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How to Support Primary Teachers' Implementation of Inquiry: Teachers' Reflections on Teaching Cooperative Inquiry-Based Science

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Abstract Many primary teachers face challenges in teaching inquiry science, often because they believe that they do not have the content knowledge or pedagogical skills to do so. This is a concern given the emphasis attached to teaching science through inquiry where students do not simply learn about science but also do science. This study reports on the reflections of nine grade 6 teachers who taught two cooperative, inquiry science units once a term for two consecutive school terms. The study focused on investigating their perceptions of teaching inquiry science as well as the processes they employed, including the benefits and challenges of this student-centred approach to teaching, with longer task structures that characterises inquiry learning. Although the teachers reflected positively on their experiences teaching the inquiry science units, they also expressed concerns about the challenges that arise when teaching through inquiry. Implications for teacher education are discussed.

Keywords Inquiry science · Teachers' reflections · Cooperative learning · Guided inquiry learning

Introduction

Greater emphasis, in recent years, has been placed on having teachers teach science using an inquiry approach where students are actively involved in scientific investigations that provide them with opportunities to explore possible solutions, explain phenomena, elaborate on potential outcomes, and evaluate findings (Duschl et al. 2007; Harris and Rooks 2010). Inquiry learning has many potential benefits. It can (1) capture students' interest in science by providing opportunities that not only challenge but also inspire and fascinate them with what it has to offer (Norton-Meier et al. 2008; Osborne 2006); and so (2) address the decline in numbers of students choosing to study science (Osborne 2003), particularly in the senior high school years where the decline is marked (Goodrum et al. 2012), and (3) foster collaborative student talk and be used to promote reasoning and scientific understanding during small-group discussions (Kuhn 2010; Kuhn et al. 1997; Mercer et al. 2004).

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The decline in students studying science is a trend in the developed world, including Australia (Marginson et al. 2013), Israel (Vedder-Weiss and Fortus 2011), and the UK (Ruthven 2011). This trend possibly exists for a number of reasons, not the least being primary teachers' lack of confidence in being able to teach science (Appleton and Kindt 2002; Hackling 2008) with fewer than one third of elementary teachers (K-5) in the USA feeling very well qualified to teach science and three quarters perceiving a substantial need for professional development to deepen their own science content knowledge. The 2000 National Survey of Science and Mathematics Education: Status of Elementary School Science Teaching found that only 4 % of elementary science teachers have undergraduate degrees in science or science education with 40 % of elementary teachers indicating that they had taken four or fewer semesters of science coursework, suggesting that they had not received an adequate background in science (Fulp 2002a). Similarly, the 2000 National Survey of Science and Mathematics Education: Status of Middle School Science Teaching found that two thirds of middle school science teachers received their undergraduate degree in areas other than science or science education raising concerns about the lack of in-depth content preparation for teaching any science (e.g., life science/biology, physical science, earth science) (Fulp 2002b).

These findings were virtually unchanged in the 2012 National Survey of Science and Mathematics Education (Banilower et al. 2013), with only 5 % of elementary teachers indicating that they have science/engineering or science education degrees. However, while 85–90 % of elementary teachers indicated they had completed at least one course in the life sciences or science education, and approximately 70 % had a student teaching experience that included science, only 1–2 % of elementary teachers had completed a course in engineering or physics (National Research Council 2012). Not surprisingly, when elementary teachers were asked about their perceptions of their preparedness to teach science, only 39 % felt very well prepared to teach science.

While the National Science Teachers' Association (2002) supports the notion that inquiry science must be a basic in the daily curriculum of every elementary school student at every grade level, research indicates that a lack of understanding of the inquiry process is a contributing factor to teachers' lack of confidence in teaching inquiry science (Lee et al. 2004; Yoon et al. 2012).

Knowledge of science content as well as content-specific strategies in identifying students' misconceptions, promoting inquiry, and encouraging group collaboration and problem solving are critically important if teachers are to be effective in implementing inquiry science in their classrooms (Appleton 2003; Osborne 2003). The National Research Council (2000) noted that when children participate in inquiry science, they are engaged by scientifically–oriented questions, learn to give priority to evidence, evaluate explanations in the light of alternative explanations and learn to communicate and justify their decisions—dispositions needed to promote understanding and learning. “Scientific inquiry requires the use of evidence, logic, and imagination in developing explanations about the natural world” (Newman et al. 2004, p. 258).

Scientific inquiry recognises the diverse ways in which scientists study the natural world" and propose explanations based on the evidence derived from their work. It also refers to “the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Science Teachers Association 2004, p. 1). When students have opportunities to engage in scientific inquiry, they learn to use their ideas and, in so doing, deepen their conceptual understanding of scientific content as well as their understanding of how to do science. “This science-as-practice perspective brings together content knowledge and process skills in a manner that highlights their interconnected nature” (Harris and Rooks 2010, p. 229), facilitating student engagement with complex science ideas and participation in scientific activity.

