual tends not to be completely personal (Lederman 2009). Their studies revealed that the social constructivist perspective is well situated for studying how science teachers think and enact inquiry in their classrooms. Their study has shown that social constructivism is an appropriate framework for studying science teaching.

In line with the constructivist views, the South African curriculum requires teachers to teach Physical Science through inquiry. Resta (2002) defines a constructivist environment as one that encompasses communities of learners, teachers and experts who:

- perform authentic tasks in authentic contexts which relate to work done in the real world,
- provide opportunities for learners to experience multiple perspectives,
- enable the learners to see issues and problems from different points of view, to negotiate meaning and develop shared understandings with others, and
- emphasise authentic assessment of learning rather than the traditional paper and pencil test.

In other words, only when learners actively construct meaning through personal and social processes and integrate new knowledge into their pre-existing mental models of the world and experiences; then learning can occur (Luera and Otto 2005). If predictions based on a related existing idea or model fit the new observations, then the range of applications of the idea or model is extended. But if the evidence does not fit the prediction, this may mean that the idea or model has to be modified or rejected in the light of the new evidence (Luera and Otto 2005).

The constructivist believes in the value of discourse during social interactions. Burris and Guadalupe (2003) add that social constructivism is context dependent rather than content dependent and focuses not on the content or its objectives, but rather on the diverseness and richness of the learning environment: human skills, perception, experience and competencies. For meaningful learning to occur, a learner needs time to engage in the processes required to evaluate the adequacy of specific knowledge, make connections, clarify, elaborate, build alternatives and speculate (Gredler 2008). This is to say, a learner requires a deliberate effort to relate new knowledge to relevant concepts he/she already possess.

In response to the criticism that the learning process may challenge learners' prior knowledge and conceptions, Gold (2001) contends that this construction of knowledge requires learners to go through an active period of thinking critically about any given task which can be facilitated by the interaction with peers and/or critical review of the work of peers; and conducting some form of research work. Teachers in a constructive classroom need to facilitate this interaction. Researchers within a constructivist paradigm, especially those using case study researches, attempt to reconstruct participants' understanding of the social world (Denzil and Lincoln 2011). With regards to this study, the researcher have interrogated both; Physical Science teachers' understanding of scientific inquiry and classroom practice.

METHODOLOGY

A qualitative research approach was employed since the purpose of this case study was to explore PSTs' conceptions of inquiry in relation to their classroom practices (Creswell 2014). A case study was deemed appropriate in gaining a better understanding of this particular case with little control over events and focus on a contemporary process within a real-life context (Yin 2009). The participants' conceptions of inquiry were informed by data from four participants, it can be thought as collective case study (Stake 2006). The rationale for using a multiple participant design was to inform the case by producing potentially contrasting results for predicable reasons (Yin 2009).

Participants

The study used a purposive and convenience sample of four PSTs from Limpopo Province, South Africa (Leedy and Ormrod 2010). All the participants teach Physical Science at the Further Education and Training (FET) Band. Within the context of South African education the FET Band includes grades 10 to 12.

Table 1 illustrates the characteristics of the participants. The researcher is aware that this sample cannot be regarded as a representative of all the PSTs in Limpopo Province; the findings may nevertheless be substantively applicable to other teachers in similar settings.

Data Collection

Two methods of collecting data were used, namely, individual interviews and lesson observations. The choice to use multiple data collection methods has long been emphasised by researchers in science education (Lederman et al. 2002; Schwartz and Lederman 2008). The researcher collected data in two

Table 1: Characteristics of the participants

Teacher	*Gender*	*Academic qualification*	*Teaching experience in years*	*Teaching load per week*	*Average number of learners in class*
T1	Female	Diploma	13	25	50
T2	Male	B.Ed.*	10	36	55
T3	Male	Diploma	24	36	50
T4	Male	B.Ed.*	19	42	50

* Bachelor of Education

phases. *Phase one* involved open ended interviews with participants and sought to elicit their understanding of inquiry teaching and substantiate the key information gained from the literature review (Gubrium and Holstein 2002). *Phase two* involved observation of lessons order to establish the presence of inquiry aspects in the observed lessons. This approach afforded me an opportunity to review and analyse the interview questions and then triangulate interview results with lesson observations to make clarifications and follow-up on significant responses (Corbin and Strauss 2008), as well as information on their understanding of scientific inquiry.

Data from *phase one* was audio-taped after securing consent of participants. Research ethics require researchers to ask for consent whenever their utterances are to be recorded. The duration of these interviews were between 45-60 minutes. Each participant was observed twice in a period of twelve months.

In order to establish the presence of inquiry aspects in the observed lessons that is, *phase two*, the researcher was guided by *abilities* and *essential features of inquiry* as displayed by teacher and students. In addition, the researcher noted the amount of learner self-direction and the amount of direction from teacher or material. Based on the characteristic of a particular *ability* and *essential feature of inquiry*, the researcher was able to determine to what extent PSTs in the study demonstrated each ability and essential feature of inquiry in their respective observed lessons. The researcher also noted if the teacher addressed his/her understandings of inquiry in the observed lesson. In situations that were not clear, the researcher sought clarity during individual interviews.

