Inquiry-Based Teaching in Physical Science: Teachers' Instructional Practices and Conceptions

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Doi:10.5901/mjss.2014.v5n23p1074

Abstract

This study aimed at exploring teachers' instructional practices and conceptions of teaching Physical Science through inquiry. Data were collected using qualitative research methods of individual interviews and observation protocol with the four experienced teachers that were purposively selected. The results revealed that participants used traditional classroom activities more frequently than inquiry-based activities; and whenever they made use of inquiry, they followed a specific order of activities that leads to a more structured or direct type of inquiry. Few used a combination of both traditional classroom activities and inquiry-based activities, leading to a guided type of inquiry. In addition, all participants understood teaching through inquiry as a kind of pedagogy that involves experimentation. This suggests a need for teachers to possess sound knowledge of inquiry and the Nature of Science (NOS); as these are prerequisite for implementing inquiry-based instruction in the classroom.

Keywords: *inquiry teaching approach, teachers' conceptions, Physical science, nature of science*

1. Introduction

A major goal of science education today, is promoting scientific literacy amongst students. This is done by fostering students' intellectual competencies in the form of independent learning, problem solving, decision-making and critical thinking (American Association for the Advancement of Science (AAAS), 1994; National Research Council (NRC), 2011). For this goal to be achieved, science teaching requires a major shift from traditional methods to more learner-centered instruction. Schraw, Crippen and Hartlely (2006) outline six areas critical for achieving this goal: (i) inquiry-based approach (ii) collaborative support (iii) strategy instruction to improve problem solving and critical thinking (iv) strategies for helping students to construct mental models and experience conceptual change (v) the use of technology; and (vi) the impact of students' and teachers' beliefs.

These ideas are not new among science teachers and researchers, yet the changes instigated at school level have been very slow. Science is still being taught from the perspectives of normal logical positivism, with more emphasis on the mastery of abstract concepts and principles, and little connection with day-to-day lived experiences of students (Kyle, 2006; Onwu & Kyle, 2011). Common constraints to implementing inquiry environments include: inadequate content knowledge, inadequate knowledge of the Nature of Science (NOS) and lack of pedagogical skills (Hashweh, 1996; Lederman, 2007). There seems consensus among researchers in science education that in order to foster students' higher-level thinking, teachers must possess not only in-depth content knowledge, but also a good pedagogical knowledge on how to develop students' higher-order thinking in the context of the subject matter they are dealing with (Shulman, 1986; Roohan, Taconis & Jochems, 2011; Mudau, 2013; Park & Oliver, 2008; Rollnick et al., 2008; Lederman, 2009; Lederman et al., 2014). This puts teacher's craft as the ultimate variable in the classroom practice for students' learning.

2. Literature Review

2.1 Teaching Physical science through inquiry

Recent policy initiatives in South Africa and the rest of the world have focused on student-centred or inquiry-based instruction to learning (NRC, 2011; DoE, 2007; DBE, 2011) with desired outcomes much broader than increased knowledge. The research community considers the inquiry approach to the teaching of science as most effective. This intensifies a need for all science teachers and other educational stakeholders to have a clear understand what is meant to teach Physical science through inquiry. It is equally important for teachers to hold refined conceptions of scientific knowledge so as to develop good inquiry skills (Winning, 2010).

The journey of defining inquiry-based teaching begins with defining what inquiry is. Numerous researchers (see for example; Barrow, 2006; Minner, Levy & Century, 2010; Smithenry, 2010) posit that the word inquiry has no clear-cut meaning; it is an elastic one which is stretched and twisted to fit diverse paradigms to which different people subscribe. Nevertheless, researchers worldwide draw their definition of inquiry from the National Research Council of America (NRC, 1996) which states that:

Inquiry is a multi-faceted activity that involves making observations, posing questions, examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking and consideration of alternative explanations (p. 23).