Teachers capture children's interest in science by providing opportunities for them to: investigate natural phenomena through experimental and conceptual explorations, ask thought-provoking questions, and engage in collaborative discussions to communicate scientific ideas and develop consensus on the topic under discussion (Lee et al. 2004; Metz 2008). Developing these dispositions in children often requires that teachers have the opportunity to participate in professional learning experiences that deepens their own knowledge of scientific content, enables them to learn the pedagogies appropriate for teaching science and develops their ability to interpret and respond to observations and assessment results (Duschl et al. 2007). However, while professional learning activities can produce fundamental changes in teachers' knowledge, beliefs, and practices (Lumpe et al. 2012; Rushton et al. 2011), these can be adversely affected by too short a duration (Borko 2004), limited funding and resources to facilitate follow-up (Lee et al. 2004), and a lack of application of information and ideas emanating from the professional learning workshops to classroom practices (Posnanski 2010).

There is no doubt that teaching inquiry in elementary science classes can create dilemmas for teachers who often struggle to provide sufficient inquiry science experiences, given the constraints on time, the crowded curriculum, and students' lack of experience with inquiry learning (Newman et al. 2004). Knowing how to establish small cooperating groups so children understand that they are to work together to share ideas, discuss differences, and construct new understandings are additional difficulties that teachers have to contend with when they implement inquiry learning (Gillies and Boyle 2010).

Cooperative Learning

Cooperative learning is widely seen as a pedagogical practice that promotes students' engagement and learning (Gallardo-Virgen and DeVillar 2011; Howe and Tolmie 2003), principally because students are required to work together to achieve a common goal or task. When children cooperate, they learn to listen to what others have to say, share ideas and information, clarify misconceptions, and generate new understanding (Johnson and Johnson 2002; Slavin 1995). In fact, when this happens in science classrooms, Ford and Forman (2014) argue that students engage in a process of dialogical discourse that encourages them to collaboratively construct and critique different ideas and points of view and, in so doing, they begin to learn how to function as a scientific community. This give and take of talk, Ford and Forman believe, is essential if productive scientific talk is to occur, and it is this dialogical discourse that, in turn, supports changes to students' reasoning and scientific habits of mind.

From a socio-cultural perspective, the group context enables students to interact with others and think about issues in new ways. In so doing, information and ideas exchanged are transformed and appropriated so they become part of new ways of thinking and doing or generating knowledge (Palinscar 1998). By engaging in reciprocal interactions with each other, children also learn to use language differently to explain experiences and realities and, in so doing, find new functions for language in thinking and feeling (Mercer et al. 1999). Moreover, when children are taught to talk and reason together and apply these skills in their study of science, Mercer et al. (2009) found that they used 'talk' more effectively as a tool for reasoning and that their talk-based activities had a useful function in scaffolding the development of reasoning and scientific understanding.

While it is acknowledged that the knowledge-building practices of scientists are essentially social and cooperative, small-group learning provides opportunities for students to investigate phenomena of interest, discuss potential research questions, work out how to collect and analyse data, and communicate and represent scientific ideas and information (Duschl and Grandy 2009; Herrenkohl et al. 1999). Research also indicates that small-group work in elementary classrooms seldom reflects the purposes or practices of scientific knowledge building (Kelly 2008; Metz 2008). This, in part, may occur because of primary teachers' lack of confidence in teaching science. "Many teachers appear to have difficulty creating classroom environments that are inquiry-based, that support their students in developing informed views of scientific inquiry" (Crawford 2007, p. 613) while others need to develop the necessary content-specific pedagogical understandings to be successful at facilitating scientific inquiry experiences (Marshall et al. 2009). Further difficulties may also arise in establishing cooperative learning experiences where children learn to share, critique, and evaluate plausible explanations to the problem at hand (Gillies and Khan 2009).

The Teacher's Role in Inquiry Science

Inquiry learning is seen as critically important to helping students engage in science, yet teachers continue to struggle with what inquiry should look like and how it should be taught. Zuckerman et al. (1998) identified three factors that they considered crucial for teaching inquiry science to primary students. First, teachers must arouse "students' imagination by presenting new and breath-taking phenomena that are already within students' zone of proximal development, that is, within the child's ability to recognise the new elements in these phenomena and to relate these new elements to the context and structure of existing background knowledge" (p. 208). Second, teachers need to provide opportunities for students to work with others to resolve the problem under discussion, and, finally, students need to be encouraged to engage in continually asking questions to test out their ideas and eventually verify their hypotheses.

