South African Journal of Education

Vol 31:91-101

Teachers' use of questioning in supporting learners doing science investigations

Umesh Ramnarain
uramnarain@uj.ac.za

I examine how teachers employ a questioning strategy in supporting Grade 9 learners doing science investigations in South African schools. A particular focus of this study was how teachers use questioning in contributing towards the autonomy of these learners. The research adopted a qualitative approach which involved the collection of data by means of classroom observations and interviews with five teachers at schools resourced for practical work. The analysis of transcript data revealed that teachers support learners by asking probing questions at all stages of the investigation. The teachers used a questioning strategy in enabling the learners to understand more clearly the question or hypothesis they intended investigating, to review and reconsider their planning, to rethink some of their actions when collecting data, to make sense of their data, and to revisit and amend their plan after generating incorrect findings. The significance of this study, in making explicit teacher questioning at the stages of the investigation, is that it provides a guideline for teachers on how to support learners attain greater autonomy in doing science investigations.

Keywords: learner autonomy; questioning; science investigation

Introduction

Practical work in the school science curriculum has formed the focus of curriculum reform initiatives which have taken place worldwide (Gott & Duggan, 2007:271). In South Africa, a cornerstone of reform of the school science curriculum is the introduction of science investigations in practical work. A science investigation is described as a process which takes place in stages. These stages as identified by the Revised National Curriculum Statement (RNCS) (Department of Education, 2002:17) for Natural Sciences include:

- Planning investigations
- Conducting investigations and collecting data
- Evaluating data and communicating findings

Although this curriculum is expected to undergo revision, the proposed changes reaffirm the pivotal role of science investigations in the teaching and learning of science, and learners developing competence at each of these stages of an investigation. When planning the investigation, learners identify the materials to be used, identify the type of variables involved (control, independent, dependent), formulate a question or hypothesis, and determine how the variables can be manipulated, controlled, and measured (Chin, 2003:35). In conducting the investigation, learners manipulate apparatus and materials to make observations and measurements (Corry, 2005:64). The learner then evaluates the collected data by seeking patterns and trends, and generalises in terms of simple principles. At this stage learners also consider the extent to which the conclusions reached are reasonable answers to the focus question of the investigation (Department of Education, 2002:17).

This new emphasis on the investigative approach is in stark contrast to the traditional 'cookbook' approach to practical work where learners followed 'recipes' for the execution of procedures handed down by the teacher without much thought and purpose (Anderson, 2007; Kim & Tan, 2010). Many of the practical activities carried out by learners merely confirmed or illustrated theory. The educational value of this approach was questionable, as when the findings disagreed with the theory provided by the textbook, learners often fudged their data in order to get the expected results (Viechnicki & Kuipers, 2006:115).

The investigative approach to practical work advocates greater learner autonomy, a notion that is promulgated in the South African curriculum (Department of Education, 2002:1). The literature on learner autonomy is abundant, but there is not a general consensus on what this term means or implies (Black & Deci, 2000:741). However, in the context of this study, learner autonomy is synonymous with independent learning where learners are able to work on their own with some guidance from the teacher. Granting the learners autonomy in doing investigations would therefore require that teachers surrender much of the control of the learning situation. According to Billings (2001:2), if a "sage-on-the-stage" is the metaphor for the traditional passive learning environment, then "learner-on-stage, and support staff as stage hands, with the teacher directing it all" is the metaphor for learner-centred learning. In this autonomous learning environment the role of the teacher when learners are doing investigations is re-defined as he/she supports learners. This study focuses on the teacher in this new environment in exploring how he/she uses questioning as a support strategy.

Background

In recent years there has been increasing research interest in the implementation of science investigations, with a focus on how much autonomy learners have in doing investigations. The studies cited below have revealed that despite curriculum imperatives for students to have more autonomy when doing investigations, they remain largely teacher controlled. In a survey of science education in the United States conducted in 2000 by Horizon Inc. for the National Science Foundation (NSF) it was shown that only 12% of teachers indicated students were asked to design or implement their own investigation (Smith, Banilower, McMahon & Weiss, 2002:42). Science investigations continue to be presented in teacher scripted labs where learners follow directions to merely confirm textbooks answers (Trumbull, Scarano & Bonney, 2006:1718). In South Africa, two relatively recent studies (Seopa, Laugksch, Aldridge & Fraser, 2003; Rogan & Aldous, 2005) have highlighted the lack of learner autonomy in science practical work as practical work was still dominated by teacher demonstrations and a cookbook approach where learners merely followed the teacher's directions.