For instance, the National Science Education Standards (NSES) describes five essential features of classroom inquiry that apply across all grade levels from the NRC's definition. These are student should (i) engage in scientifically oriented questions (ii) give priority to evidence in responding to questions (iii) formulate explanations from evidence (iv) connects explanations to scientific knowledge, and (v) communicate and justifies explanations.

These five features are central to students' developing knowledge of any science concept and becoming a critical thinker. Depending on the amount of teacher or student involvement, one can determine whether an experience is categorized as full or partial inquiry. A case in point, students 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 students will be able to pose questions and seek answers based on observation, exploration and evidence they have gathered. As a non-linear process, the phases of inquiry are cyclic and iterative in nature and a student may decide to revisit, say the original question or alter data collection procedure at any stage or phase. Figure 1 below illustrates this cyclic and iterative process that students get involved in when engaged in inquiry.

The implication to the teaching is that a teacher can facilitate inquiry in the classroom by posing thoughtful questions and

helping students to do the same; by encouraging dialogue among students. This is vital in keeping students' curiosity alive; and, a teacher remaining a curious, life-long learner (Bybee, 2000). In essence, this is the case within the 5Es instructional model by Barman (2000), where students must *explore, engage, evaluate, elaborate and explain* a phenomenon. The 5Es model is praised for explicitly pointing out the importance of the teachers' role in exposing students to the new scientific ideas, hence influencing various contemporary teaching strategies and programmes (Whithee & Lindell, 2005). These include, among others, the Australian Primary Investigations Project and the Primary Connections (Australian Academy of Science, 2009; Hackling, Peers, & Prain, 2007). Barman (2002) concludes that an inquiry-based classroom should focus on accomplishing two major goals: (i) students should develop proficiency in using the investigative skills of science and (ii) they should learn specific science concepts by actively engaging in lessons to answer questions they generate or posed to them.

2.2 Teachers' conceptions

The term "conception" is used quite broadly to describe any mental construct of an individual teacher that potentially provides a rationale for a particular instructional practice (Dancy & Henderson, 2007). According to Marton and Booth (1997), conceptions are seen as a way of experiencing a phenomenon but they are less tangible and, therefore, are difficult to measure. An individual may have different conceptions of a phenomenon in different circumstances and experiences, adds Akerlind, Bowden and Green (2005). This is to say, different people not only have different experiences of the world, they also interpret these experiences in different ways, and this is influenced by the framework(s) of meaning they are using. Ones' conceptions are influenced by factors such as the cultural and educational environment, technical expertise and staff development opportunities. This argument is supported by Mokiwa and Msila's (2013) study which explored English Second Language (ESL) science teachers' conceptions on teaching strategies. They found that conceptions of ESL teachers were highly influenced by the educational institutions they attended and the perceived teachers' role in the learning of science. Wallace and Kang's (2004) study on six experienced teachers revealed how teachers' conceptions had influenced the degree of implementation of inquiry in their science classrooms.

There also exists much literature relating to teachers' conceptions of NOS. Lederman (2007) refers to the construct 'nature of science' as the values and assumptions inherent to scientific knowledge and its development. Embedded in the NOS are the seven desired contemporary (or simply known as, *informed*) views of NOS as outlined by Abd-El-Khalick, Bell and Lederman (2000, p.564) and Lederman (1999, p.917). According to these authors, scientific knowledge is:

- Tentative or subject to change (NOS1)
- Empirically based (based on and/or derived from observations of the natural world) (NOS2)
- Subjective or theory laden (NOS3)
- Partially the product of human inference, imagination and creativity (involves the invention of explanation) (NOS4)
- Socially and culturally embedded (NOS5)
- Developed by observations and inferences (NOS6)
- Developed by an understanding of the relationships between scientific theories and laws (NOS7)

For example, science teachers who hold views about NOS as a body of factual knowledge to be learned are less likely to use inquiry approaches (Cronin-Jones, 1991). On the other hand, science teachers can hold reform-based views about NOS but due to their lack of knowledge regarding the philosophy and NOS (Gallagher, 1991) or their instructional intentions (Lederman, 1999); their instructional practices would not reflect these reformed-based views.