RESULTS AND DISCUSSION

Traditional Practice: A Challenge to Reform

Using description of observed lessons, the researcher found a wide range of instructional practices in relation to *abilities* and *essential features of inquiry*. This variation was not related to PSTs' gender, academic qualification, teaching experience or the teaching work load. For example, one would expect a PST with a degree in science education and 10 and 19 years teaching experience to be able to teach Physical Science as inquiry but, instead, they taught using *structured or direct inquiry* of which can be considered as not a true form of inquiry. On the other hand, two teachers who demonstrated the ability to teach through inquiry were a female and a male with a Secondary Teachers Diploma (STD). They accidentally employed *guided inquiry* since elements and essential features of inquiry were observed in less than half their lessons. Their lessons too were dominated by traditional classroom activities of lectures, discussion, and recitation. The finding did not come as surprise as argued by Cherian (2007), Lederman (2009), Lederman et al. (2014) and Lustick (2009) that even experienced teachers of science find it difficult to teach through inquiry. One might argue that PSTs' challenges are a function of their understanding and belief about inquiry. A case in point, when asked about how does inquiry look like in class? They said:

It is something that was investigated by scientist in the past and it is there as a rule. So when you teach to the learners you have to give them an example. For example, Newton first law of motion … an object on the table, or a moving object; you must demonstrate to them what the law says. They can see the link between school science and their daily lives. If you just explain without demonstrate it they will just cram it. (T1)

Through demonstration of experiments (T2)

Whatever you do there must be … tasks in the form of projects or investigation (T3)

Aaah, we just take them to the lab where they can do experiments. We have the lab where we can take them to do the experiment (T4)

PSTs in the study held beliefs about inquiry as a kind of pedagogy that focuses on activities involving practical works, experiments, problem solving and hands-on activities; hence his focus on a particular *ability* and *essential feature of inquiry that is,* use of tools and techniques to gather, analyse, and interpret data. They all affirmed their conceptions of scientific inquiry by arguing that inquiry cannot exist without experiment. However, their approach to teaching Physical Science was not in line with their views about inquiry since they still cling to the old way of teaching that is, teacher centered. This mismatch is mainly due to their unclear understanding of how to implement an inquiry lesson.

All PSTs' instructional strategies followed a pattern where a teacher would initiate responses from learners by asking them questions that would need a "yes" or "no" answer, or by asking them the value to substitute in an equation from given data. This approach had its merit and demerits. The merit lies in the fact that it afforded the teacher with an opportunity to immediately give a correct answer when learners are wrong. A major demerit of this approach is that it restricts learners' thinking; hence it encourages responses that are teacher framed. Eventually, learners fail to link classroom science and their daily lives. Following the argument of Onwu and Kyle (2011), this failure of PSTs to develop curricular connection between science and the real life experiences of learners is likely to diminish the interest of the subject and relevance of science in their lives. Above all, it poses a serious challenge to the on-going reforms in science education.

Preparing Physical Science Classroom for Inquiry-based Lesson

The word *inquiry* has an elastic nature that is stretched and twisted to fit diverse paradigms to which different people subscribe. This study adopted the NRC (2011) definition which outlined the five *essential features* of classroom inquiry that apply to all school levels. The fundamental aspect to any inquiry lesson is for learners being able to formulate questions and provide answers to questions during investigations. Furthermore, a question that generates a *need to know* in learners stimulates additional questions of *how* and *why* a phenomenon occurs. In this way, learners will be able to see the relevance of classroom science in their day to day life. It is important to mention here that, this is not an automatic pursue. In a typical constructivist science classroom, teachers must create learning environment for their learners to fully engage in investigations and answer questions posed to them or by themselves. At a nutshell, teachers are expected to promote the learning of scientific concepts and processes as well as how scientists study the natural world. To achieve this, they need to possess a sound knowledge of how to teach Physical Science through inquiry as required by the curriculum.

This brings us to the idea of how teachers' views and ideas of the processes and products of science knowledge and how learners' acquire them. Teachers' conceptions influence the degree of implementation of inquiry in their science classrooms. For instance, teachers in the study held beliefs about inquiry as a kind of pedagogy that focuses on hands-on activities that is, use of tools and techniques to gather, analyse, and interpret data. They all affirmed their conceptions that inquiry cannot exist without experiment. However, PSTs' approach to teaching was not in line with their views about inquiry since they still cling to the old way of teaching that is, teacher centered. In most occasions learners were given data and told how to analyse it, hence limits their thinking. This mismatch between PSTs conceptions of inquiry and classroom practice is mainly due to their unclear understanding of how to implement an inquiry lesson.

CONCLUSION

Literature on the teaching and learning of science provides us with many different approaches on the subject. Likewise, the word inquiry has an elastic nature that is stretched and twisted to fit diverse paradigms to which different people subscribe. At the core of inquiry-based teaching, learners are fully engaged in investigations to answer questions. However, for the purpose of this study the form of inquiry expected for the PSTs is the learner-centered approach in order to achieve the three outcomes of Physical Science curriculum. PSTs in the study do not have a clear understanding of what is meant to teach through inquiry. They lack the supportive backgrounds and experiences necessary to facilitate inquiry lessons. Within the current context of curriculum change in South Africa, it is important for PSTs to have clear understanding on what is meant to teach through inquiry. The current trend of education authorities to run a day or two-day workshop is insufficient to equip teachers with the necessary skills required to implement inquiry-based instruction. Until that time PSTs are able to recognize where the thin line between inquiry and traditional teaching exists, then achievement of three outcomes of Physical Science curriculum remains under threat.

RECOMMENDATIONS

The following recommendations were made based on the study findings:

- Education authorities and stakeholders should have effective professional development programmes (PDPs) that will enrich teachers' knowledge of inquiry-based instruction.
- Education authorities should effectively monitor teachers' instructional activities especially in the rural areas in order to realize goals of teaching science; but more specifically, the three outcomes of Physical science curriculum.

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