The advancement of inquiry is dependent on the teachers' timely efforts to guide students as they engage in the inquiry process (Duschl and Duncan 2009; Veermans et al. 2005). When teachers actively engage in challenging children's thinking and problem solving during cooperative learning by making explicit the types of thinking they want children to participate in, Gillies and Boyle (2006) found that children, are more focused and explicit in the types of help they provide. The effective enactment of inquiry science instruction therefore requires that teachers strategically scaffold activities so that students understand how to think as they participate in tasks, as well as acquire the procedural knowledge of how to complete them; how to cooperate with peers; and how to critically reflect on their learning (Harris and Rooks 2010; Hmelo-Silver et al. 2007).

Purpose of the Study

Given that research recognises that many elementary teachers face challenges in teaching inquiry science, the purpose of this study was two-fold: first, to investigate the participant teachers' perceptions of teaching inquiry science (Bryan 2003), including the teaching processes that they employed (Hackling 2008), and, second, because inquiry science adopts a student-centred approach requiring students to work in small teams to investigate topics, the benefits and challenges posed are also explored.

Method

Materials and Procedures

Prior to the study commencing, the teachers participated in 4 days of professional learning workshops which provided them with the background information and training on the implementation of the inquiry science units (2 days) that they had agreed to teach and the integration of cooperative learning strategies (2 days). Previous research has demonstrated that teacher professional workshops of a total of 2–4 days are effective at helping teachers to implement curricula changes (Gillies and Haynes 2011; Thurston et al. 2010; Topping and Trickey 2007; Topping et al. 2011).

The teachers agreed to teach two inquiry science units investigating living versus non-living things and genetically modified (GM) food. The focus of the living and non-living unit was on helping students identify the differences between these by having them explore their own pre-conceptions of what characterises living things and apply this knowledge to a novel situation. The unit consisted of 12 lessons taught over a 6-week period, which encouraged students to draw upon their prior knowledge to identify living things, and explore how living things acquire energy, move, respire, excrete, reproduce, and grow and develop.

The students were introduced to the unit by a stimulus activity, “We’re off to look for aliens” (McNaughton 2007), which was designed to engage students with the topic and to begin the questioning process. By drawing upon students’ own pre-conceptions of living things, the teacher helped the children generate a list of inquiry questions and categorise and organise the questions around themes using the 5W questioning framework (what, who, why, when, where, how). The children examined the pictures in the book and discussed the characteristics the aliens had (e.g., huge eyes, tentacles with smoke, etc.) and whether these characteristics were found in living things on earth. Subsequent lessons explored the following questions: *What makes something living*? *How do living things get their energy*? *Do all living things move*? *How do they move*? *How do living things reproduce*? *Do all living things respond to stimuli*? *How do I respond to stimuli*? *Do all living things respire*? *How do they respire*? *Do all living things grow and develop*? The remaining lessons in the unit were designed to help students refine their lists of characteristics for the various topics and coalesce their ideas. The final topic, *The Martian and the car*, presented the students with a novel scenario that required them to develop a group response to whether the car was living or non-living and justify their answers in a presentation to the whole class.

Students used the internet, books, and other resources, including their own pre-conceptions to investigate the different topics, either individually or in small groups, organise and analyse the data collected (e.g., collect information on living and non-living things and identify the characteristics of living things; identify if all living things need energy and if so how they get their energy; identify if all living things move and if so how; identify if all living things reproduce and if so how; identify if all living things respond to stimuli and if so how; identify if all living things respire and if so how; identify if all living things grow and develop and if so how), and present their findings to the larger class where they had opportunities to justify their propositions while challenging the opinions and arguments of others. We have previously published additional details about this unit of work (Gillies et al. 2012).

The focus in the second unit, GM food, was on helping students develop a personal position on whether Australia should grow genetically modified crops. The purpose of the unit was to guide students to come to a personal position on the question “Should Australia grow GM crops?” The unit consisted of 17 lessons involving learning about advances in biotechnology, including stem cell research and genetic engineering such as cloning. Students were also introduced to the structure of a cell, including its nucleus, chromosomes, and DNA, and they participated in a laboratory experiment involving gel electrophoresis designed to model the DNA extraction process. Data collected and analysed by the children included information on GM food, developments in biotechnology, information on the process of genetic modification, a report on a practical laboratory experience of gel electrophoresis using food dyes to demonstrate how molecules can be separated based on size to genetically modify food, and information on the social, health, environmental, and economic arguments for and against GM food. The unit was taught across an 8-week period, designed to enable the students to understand the purpose of science, practice generating questions, learn the basic content of the unit, synthesise new understandings and dispel misconceptions, engage in practical experiments, and learn to evaluate the pros and cons of growing GM food. As with the earlier unit on living and non-living things, we have previously published additional details about the unit on GM food (Gillies et al. 2012).

Inquiry science is the context in which this study was located. During inquiry science, inquiry skills are developed, which include identifying questions and concepts about scientific phenomena under investigation, learning how scientific investigations are designed, and developing logical scientific explanations. Inquiry learning helps students to understand how science is carried out in the real world, where answers to problems do not readily appear nor can they be found by quick reference to authority; rather, they are solved through conducting investigations, examining the available information, sharing ideas with peers, and reflecting on past experiences and learning (Duschl et al. 2007).