Studies about NOS understanding have shown that teachers and students in non-European countries view science as close to technology, as being useful for future careers and the development of their societies, and as an academic subject that provides knowledge used only in school-related settings and of little relevance to everyday life (Cobern, 1989). In such contexts, science is interpreted as money-oriented (Reddy, 2005) rather than a way of knowing the natural world, and usually not involved in the students' everyday thinking.

In this study, conceptions are taken as teachers' views and ideas of the processes and products of science and how students acquire them. Teachers' conceptions were explored using the seven desired contemporary views of NOS as outlined by Abd-El-Khalick, Bell and Lederman (2000) and Lederman (1999). These tenets were captured during individual interviews.

3. 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. 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 and have less teacher autonomy (Gredler, 2008). Students are also encouraged to use their prior knowledge and experiences, answer questions formulated by them or posed to them for learning to occur.

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.

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 researchers have interrogated both; Physical science teachers' understanding of inquiry and; their classroom practice.

4. Methodology

Since the study aimed at exploring teachers' instructional practices and conceptions of teaching Physical science through inquiry, we employed case study research methods (Creswell, 2014). Our study involved four Physical science teachers; one female and three males. The rationale for using a multiple participant design was to inform the case by producing potentially contrasting results for predictable reasons (Yin, 2009). In this study, the four participants were selected because they possessed varying amounts of Physics teaching experience.

4.1 Participants

Ms. Seperepere

Ms. Seperepere is a female, aged 37. She started her teaching career at the current school and has been teaching there for the last 13 years. She holds a Secondary Teachers Diploma (STD) in education with Physical Sciences and Mathematics as her major subjects. She is currently teaching Physical Science, Life orientation and Mathematics Literacy for grade 11. She is also a Head of Department (HOD) for Mathematics and sciences.

Mr. Sengo

Mr. Sengo is a 42 years old male with 10 years of experience. He holds a Bachelor Degree in Science Education. He has been teaching for 10 years but at this particular school, it is his second year of teaching. Before joining the current school, Mr. Sengo was tutoring at a college in Gauteng Province. He is currently teaching Physical science for grade 11, and Mathematics and Physical science for grade 12, with a total workload of 36 periods per week.

Mr. Kunene

Mr. Kunene is a male, aged 49. He holds a Diploma in Education majoring in Natural Science. He began his career in teaching 24 years ago in the same Province and later joined the current school about 6 years ago. He teaches Natural science for grade 9, Life science for grade 10, Physical science and Life Orientation for grade 11 and Physical science for

grade 12. His teaching workload is 36 lessons per week.

Mr. Ngoma

Mr. Ngoma is a 43 year old male. He started his teaching career at the current school and has been teaching there for the last 19 years. He holds a Bachelor Degree in education. He is currently teaching Mathematics Literacy and Life Orientation for grade 11; Physical science for grade 11 and 12. Like other teachers in the study, his teaching workload is 36 lessons per week.

4.2 Data collection and analysis

Two methods of collecting data were used, namely: lesson observations and individual interviews. The choice to use multiple data collection methods has long been emphasized by researchers in science education (Lederman et al., 2002; Schwartz & Lederman, 2008). It afforded us an opportunity to review and analyse lesson observations; and then tailor the individual interview protocol to make further clarifications and follow-up on significant responses and observations (Corbin & Strauss, 2008).