If learners doing investigations is to become widespread in South African classrooms the nature of the support the teacher offers to learners has to be properly defined so that learners retain autonomy over the investigations. According to Onwu and Stoffels (2005:80) teachers need to possess "the necessary pedagogical skills and resources to guide and facilitate inquiry-based learning through an outcomes-based education (OBE) teaching approach". Our knowledge about how to promote a learner-centred environment of scientific investigations is limited (Fradd & Lee, 1999:14). Research that has been conducted on investigations has identified role modelling, questioning, teacher feedback, teaching experimental techniques as support strategies that teachers can provide for students (Haigh, 2001; Howe, 2002; Villanueva-Hay & Webb, 2007; Wu & Hsieh, 2006). Such strategies describe the guidance the teacher gives learners in order to facilitate their progress when doing investigations. The form that this support assumes is critical and must not be confused with teacher control. Teacher control describes the degree to which a teacher determines what is done and how it is done. Teacher questions in particular form an important component of classroom discourse (Chin, 2007:816), and the types of questions are important indicators of the classroom environment. My study therefore examines how teachers employ a questioning strategy in supporting learners who are doing scientific investigations. The type of questions posed by the teacher in supporting the learners' progress through the stages of the investigation is different from that in a traditional teacher-dominated classroom where the teachers' questions have the purpose of controlling the social situation (Lemke, 1990:19). In such an environment the teacher asks closed questions that are information-seeking, and students are discouraged from articulating their thoughts (Chin, 2007:818). In an activity which is more learner-centred with aspects of learner autonomy, the teacher is encouraged to ask a "productive" type of question which calls for reflection and analysis that promote a view of science as a dynamic search for answers. Such questions by the teacher provoke thought and encourage learners to justify their actions (King, 1994).

The theoretical underpinning of this supportive approach is Vygotsky's (1978) notion of learning in the zone of proximal development (ZPD) and the related apprenticeship model of Rogoff (1990). Vygotsky's model for the mechanism through which social interaction facilitates cognitive development resembles apprenticeship, in which a novice works closely with an expert through dialogic discourse in the zone of proximal development. The novice is thereby able to receive support in participating in the activities beyond those that he or she is independently capable of handling (Rogoff, 1990). The apprenticeship model described by Rogoff (1990:7) considers children as apprentices who develop skills and understandings from participating with more skilled members of their society within the context of sociocultural activity. In the science class the more knowledgeable and skilled teacher guides learners through the stages of the investigation while they are doing the investigations working with their peers. My study, informed by this framework, examined how in classes where learners are doing science investigations teachers use a questioning strategy in supporting them through the stages of the investigation. The research was therefore guided by the following question:

> How do teachers at schools resourced for practical work use a questioning strategy in supporting learners through the stages of science investigations ?

Method

A case study method was followed using a qualitative approach to gain an in-depth understanding of how teachers use questioning in supporting learners when doing science investigations. The cases were five teachers who taught Grade 9 Natural Sciences. Grade 9 was considered significant as it is the first grade in the South African school science curriculum where learners are expected, apart from conducting investigations, to also plan their investigations.

The teachers were purposively selected from a sample of 55 teachers who had responded to a questionnaire that had been sent to 150 schools in KwaZulu-Natal. The questionnaire sought information on the implementation of science investigations at schools. In particular, the questionnaire survey sought to establish the extent to which learners had autonomy in doing science investigations. The content validity of the questionnaire was established by having it reviewed by two researchers in science education at Michigan State University, which I visited as a result of collaboration between the National Research Foundation of South Africa and the

National Science Foundation of the United States. Thereafter, the content validity was confirmed by three researchers in science education at a South African university. The five teachers in this study had indicated that learners in their classes had autonomy in all three stages of the investigation process as described earlier. This was an overriding criterion in their selection for this study as I wanted to understand how teachers used questioning in supporting learners who were autonomous in doing investigations. The location of the schools where they taught was convenient as they were accessible to me in terms of travelling distance. Table 1 summarises the profiles of these teachers and the context in which they worked. The names used are all pseudonyms. In this profile, a well-resourced laboratory is considered to have water, electricity and gas connections; a supply of apparatus and chemicals for all learners to do practical work; and work benches for all learners. An adequately resourced school has a reasonable supply of apparatus and chemicals, but these are not sufficient for all learners to do practical work.