During the inquiry science activities, the children worked in small groups to study a real world problem, make their own observations, and propose explanations based on their discussions and reflections. In this study, the teachers used researcher-designed inquiry units structured using the 5E Instructional Model (Bybee 2006). This type of inquiry approach may also be considered as a guided Level 2 inquiry (Blanchard et al. 2010) where students are scaffolded to generate questions that guide the inquiry. The questions are then explored through theoretical and experimental approaches with whole class and small group social interactions. Tables 1 and 2 describe details of the lessons and activity sequences in the two units of inquiry.

Researchers modelled teaching of the units by stepping the participating teachers through the lessons and 5E phases that specifically included: (a) an engagement phase that was designed to capture students' interest (e.g., Should Australia grow genetically modified food? Watch the video clip: *GM Food* to stimulate interest in the topic and help to pose questions. Organise into groups to work collaboratively to complete graphic organiser (see Fig. 1) '*biotechnology in the news*' and devise a list of questions to drive inquiry. Devise whole class list grouping questions into when, where, what who and why (5Ws). For example, *How do you genetically modify something? What is a nucleus? Where are GM crops grown? Who does genetic engineering? Why should Australia grow GM crops?* Students and teachers update the list at any stage of the inquiry; (b) an exploration phase, which provided experiences to challenge students' current understandings (e.g., students had opportunities to explore the core foundational learning in the unit and formulate questions such as, *What is DNA? What is genetic modification? How many cells? What is in every cell?*; (c) an explanation phase that enabled students' explanations to align with scientific explanations (e.g., students are introduced to the process of genetic modification and participate in a laboratory experiment that simulates the DNA extraction process; *How do you extract DNA? What is a blue print?* (DNA contains blueprints) *Why is DNA structured that way?* (twisted strands); (d) an elaboration phase that enabled the application of scientific concepts to new situations (students use different websites, books, and video clips to gather information about the advantages and disadvantages of GM food; What are the advantages of GM food? What are the disadvantages of GM food?); and (e) an evaluation phase that provided opportunities to assess scientific understandings and conceptual development (e.g., students work in small groups to present their arguments). The purpose of the 5E model was to enable longer instructional sequences to allow students to recognise the inadequacy of their own current ideas, to explore new ways of explaining the world, to reflect on their thinking, and to construct new conceptions during their small group discussions.

Table 1 Activity sequence of the guided inquiry unit on living and non-living things organised using 5E's

Day 1 Use stimulus story "We're off to look for Aliens" Pose question "if we were able to explore our solar system, how would we know if something were alive?" To engage the students in the topic of living things and their characteristics. Generate a class list of inquiry questions. Day 2 Organise into groups to work collaboratively to complete organiser—*what makes something living?* and devise characteristics of living things Devise whole class list. Students decide in which order they will investigate each characteristic. Day 3 Explore how living things acquire energy to challenge this characteristic as a feature of all living things In groups students work collaboratively to group living things according to how they obtain energy. Day 4 Explore how living things move to challenge this characteristic as a feature of all living things. In groups students work collaboratively to group living things according to how they move. Day 5 Explore how living things reproduce to challenge this characteristic as a feature of all living things. In groups students propagate plant of their own from seeds or cuttings. Introduce concepts of sexual/asexual reproduction and mindmap two types providing examples.	Day 6 Explore how humans respond to stimuli to challenge this characteristic as a feature of all living things. In groups students spend time at each activity station and explore different senses: sight, taste, hearing and touch. Day 7 Explore how living things respire to challenge this characteristic as a feature of all living things. In groups students carry out experiments with lime water and yeast. As a whole class discuss differences between breathing and respiring. Day 8 Explore how living things grow and develop to challenge this characteristic as a feature of all living things. In groups students compare and contrast different lifecycles and differentiate between growth and development. Day 9 In groups students consolidate ideas around the list of characteristics (further discussion of particular characteristics, e.g., motion) and reason conceptually to arrive at a consensus on what are the characteristics of living things. Day 10 In groups students apply, evaluate and refine list using the Martian and the car activity. Days 11 and 12 Groups report back to whole class about the reasoning required to reach final decision of whether the car is living or non-living. Students present their solutions, logic and justifications to the rest of the class.