The following research questions guided the study:

- *What are Physical science teachers' classroom practices?*
- *What are the Physical science teachers' conceptions of inquiry teaching approach?*

Data collected from participants was analysed thematically through open, axial and selective coding (De Vos et al., 2011). Open coding refers to the creation of categories pertaining to a certain segment (line/ paragraph) of transcript, and allows for the emergence of specific units of meaning and themes. After listening several times to the audio-recorded observed lessons and interviews we transcribed them and, where necessary, sought help from Sepedi-speaking professionals because some participants were mixing English and Sepedi while teaching Physical science. The audio files were recorded verbatim then labelled carefully. This step was followed by axial coding with data being put back together to make connections between categories and sub-categories, hence giving it precision. Lastly, core categories or themes relevant to the study were selected during selective coding. When analysing lesson observations we used a prior coding scheme, looking for evidence of inquiry as defined in the science reform documents (see for example, NRC, 1996, 2000, 2011) and aspects of NOS (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002).

5. Findings and Discussion

The discussion focuses on the two major findings based on the themes that emerged from data analysis. These are the teachers' conceptions of inquiry teaching approach, and teachers' classroom practices.

5.1 Teachers' understanding of inquiry teaching approach

From analysis of interviews with participants it was clear that all participants have little understanding of what it means to teach Physical science using inquiry. This was evident based on their responses to question 4 of the interview protocol. For example:

... we use that especially when we do practical because there is an expected format that we have to follow in order to achieve our objectives...., they have to inquire scientifically, but myself as educator sometimes I don't know what to do, then how do I help them to inquire scientifically? But during practical I know that in Grade 10, I start by doing everything for them but in grade 11, I can give them the materials, they know the procedure, I just sit and wait they do things on their own, I just supervise (Ms. Seperepere).

In my view, what I think is that you have to learn by investigating using the scientific methods of experiments (Mr. Kunene).

Inquiry approach is when students have to relate science with what is in their everyday life. They have to practice science, they have to do experiment, and they have to inquire each and everything they observed in science (Mr. Ngoma).

Teaching through inquiry is when we conduct experiments with students (Mr. Sengo).

Ms. Seperepere further believed that there was a recipe-like step-by-step procedure in scientific investigation and that the students were supposed to memorise and recall them each time they conducted an investigation. After she had shown them the steps to be followed when conducting an investigation in the previous year, students had to be able to recall those steps as she would be supervising them, hopefully for their safety in the laboratory. From a social constructivist perspective, learning science content may also take place as students engage in investigation, and pose and respond to each other's questions. However, Abd-El-Khalick et al., 2008 and Lederman et al., (2013) warn that there is no single scientific method that guarantees the development of scientific knowledge. Nor is there a single sequence of practical conceptual or logical activities to be followed for the accurate development of scientific knowledge (Abd-El-Khalick et al., 2008), hence the teacher facilitates the learning process by creating opportunities for students to think critically rather than just play a supervisory role.

Mr. Kunene also understood scientific inquiry as experimenting, viewing scientific inquiry as focussing on the use of tools and techniques to gather, analyse, and interpret data. This is also in line with his view of NOS, that science is a body of factual knowledge and, therefore, scientists conduct experiments in order to prove whether theories are correct or incorrect. His views of NOS do not reflect constructivist ideas in that constructivists reject the notion of a single reality and universal truth that can be discovered context-free, but rather they note that there may be many ways of knowing and different realities (Kuhn, 1962). Through interactions and dialogue, members of society come to an agreement on understanding of truth within a particular context, for instance within a Physical Sciences classroom. The interaction with the environment can be experienced when students use tools and techniques to gather, analyse, and interpret data. However, the existing models on how things work do not necessarily reflect reality or absolute truth but rather the best construction of current experience (Driscoll, 2005).

The explanations of both, Mr. Ngoma and Mr. Sengo, situated experimentation at the heart of scientific inquiry. They believed that inquiry existed when students conduct experiments. They considered this an excellent opportunity for students to experience *doing science* and that the successful completion of experiments and the transition from student to scientist emerged through social interaction. From a social constructivist perspective, learning occurs when a teacher creates a learning environment that will allow the students to construct their own meaning by experiencing and interacting with the environment (Hill, 2002). The interaction with the environment can be experienced when students use tools and techniques to gather, analyse and interpret data.