Table 1 Profile of case study teachers and the context in which they worked

Teacher	Age	Qualification	Class size	Laboratory facilities
Ms Essop	42	Teaching diploma and science degree	24	Well resourced
Mr Botha	37	Teaching diploma and science degree	24	Well resourced
Mr Pillay	35	Teaching diploma and science degree	25	Well resourced
Ms Reuben	34	Teaching diploma	40	Adequately resourced
Ms Zulu	36	Teaching degree	38	Adequately resourced

I observed 15 lessons in total, with three observations for each teacher. I also interviewed each teacher on four occasions. The classroom observations focused on the questioning used by the teacher in supporting learners. I made written field-notes on the actions of the teacher and learners, and the teacher-learner interactions which took place. A permanent record of this observation was obtained by video- and audio-recording the classroom observation. Follow-up interviews with these teachers provided in-depth information on how teachers used questioning to support learners doing investigations.

The transcript data collected from the interviews and observations were analysed qualitatively using the NVIVO computer programme (Bazeley & Richards, 2000). The data were coded by means of nodes which were operationally defined as teacher questioning taking place at each stage of the investigation. The nodes were called 'teacher questioning in planning' and 'teacher questioning in conducting' and 'teacher questioning in evaluating data'. The data were then chunked together according to these nodes. Following inter-reliability checks with other researchers in science education, the coding was revised and each node was turned into a tree node with the role of questions at each stage as its children. Three researchers in science education were asked to independently identify the roles of teacher questioning evident in excerpts of the interview and observation data. There was a high inter-coder agreement between the researchers and myself. The consolidated coding scheme described the categories of questions at each stage which encouraged learners to articulate, reflect on, clarify and review their thinking and actions. The chunks of data representing words were then clustered, sorted and systematically arranged into categories of questions at each stage of the investigation.

The KwaZulu-Natal Department of Education, as well as the principals and participating teachers and learners of the five schools gave consent for conducting the study. The research design was also approved by the ethics committee of the university which funded this project. Both teacher and learner participants were informed that their participation would be voluntary and they could withdraw at any time. However, no participant withdrew.

Findings

Arising from the analysis of the interview it became evident that teachers saw questioning as an important strategy in supporting learners doing investigations. The following comment from Ms Essop expressed this well:

> *I know they must do it but I will be there for them. I do not tell them what to do, but I ask certain questions which make them think about it. It helps because they change their mind on their own*.

The asking of questions was a dominant support strategy, and it was evident teachers use different types of questioning in supporting students through the stages of the investigation. I will now examine the types of questions used by teachers at each stage of the investigation and how learners responded to these questions.

Questioning at the planning stage

The teachers often asked clarifying questions at the planning stage in supporting learners when formulating the investigation question. Good science investigations begin with a clear and well formulated question which will enable the investigator to plan a procedure to be followed. The investigation question often asks "what if", "how" or "what effect will something have" and involve the identification of variables which need to be measured. Such questions often stem from the natural curiosity of the learners on a physical phenomenon, and are often poorly formulated. In the interview, Mr Botha explained that he supports learners in formulating the investigation question by asking them to "spell out exactly what these variables are" and when necessary he would "intervene and ask them to rethink it".

The focus on the need to clarify variables under investigation also arose during one of the class observations. The excerpt below is from an exchange which took place in Ms Essop's class where a practical on pulse rate was observed, and provides an example of how the teacher, by employing probing questions, enabled the learners to think through more clearly the relationship between the variables under investigation.