In addition to receiving training on the implementation of the inquiry science units as described in detail in Tables 1 and 2, the participating teachers were introduced to the key elements required for successful cooperative learning and they were shown how to embed these elements into their science activities. This included ensuring that the tasks were structured so that all students were required to contribute (i.e., the larger group task was divided into smaller tasks so each group member completed one of these smaller tasks), students were taught the small-group and interpersonal skills needed to facilitate group cooperation (i.e., active listening, one person speaks at a time, students share resources), individual accountability was established to ensure that all students were responsible for completing their part of the group task (i.e., each student had to share the task he/she had completed with the group), students encouraged others to share ideas and information (i.e., students were taught to politely ask each other to share their ideas or information), and students were encouraged to reflect on the group's progress in achieving its goal (i.e., What have we achieved? What do we still need to do?) (Johnson and Johnson 1990). When these key elements are evident, research indicates students consistently obtain higher learning outcomes, engage in more helping discourses that promote reasoning and learning, and demonstrate more positive peer relationships than peers who do not work in cooperative groups (Roseth et al. 2008).

Table 2 Activity sequence of the guided inquiry unit on GM food organised using 5E's

Day 1

Use stimulus clip "Science through the ages." Pose question "Should Australia grow GM crops?"

To engage the students in the positive and negative implications of science on society and the planet.

Generate a class list of inquiry questions that inevitably include "What is a GM crop?" explored in future lessons.

Day 2

Organise into groups to work collaboratively to complete organiser—*biotechnology in the news* and devise a list of questions to drive inquiry.

Devise whole class list grouping questions into when, where, what, who and why (5Ws).

Students and teachers update list at any stage of the inquiry.

Day 3

Explore 'Tour of the basics' website for foundational content on DNA in groups and structure their exploration with the 'Discoveries and Wonderings' organiser. More inquiry questions may be added to the class list.

Day 4

Students have opportunity to explain understanding of content from 'Tour of the basics' site. Small group collaboration to complete a mindmap on DNA using organiser from day 3. Teacher to guide construction of mindmap at first and hand over more control as map emerges.

Days 5–6

Explore further foundational concepts and add to DNA mindmap through interaction with digital learning objects from the Learning Federation.

Day 7

Students are introduced to genetic modification with a poster on 'How do I genetically modify something?' As a first step in the genetic modification, students explore DNA hands on by extracting DNA from strawberries. Homework prior to this lesson is exploring the procedure. Prior to extraction, teacher leads discussion of procedure using drawings and encourages explanations.

Day 8

In groups, students explore virtual simulation of gel electrophoresis (next step in genetic modification). Then run a gel electrophoresis with food dyes.

Days 9–12

In expert groups students gather information specific to their argument around the question of the unit. Teacher models use of 'arguments for and against GM food' organiser. Students classify information as fact, opinion or speculation, and as social, environmental, health or economic, as well as benefit or disadvantage.

Days 16–17

Students, in groups, will present their arguments.

The participating teachers worked in cooperative groups during their professional development days (as children would in schools) to read the materials, construct word lists and

Discoveries (Knowledge/comprehension)	Wonderings 5Ws (Synthesis)	Discoveries (Knowledge/comprehension)	Wonderings 5Ws (Synthesis)
Sports stars stem cells, ABC News			
Sports clubs to store stem cells	What are stem cells? Are there other types of stem cells?		
Take stem cells from bone marrow	What's bone marrow?		
To be used for bone, ligament or cartilage injury	What would they use for muscle injuries		
Injected stem cells reduce recovery time			
Ethical issues still need to be addressed	What are the ethical issues?		
Human use still a few years away	Why does it take so long? So can I use it on my injured dog?		
$20,000 for the procedure			

Fig. 1 The biotechnology in the news graphic organiser. An example of graphic organisers used in the science inquiry units

charts of specific scientific words (e.g., herbivore, carnivore, omnivore, phototrophic, chemotrophic), identify questions they needed to ask, participate in different science experiments (e.g., blowing air through lime water to detect carbon dioxide), and complete graphic organisers to assist them to classify and categorise living and non-living things in regard to being able to breathe, move, grow, respire, and reproduce. As part of their cooperative experiences, teachers were asked to identify the small-group skills that would be important for successful cooperation (e.g., listening to each other, sharing ideas and resources, democratic decision making, contributing, reflecting on the group's progress). The teachers developed a list of these skills for use in their own classes. Other issues that were discussed were cooperative tasks that the students could work on in their groups, size of groups, and different grouping arrangements based on ability, friendship, or learning needs.

Interviews

Nine teachers who taught two inquiry science units volunteered to participate in the interviews that were conducted following the completion of the second science unit (see Gillies et al. (2012) for a description of the larger study in which these teachers participated). All teachers taught grade 6 and were from five different schools with similar socio-demographic profiles in a large metropolitan city in Australia. Six of the teachers were females and three were males and seven had had more than 5 years of teaching experience. While all of the teachers had a bachelor's degree (4 years of university study), only one had a qualification to teach science and mathematics in secondary school. The remaining eight teachers had completed a general education degree for primary teachers with no more than two courses in science education across the 4 years. Furthermore, none of the teachers had previously taught science using an inquiry approach involving students working in cooperative small groups on specific scientific tasks requiring investigation.