5.2 PSTs' classroom practices

Using a description of observed lessons, we found a wide range of instructional practices in relation to ability to do inquiry and its features. This variation was not related to teachers' gender, age, teaching experience or the teaching workload. For example, one would expect a teacher with a University degree in Science Education and 10 years' teaching experience (i.e. Mr. Sengo) to be able to teach Physical science as inquiry, but instead he taught using *structured or direct inquiry* which is often considered a *cookbook* version of inquiry. Conversely, one of the two teachers who demonstrated the ability to teach through inquiry was Ms. Seperepere and Mr. Kunene who had a Secondary Teachers Diploma (STD). They employed *guided inquiry*.

Their approach to teaching was in line with their views about NOS. These teachers held beliefs about NOS as a body of factual knowledge to be learned and it was not a surprise that they were less likely to use inquiry approaches (Cronin-Jones, 1991).

5.2.1 Teacher-centred approach

The analysis of data showed that teacher-centred approach dominated in teachers' lessons. Here, the teachers did most of the talking while students were passive recipients, which was also reported by Gallagher (1991) in that lecture-discussion, with an occasional demonstration, is most common in secondary school science classes.

Most of the teachers' instructional strategies followed a pattern in which a teacher would initiate responses from students 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 lay in its affording the teacher with an opportunity to immediately give a correct answer when students were wrong. A major demerit of was that it restricted students' thinking, hence encouraging responses that were teacher framed (Gallagher, 1991). Although most of these teachers' communicative approaches were interactive they were also highly authoritative (Mortimer & Scott, 2003), since the direction of the lessons was determined by the teacher.

From a social constructivist perspective, teachers are facilitators of learning. Unfortunately, the teachers'

authoritative approach denies students an opportunity to interrogate information and consequently discourages critical thinking amongst them. In some cases students were constantly made to remember definitions and concepts during examination.

Following the argument of Mortimer and Scott (2003), that meaning-making in a constructivist class occurs in three phases, namely: the *social plane*, *internalisation* and, lastly, the *application* of the new knowledge, we argue that most of teachers in the study demonstrated only phase one of knowledge-making by providing new content through the lecture method or direct instruction, and compromised other phases. These teachers helped students acquire scientific information and then test them to see if they have acquired it. They then proceeded to the next topic. While acquiring scientific information is an important step in learning, students also need to go through the remaining two phases if they are to understand and be able to apply scientific knowledge.

These teachers expect students to make sense of science and figure out its application on their own through reflection or individual study. Both research and experience have shown that students are not very effective at either of these activities when left to do them alone outside the class. With lack of guidance this process is bound to result in poor understanding and inability to apply knowledge. Additionally, it may contribute to the development of students' misconceptions. Also, it is a source of frustration on the students' part, especially when they are unable to understand and use scientific knowledge effectively.

For cases in which teachers asked questions throughout the lesson their focus was not on understanding *per se* but rather on the development of the lesson and on preparing students for examinations. For example, Mr. Kunene continued to remind students to remember definitions and concepts during examinations. He believed that science was a body of factual knowledge, and that *knowledge* and *truth* were 'out there' to be discovered. This is not a social constructivist belief. Social constructivists reject the notion of a single reality and universal truth that can be discovered context-free, preferring to believe that there may be many realities and many ways of knowing (Kuhn, 1962). In other words, social constructivists believe that there is no truth 'out there' to be discovered and that reality is subjective and can only be *constructed* through social interaction and through the considerate understanding of the peoples' meanings from their experiences. A case in point, when Mr. Sengo and Mr. Ngoma decided to assign activities related to electrochemical processes, they should have let students, in pairs or small groups, spend some time at least thinking about electrochemical processes. To be more specific, if these teachers asked students to discuss the definitions of oxidation or reduction in small groups, they would have given their thoughts to oxidation and reduction and begun the process of making sense of these concepts. By so doing, teachers are not transferring knowledge to anyone, but assigning a particular activity may result in students constructing certain experiences rather than others. These teachers would have played their role as facilitators. If students do as the teacher wishes their thinking will be occupied by engaging in the activity and thus increase their chances to learn about these concepts.