Ms Essop:	*Okay, tell me what your hypothesis is* ?
Smith:	*We want to investigate the effect of drinking coffee on the pulse rate.*
Ms Essop:	*Yes, but is this your hypothesis. Do you remember the hypothesis* ?
Ruan:	*It is a something you say which may be true. That's what you want to investigate.*
Ms Essop:	*Good. Now, can we try again. Yes, Smith.*
Smith:	*Coffee causes the pulse rate to increase*
Ms Essop:	*Can we identify the variables in this hypothesis* ?
Ruan:	*The independent variable is the amount of coffee and the dependent variable is the pulse rate.*
Ms Essop:	*I need you to explain to me how you will investigate this.*
Ruan:	*We will choose a group of people. We will take their pulse before and after*

the coffee.

Ms Essop: *In making the coffee will you add different quantities of instant coffee to the water?*

Ruan: *No, it will be two teaspoons for all.*

Ms Essop: *Then I want you to have a look at your independent variable. You said it is the amount of coffee. That doesn't seem right does it* ?

Smith: *No, we will need to change that to drinking coffee.*

Ms Essop: *So, what is the control variable* ?

Smith: *The number of spoons of coffee.*

By intervening, the teacher encouraged the learners to articulate and clarify their thinking. Furthermore, the probing questioning forced learners to reflect on what they had said and rethink the hypothesis they had formulated. This was crucial since a hypothesis which is misinterpreted or poorly formulated will lead to invalid results.

Questioning as a support strategy is also used by teachers in guiding learners when planning how to conduct the investigation. This often results in learners rethinking their plan. This is illustrated in the following excerpt from an experiment in Ms Reuben's class to show that one of the products of combustion of a candle is carbon dioxide. The teacher used a series of probing questions to influence students to rethink their plan.

Ms Reuben: *Guys tell me what you will do.*

Trevor: *Ma'am, we will burn the candle. This gives* CO_2 *. We then take something burning like a match. If it goes off it proves the candle gave* CO_2*.*

Ms Reuben: *Okay so will you hold the burning match close to the candle flame* ?

[The learners all answered '*yes ma'am*'.]

Ms Reuben: *Okay, I want you to think about this before you conduct your experiment. How do things burn and what is needed for burning* ?

[The learners reflect on this question and engage in a group discussion. Thereafter teacher returns to the group.]

Ms Reuben: *Have you thought about this* ?

Vijay: *Ya, we know that oxygen is needed for burning.*

Ms Reuben: *Good. You are saying that the match that's burning will go off in air when held near the candle* ?

Vijay: *Ya.*

Ms Reuben: *Think about this ... in air. Yes, Suren* ?

Suren: *I am not sure ... but with the oxygen in the air it will carry on burning.*

Ms Reuben: *Good. So what do you think you need to do* ?

Suren: *Collect the gas in a container.*

Ms Reuben: *Yes, now I want you to design this and show me what you will do.*

[After a discussion, the group leader calls for the teacher.]

Ms Reuben: *Okay Trevor what's your plan* ?

Trevor: *We think we need to have a bottle to store the* CO_2*. We can put the candle in the bottle ... light it and then quickly put the match there.*

The above excerpt reflects that although the teacher was deliberate and focused in her questioning, the learners ultimately realised they had to reconsider their original plan.

Conducting stage of the investigation

Teachers also question the learners about what they are doing while they are busy conducting the investigation. This is illustrated in the following excerpt from an investigation described in Mr Pillay's class where learners investigated the relationship between current strength and potential difference across a light bulb in a circuit.

Mr Pillay: *Okay, what seems to be the problem here* ?
Johnson: *The bulb is off.*
Mr Pillay: *Have you checked to see that your circuit is complete ? Are there any gaps in your circuit ? Is your circuit closed* ?

[The learners answer, '*yes sir*' in unison.]

Mr Pillay: *Okay, I want you to look closely at your connection of the voltmeter. What is the voltmeter doing in this circuit* ?
Kelly: *Measuring volts*.
Mr Pillay: *What do you mean by that* ?
Kelly: *The voltage*.
Mr Pillay: *What is voltage* ?

[The learners are unable to answer.]

Mr Pillay: *I want you to get out your notebooks and look up what voltage is*.

[The learners page through their notebooks and then Johnson answers.]