All of the teachers had indicated that they had generally adhered to the structure of the inquiry units and the cooperative learning strategies as demonstrated during the professional development days. All activities of both units were completed, although there were minor variations in the time taken to complete the units and the required activities. The variation in completion times was mainly due to various school demands/activities.

Five of the teachers were interviewed individually and four were interviewed in pairs, following the completion of the study. The interviews were semi-structured to enable the teachers to elaborate on the open questions that were asked (see Appendix 1 for examples of the interview questions). Given that the emphasis in inquiry learning is on student-centred, "hands-on" learning to explore, explain, elaborate, and evaluate scientific phenomena through group investigations and discussion and the research that indicates that students' reasoning, problem solving, and learning are enhanced when they work cooperatively together (Thurston et al. 2010; Topping and Trickey 2007), the study sought to investigate teachers' reflections of their experiences teaching cooperative, inquiry science. In this study, inquiry science involved students working in small cooperative groups to investigate a key question, discuss possible explanations for the phenomena under investigation, seek the evidence, and communicate and justify proposed explanations to their peers. Inquiry science recognises "robust knowledge and understandings are socially constructed through talk, activity, and interaction around meaningful problems and tools" (National Research Council 2000, p. 184).

Each interview was audiotaped (approximately 1 h in duration) and fully transcribed by a research assistant (RA) and checked for accuracy by a second RA. The transcribed interviews allowed us to identify meaningful themes that emerged (Guba 1978). Coding and re-coding were undertaken until we (the two RAs and both authors) were satisfied that the themes that we identified were representative of the interview data (see Table 3). Both RAs have had extensive experience coding video data (student discourse) over 10 years, and their expertise in conjunction with that of the authors ensured that our identification of the themes was reliable and valid.

Results and Discussion

We grouped the various themes that emerged from the interviews into four main themes that reflected issues that are identified in the research on teaching inquiry science: teachers' perceptions of teaching inquiry science (Bryan 2003; Fitzgerald et al. 2013), the scientific inquiry process (Hackling 2008), the role of cooperative learning (Gillies and Boyle 2010), and the challenges of teaching inquiry science (Yoon et al. 2012) (see Table 4 for the themes that were identified in each teacher's interview).

Teachers' Perceptions of Teaching Inquiry Science

It is well known that when teachers are interested in teaching a subject, they are more likely to invest time and energy in communicating these attitudes to their students (Graham et al. 2001), and this was certainly the case with the teachers in this study. One teacher commented:

"*….I think for me, in terms of teaching science that was one really huge aspect that I enjoyed about the units, was the open-endedness of it and the discussion. Like some of the discussions that came out of it was just phenomenal.*" (1a)

Another teacher noted,

"*Yeah, I loved it. I think it gave them (students) a lot of ownership of the unit and, being that co-operative, they could sort of persuade which way it was going to go, even though we were supplying them with a basis of the work, I noticed every group had something different.*" (2)

A third teacher, when asked if she had enjoyed teaching the two science units, commented:

"*Absolutely…the two topics just captivated the kids from the beginning.*" (7)

The teachers seemed to appreciate the opportunity they had to teach differently and be creative in the way they taught so that the students were exposed to more open discussions on topics that were anchored in "real world" experiences. Teaching science so students have opportunities to engage in open inquiries where they have been able to explore ideas helps them to develop a more secure and deeper understanding of why some ideas are more or less supported by evidence than others (Osborne 2009/2010).

The teachers also spoke positively about their experiences with teaching the inquiry science units:

"*I was very pleased with the amount of stuff we got through in Term 4…so I was really pleased about that*" (3b): Another teacher reflected,

> "*Yeah, I mean I, as I said, I was very influenced by it because I rewrote units for the inquiry-based thing and to tailor because I thought, well if we're doing inquiry base for GM, we should be doing inquiry base for the other Studies of Society and the Environment (SOSE) part of it and also the literacy, so I did that. So we were doing an inquiry based thing right across the board in that term*"*(3b)* Another teacher reflected,
> *"But the biggest thing for me is the outcomes. I get results. The kids get results. They're happy. The parents are happy. I'm happy and I go home every day thinking that we've achieved something."* (6)

Comments such as the above undoubtedly influenced the teachers' self-confidence in teaching the inquiry science units. Teachers who are more efficacious in their teaching are

Table 3 Themes that emerged from the teachers' interviews on teaching inquiry science