For effective learning to occur, a student 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). A student requires a deliberate effort to relate new knowledge to relevant concepts he/she already possesses.

The majority of teachers in the study were not aware of this time factor. It was the teachers who determined the pace and direction of the lessons. Even when a teacher asked a student to answer a question on the chalkboard there was no serious interaction amongst the peers and much time was wasted because students did not value this learning strategy. Following the argument of Onwu and Kyle (2011), this failure of teachers to develop curricular connection between science and the real life experiences of students is likely to diminish the relevance of science in their lives.

5.2.2 Code switching strategy

Ms. Seperepere and Mr. Ngoma were aware of the linguistic challenges facing their students and, therefore, opted to employ code switching as a strategy in their teaching. Though it is not officially adopted, code switching is reported to be a common practice in South African classroom, whereby a teacher alternates between two languages, mainly between English and the students' main language. Ms. Seperepere and Mr. Ngoma had empathy with the students whose first language is Sepedi, the use of which in teaching was to make sure that they followed the conceptual understanding in Physical science classrooms. Additionally, the importance of examinations which are all in English made these teachers adjust their teaching to be suitable for this purpose.

Following the claims by Kuhn (1962) that knowledge creation requires the development of language, meaning, and dialogue to facilitate consensus within a community, we argue that teachers who use language effectively will be able to demystify science and guarantee their students' success. Code switching is needed in order for students to continue developing proficiency in the LoLT simultaneously with learning the subject. It is difficult for many students who speak

English as an additional language to bridge the gap and acquire not only proficiency in English but also the kind of Cognitive Academic Language Proficiency (CALP) required for academic learning and effective engagement with the curriculum.

On the other hand, Mr. Sengo and Mr. Kunene used English only in their observed lessons, in spite of their awareness of the linguistic challenges facing their students. They justified their use of English by citing the final assessment, which is in English, a foreign language to their students. Additionally, these teachers viewed science as culturally and socially embedded, which means that for African students to learn science they also need to learn a foreign culture, i.e., the English language or, in Ogunniyi's (1988) words, they need to do 'border crossing'. In multilingual South Africa, students are introduced to the written form of the scientific register in Grades 5 and 6, and when they reach higher grades they are expected to cope with a complex form of this register, with which they are relatively unfamiliar and for which they may have no appropriate strategy to effect useful learning. It can be concluded from these teachers' views that code switching *per se* does not bring additional complications to the teaching and learning of science but, rather, as an additional opportunity for learning as it helps students to think more analytically, which results in a greater understanding of science.

Following the claim by Mortimer and Scott (2003) that meaning-making takes place in three phases, namely, the social plane, on which the teacher provides new content; internalisation, by which the teacher helps students make sense of the new knowledge; and, lastly, the application of the new knowledge. We argue that Ms. Seperepere and Mr. Ngoma succeeded in the three phases while Mr. Sengo and Mr. Kunene compromised all three phases by focusing on memorisation of 'facts' for examination purposes. In the lessons observed, these teachers compelled their students to remember information taught, including definitions, for the examinations. This again questions their understanding of science teaching goals, is it to *prepare future scientists* or to promote *scientific literacy*, or neither of these?

6. Conclusion and Recommendations

The current trend in science education worldwide requires teachers to incorporate inquiry-based instruction into their teaching. Teachers in the study provided an indication of how inquiry is understood and implemented in their respective schools. It was evident that teachers' views and ideas emanate from their pedagogical content knowledge, contextual factors and how they were trained in the teaching profession. These findings call for teachers to possess sound knowledge of inquiry and the NOS; as these are prerequisite for implementing inquiry-based instruction in the classroom.

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