Johnson: *It is the energy transfer per Coulomb of charge*.
Mr Pillay: *Explain this to me in your own words*.
Johnson: *How much energy the current supplies to the circuit* ?
Mr Pillay: *Good. Now let's go back here. Why do we have this voltmeter in the circuit* ?
Visharlan: *To measure the energy transfer across the bulb*.
Mr Pillay: *Now to measure this energy transfer across the bulb, how should the voltmeter be connected. In series or parallel ? Yes, Vishalan* ?
Visharlan: *I think in parallel* ?
Mr Pillay: *Good. Now look at what you have done here*.

[The learners then make the changes to the circuit and the bulb glows.]

This exchange between the teacher and learners shows how the teacher, by redirecting the learners to a concept already studied, is able to get them to reflect on and rethink their connections in the circuit. The teacher did not tell or show the learners what to do. Instead, the teacher checked on the conceptual understanding of the students by asking the learners to explain in their own words the concept of 'electrical potential difference'. This was crucial in deciding whether a series or parallel connection of the voltmeter would be correct.

A similar exchange took place in Ms Zulu's class where learners were investigating the floating and sinking of objects. The learners who had previously been instructed on the use of the measuring cylinder were using it to measure the volume of a sample of water. On one occasion Ms Zulu had observed that a group of learners had used an incorrect technique in measuring the volume of water. Through the use of focused, probing questions she was able to direct the learners to the error and get them to reconsider measuring the volume using the technique they had been instructed on.

Evaluating data and communicating findings

Teachers asked questions to guide learners in analysing the data and drawing a conclusion. In Ms Zulu's class the learners after taking and recording mass and volume measurements of materials were trying to formulate a rule on the flotation and sinking of objects. The teacher used questions to guide a group of learners who were having difficulty in analysing these results in working out the rule. This is illustrated as follows:

Ms Zulu: *We have three things. We have the mass, volume … what else* ?
Cindy: *We found the density.*
Ms Zulu: *Good so we have calculated the density. Now some object float and other sink. What do you think determines this* ?
Natalie: *It must be the size.*
Ms Zulu: *What do you mean by size* ?
Natalie: *The mass.*
Ms Zulu: *Now look at your table. Compare the glass and the piece of wood. Which has the bigger mass* ?
Learners: *The wood.*
Ms Zulu: *But did this sink* ?
Learners: *No.*
Ms Zulu: *So what makes an object sink* ?
Sita: *The density.*
Ms Zulu: *When will the object sink in water ? Remember water has a density of 1 g/cm^3. Yes, Natalie* ?
Natalie: *If the density is bigger.*
Ms Zulu: *That's right.*

Through this guiding questioning the learners were able to make sense of their data and arrived at the conclusion that "if an object is more dense that water, it will sink".

Teachers also ask probing questions when asking learners to review their plan if the findings are incorrect. An example of this support strategy was evident in the observation which took place in Mr Botha's class. A group of learners who had investigated the effect of temperature on the resistance in the circuit had erroneously concluded that resistance in a circuit is lower at a higher temperature. Upon using probing questions about the procedure they had followed, the learners were led to discover the flaw in their plan. During the experiment the learners had failed to control other variables such as the length of the conductor and its thickness. By reviewing their plan, the learners were able to redo the investigation and control the variables correctly.

Mr Pillay explained why it is necessary to intervene at such a stage, by stating that incorrect findings should not be allowed to hang in suspension. He explained that through probing questions, the learners should be made to review what they have done wrong:

> *The teacher should not accept an incorrect finding. This will lead to misunderstanding in science. He must quiz them about their plan. They need to see where they had gone wrong. If there is time they must go back and do the investigation again* (Mr Pillay interview).

In general the data gathered showed that teachers used a questioning strategy in enabling the learners to understand more clearly the question or hypothesis they intended investigating, to review and reconsider their planning, to reflect on and rethink some of their actions when collecting data, to make sense of their data in arriving at a conclusion, and to review their plan after generating incorrect findings.

Discussion of findings

The study reveals that although autonomy may be transferred to learners in doing practical investigations, teachers believe that they have a pivotal role to play in supporting these learners through the investigative process. The types of questions employed by the teachers in supporting learners were consistent with the "productive" type of question described by Chin earlier which enables learners to reflect upon their actions and decisions, and when necessary to reconsider them. The teachers' use of questioning invokes Vygotsky's notion of mediated learning in the ZPD as learners appropriated knowledge and skills through this interaction during the stages of an investigation.