Themes	Example
1.0 Teacher interest in inquiry science	I think something it was inquiry method, like coming from teaching science in a high school which, you know, I hadn't had any experience teaching high school before, so it was very much textbook based, this is the unit. So that's how I got taught to teach science and this is the experiment which goes with that theory. That's one thing that I really liked about the units, it was inquiry, it was hands on, the kids did a lot more of the investigation and I was just there as a facilitator rather than a teacher. I think for me, in terms of teaching science… that was one really huge aspect that I enjoyed about the units, was the open-endedness of it and the discussion. Like some of the discussions that came out of it was just phenomenal. (1a)
1.1 Student interest in inquiry science	… things I guess within my class was seeing that by the end of it they became more and more confident to actually voice their opinion, because you weren't judged, you weren't laughed at, you weren't—it's like, okay, this is my opinion and this is why I think that way and so that justification too gave them confidence to say, well I don't agree with you, this is what I think and this is why I think that. (1b)
1.2 Student ownership	I think it gave them a lot of ownership of the unit and, being that cooperative, they could sort of persuade which way it was going to go, even though we were supplying them with a basis of the work, I noticed every group had something different. (2)
2.0 Scientific inquiry process	I think, for my class, I think they loved it. They seemed to soak it up. (2)
2.1 Benefits of inquiry units	Yeah and they took more ownership over what it is that they did, you know, the posters that we did, they were able to say, okay well this is what I've got from it. And I asked a number of kids, how do you feel about that, you know, I really feel good that I could actually contribute that much to something. Whereas if it was me directly teaching that, they wouldn't have that input as much, if that makes sense. (3b) Yes, because I suppose because at the start they had to come up with their own, like for living and non-living things we had to come up with our own inquiry questions, just casting my mind back now, it sort of gave them a bit more ownership over it. Like they were more interested in it because they were the ones coming up with what we were talking about to begin with. So I mean that influences it straight away… (5) I think they were different because I had immediate access to latest resources, like, and information. So the kids could actually, like the video clips, the newspaper reports, that was all there. So that was great and it was hands on. The kids were just fascinated that they could extract the DNA from the strawberries so there were some unique things about it that the kids hadn't done. (7)
2.2 Concerns with inquiry units	I think like, for my class who had difficulty with how the lessons were set up and the structure, it was a little bit of a stress about, you know, you could see that they were making small improvements.… (1b) I know there were times when I was working with other teachers. They were saying, I don't think my kids are getting the depth with all the DNA stuff. (2) We don't have the computer labs, per se. Sometimes it's difficult for everyone to go to the computer, so that's improving at the school now which is great, but that was a difficulty. But then they just have to be in groups, but that was fine. (5)
3.0 Role of cooperative learning (CL)	The fact that there was an expectation that the kids work cooperatively and that cooperative learning was explicitly built in to a lot of lesson sequences and activities, that really helped my class, and in this area and in other subject areas as well. (4)
3.1 Benefits of CL	Initially, as usual, they only want to sit with their friends but we soon got to the point where we used the groups in two different ways. We spoke about the

Table 3 (continued)

Themes	Example
	difference between groups and teams. So they knew that the group was put together to do a short task that was going to end. The team had to work together. You had to have mixed ability and people took on roles. And every time they turned up with the right equipment, ready to go and heads down. It was great. (6) Powerful…working within the groups, really the sharing of ideas, it does, it has its light-bulb moments where kids say something and—because sometimes kids sit there and struggle, they don't know—know what they don't know and another kid might have information or that they provide or another—it triggers other kids' thinking. So it's that layering of depth that's powerful. And just the, I don't agree, type. I mean there's always the stronger kids in the group that will sometimes take over. So there's always those issues but that's real life, isn't it? Science, it's a real-life situation where scientists or anyone today works within a team and a group. (7)
3.2 Challenges of CL	At the moment there are some kids who won't join a group. What we do now is we get them in the group first and the others have got to go to them. Otherwise they are always the ones left, last in line, last to be picked. (6)
4.0 Challenges in teaching inquiry science	I think that showed that some children still didn't really get what was going on because it is difficult to understand, inserting a gene into another strand. So I still, even though, like I said before, some kids were asking really deep questions, I suppose I still had some kids who were asking some basic questions which said to me they didn't fully understand the concepts. (5)

Teachers were coded as 1a, 1b, 2, 3a, 3b, 5, 6, 7

more likely to try new strategies and ideas and are more resilient when confronted with challenging classroom situations (Marshall et al. 2009).

Other teachers commented on the way this approach to teaching science seemed to capture students' interest:

Table 4 Themes identified in each teacher's interview

	Teachers								
Themes	1a	1b	2	3a	3b	4	5	6	7
1.0 Teacher interest in inquiry science	x	x	x	x	x	x			
1.1 Student interest in inquiry science	x		x	x	x	x	x	x	x
1.2 Student ownership	x	x					x	x	x
2.0 Scientific inquiry process		x	x		x	x		x	
2.1 Benefits of inquiry units		x	x	x	x	x	x	x	x
2.1 Concerns with inquiry units			x				x		
3. 0 Role of cooperative learning	x	x	x			x	x	x	x
3.1 Benefits of CL	x	x	x	x	x	x	x	x	x
3.2 Challenges of CL		x	x					x	
4.0 Challenges in teaching inquiry science	x	x	x	x	x	x	x	x	
Total number of themes	3	4	4	4	4	4	4	4	3