When formulating their own questions, the teacher supports them in ensuring that the question they pose is clear and investigable. Support at this initial phase is particularly important as identifying a question plays such a powerful role because it gives meaning and direction to what follows (Kuhn, 2007; Howes, Lim & Campos, 2009). Investigation questions, although having their roots in the curiosity of learners, do not emerge spontaneously from learners and teachers have to employ strategies to elicit them (Chin & Osborne, 2008). The findings of this study show that teachers intervene in particular where learners are formulating a question for an investigation involving the relationship between variables. Brook, Driver & Johnston (1989) observe that in formulating an investigative question, learners need to have a good grasp of the notion of a variable. Setting up an experiment requires explicit definition of the variable or variables which form the focus of the investigation and of other variables which need to be controlled.

The teacher also asked questions in supporting the learners when they are conducting the investigation by manipulating apparatus to collect data. Learners maintain control over this stage of the investigation, but the teacher intervenes only when necessary. When the teacher observed an error or suspected a reading was in correct, the teacher asked them questions so that they reviewed what they had done.

Once learners had collected and recorded their data, difficulty arose in analysing the data to answer the question or address the hypothesis posed initially. The difficulty arises when learners are unable to see a pattern or relationship. The teachers supported the learners without telling by asking questions which enabled them to focus on aspects of the data. There were occasions when learners arrived at a finding which was not correct. The teachers asked probing questions which forced learners to review their plan and also to reflect on how they conducted the investigations. As a result of this they were able to identify the source of the error, and go back to an earlier stage of the investigation.

The questioning employed by teachers, apart from supporting the learners to do the investigation, also developed in learners the habit of reflection and self-criticism of what they were doing (Harlen, 2001). It is envisaged that when learners become used to reviewing their work, they will not require someone else to help them reflect on what they did, but will do so spontaneously.

Conclusion

The implementation of science investigations at schools presents a new challenge to teachers as it signals an opportunity to shift from a teacher-centred to a learner-centred approach in practical work. Teachers are now faced with a situation of relinquishing their traditional control in the classroom and using support strategies in facilitating the learners' progress towards greater autonomy. I have attempted in this paper to understand and describe how questioning, which is directed at encouraging learners to articulate, reflect on, clarify and review their thinking and actions, can support learners through the stages of the investigation. As described earlier despite curriculum imperatives for learner to do open investigations where they have autonomy over all stages of the investigation, research conducted both locally and internationally shows that learners have only limited autonomy when doing investigations. The discussion and examples of questioning as a support strategy can perhaps provide guidance to science teachers in honing their questioning skills when supporting learners towards greater autonomy in science investigations. Thus, the significance of this study is in making explicit how questioning can be used at each of the stages of a science investigation in facilitating productive learner thinking. This questioning stands in constrast to that which prevails in a teacher-controlled environment where closed questions pitched at a lower order of cognitive level dominate.

It should be emphasised that the teachers involved this study were all well qualified to teach Natural Sciences, were teaching at schools with adequate laboratory facilities and where class sizes did not exceed 40 learners. It is recommended that further research on teacher questioning during investigations be done with teachers and schools that have different profiles as those described in this paper, so that the possible influence of contextual factors on teacher questioning may be investigated.

References

Anderson RD 2007. Inquiry as an organizing theme for science curricula. In: Abell KS & Lederman NG (eds). *Handbook of Research on Science Education*. Mahwah: Lawrence Erlbaum Associates, Inc.

Bazeley P & Richards L 2000. *The NVivo Qualitative Project Book*. London: SAGE.

Billings RL 2001. *Assessment of the learning cycle of inquiry-based learning in high school physics education*. Unpublished doctoral thesis, Michigan State University, East Lansing.

Black AE. & Deci EL 2000. The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education*, 84:740-756.

Brook A, Driver R & Johnston K 1989. Learning process in science: a classroom perspective. In: Wellington J (ed.). *Skills and processes in science education: A critical analysis*. London: Routledge.

Chin C 2003. Success with investigations. *The Science Teacher*, 70:34-40.

Chin C 2007. Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, 44:815-843.

Chin C & Osborne J 2008. Students' questions: a potential resource for teaching and learning science. *Studies in Science Education*, 44:1-39.

Corry A 2005. Mentoring students towards independent scientific inquiry. In: Alsop S, Bencze L & Pedretti E (eds). *Analysing exemplary science teaching*. Berkshire: Open University Press.

Department of Education 2002. *Policy: Revised National Curriculum Statement for Grades R-9 (Schools), Overview*. Pretoria: Government Printer.

Fradd SH & Lee O 1999. Teachers' roles in promoting science inquiry with students from diverse language backgrounds. *Educational Researcher*, 28:14-20.

Gott R & Duggan S 2007. A framework for practical work in science and scientific literacy through argumentation. *Research in Science & Technological Education*, 25:271-291.

Haigh M 2001. Supporting student investigations. *New Zealand Science Teacher*, 96:39-41.

Harlen W 2001. *Primary science taking the plunge*. Portsmouth: Heinemann.

Howe AC 2002. *Engaging children in science*. New Jersey: Merrill Prentice Hall.

Howes EV, Lim M & Campos J 2009. Journeys into inquiry-based elementary science: Literacy practices, questioning, and empirical study. *Science Education*, 93:189-217.

Kim M & Tan A 2010. Rethinking Difficulties of Teaching Inquiry-Based Practical Work: Stories from

elementary pre-service teachers. *International Journal of Science Education*.
King A 1994. Guiding knowledge construction in the classroom: Effects of teaching children how to question and to explain. *American Educational Research Journal*, 31:338-368.
Kuhn D 2007. Reasoning about multiple variables: Control of variables is not the only challenge. *Science Education*, 91:710-726.
Lemke JL 1990. *Talking science: Language, learning and values*. Norwood: Ablex Publishing.
Onwu G & Stoffels N 2005. Instructional functions in large, under-resourced science classes: perspectives of South African teachers. *Perspectives in Education*, 23:79-91.
Rogan JM & Aldous C 2005. Relationships between the constructs of a theory of curriculum implementation. *Journal of Research in Science Teaching*, 42:313-336.
Rogoff B 1990. *Apprenticeship in thinking*. New York: Oxford University Press.
Roth W-M 1994. Experimenting in a constructivist high school laboratory. *Journal of Research in Science Teaching*, 31:197-223.
Seopa MA, Laugksch RC, Aldridge JM & Fraser BJ 2003. *Development of an instrument to monitor the success of outcomes-based learning environments in science classrooms in South Africa*. Paper presented at the Third International Conference on Science, Mathematics and Technology Education, East London, South Africa.
Smith PS, Banilower ER, McMahon KC & Weiss IR 2002. *The national survey of science and mathematics education: Trends from 1977 to 2000*. Chapel Hill: Horizon Research.
Sund RB & Trowbridge LW 1973. *Teaching science by inquiry in the secondary School*. Ohio: Merrill.
Trumbull DJ, Scarano G & Bonney R 2006. Relations Among Two Teachers' Practices and Beliefs, Conceptualizations of the Nature of Science, and their Implementation of Student Independent Inquiry Projects. *International Journal of Science Education*, 28:1717-1750.
Viechnicki GB & Kuipers J 2006. It's all human error!": When a school science experiment fails. *Linguistics and Education*, 17:107-130.
Villanueva-Hay MG & Webb P 2007. *Science notebooks: a useful strategy for scientific investigations*? Proceedings of epiSTEME 2 February 12-15, 2007, Homi Bhabha Centre for Science Education, HBCSE, TIFR, Mumbai. Accessed from http://www.hbcse.tifr.res.in/episteme/episteme-2/e-proceedings/hay
Vygotsky LS 1978. *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.
Wu H-K, & Hsieh C-E 2006. Developing sixth graders' inquiry skills to construct scientific explanations in inquiry-based learning environments. *International Journal of Science Education*, 28:1289-1313.

Author

Umesh Ramnarain is Lecturer in science education at the University of Johannesburg and has over 16 years' teaching experience in Physical Sciences. His research interest includes practical work in school science, with particular focus on the development of support systems.