Teachers were coded as 1a, 1b, 2, 3a, 3b, 4, 5, 6, and 7

I think, for my class, I think they loved it. They seemed to soak it up. They were engaged and they loved it…So, yeah, and so I had parents coming in and asking me, like, what all the letters were in the DNA strand and stuff like that. Can you get me some information on this, so that was cool (2);

> "*I think more of the cooperative learning focus, more group work, from my experience, just from doing the unit, more of the kids finding out information from themselves and other resources instead of relying on us to be the feeder of information*" (3a);
> "*I think the kids engaged better… The three nuclei acids that made up the DNA strand, they were interested in the fact that the DNA strand came out to be about six foot long out of a tiny little cell that you couldn't see and I think that when we went up to the lab, they enjoyed going into a real science lab, they enjoyed looking through the microscopes and they were interested to see what they could see and so on… (3b);* and
> "O*ne of the kids was really engaged in the unit. He brought one of his sister's multi-strand science units from her high school*" (4).

Another teacher noted that students were more interested because they were driving the inquiry: "*…they were more interested in it because they were the ones coming up with what we were talking about to begin with*" (5). Others noted:

> "*If we couldn't do science on any day, it was all disappointment.*" (6)
> "*It (science) was something that they could engage new learning and they could, yeah, do some thinking for themselves…. I liked in the living and non-living units when looking at getting the kids to categorise and to investigate before giving them any information, to categorise and try and work out for themselves what it was before they were told. So they had to come up, they had some go at it and then it was layered on top of what their experiences were, what it was, so they remembered that … and they were… and they were confused. So their equilibrium was upset because it wasn't as simple as they thought. They thought it was going to be easy. So they were keen to learn because they were taken by surprise.* (7)

Tytler (2007), in a review of the research on what could be done to engage students in science education noted, "Pedagogy in a re-imagined science curriculum, will need to be more varied, more supportive of students' agency through more open tasks, increased discussion and negotiation of ideas, and involve more varied settings" (p. 66). Indeed, this is the challenge in teaching inquiry science—how to teach it so that students' interest is captured so that they become excited about the phenomena under investigation, and are willing to work with others to explore their ideas and develop the strategies needed to communicate their perspectives and understandings. Teachers in this study recognised that not only were the unit topics current and engaging, and they enjoyed teaching them, but they fostered enthusiasm in students and the desire to exercise their own agency to come to a deeper understanding. The nature of the topics, the task structures of the units and the opportunity to engage in cooperative learning drove the inquiry process.

The Scientific Inquiry Process

Teachers play a critical role in guiding students through the inquiry process, with efforts needing to be carefully tailored to each student's specific needs. Veermans et al. (2005) argued that it is important for the teacher to create the context for inquiry, and encourage students to develop their own questions, build their own tentative working theories, and share their understandings with their peers. In this respect, the teacher's role is essentially to mediate students' inquiry by achieving a balance between students' self-regulation and the teacher's external regulation of the inquiry process (Hmelo-Silver et al. 2007).

In responding to a question about the inquiry teaching process, one teacher commented, "*Yeah, it's definitely changed the way I teach and the children feel empowered*" (2). In this situation, the teacher spent considerable time providing hands-on type experiences with the children, discussing what they found through the provided graphic organisers in order to help students organise their thinking, and allowing them to "*come up with their own strategies*" (2).

Another teacher noted that she needed to structure the activity:

"*…I felt with my class I still had to be there and be guiding and asking questions because at the beginning they were very reluctant to voice their opinion, like I said, they got more confident and you could start to see them doing it more by the end*." (1b)

Others concurred that structuring the inquiry process was important:

"*…a lot of oral work is important because if you're trying to impart information to them or trying to get them to think about things and how things connect, they have to do it visually*" (3b);

> "*my whole back wall was just covered from one end to the other in those graphic organisers … they could see how it was structured from step to step to step to step and, they were like stairs… to help them get to the next stage*" (6);
> "*it opened their eyes to new ways of thinking, so thinking outside the box.*" (4).

It was apparent that the teachers were doing what Veermans et al. (2005) suggest and actively mediating students' learning through the provision of guided inquiries, allowing students to exercise initiative while being ready to scaffold learning experiences as needed. McNeill and Krajcik (2008) found that students' use of scientific explanations improved significantly when teachers defined scientific explanations, modelled scientific explanations, and connected scientific explanations to everyday explanations.

Role of Cooperative Learning

Cooperative learning is a pedagogical practice that has attracted much attention over the last 30 years because of the large volume of research that demonstrates that students benefit both academically and socially when they have opportunities to work together (Johnson and Johnson 2002; Lou et al. 2001; 1996), clarify differences and construct new understandings (Herrenkohl 2006; Mercer 2008). Schroeder et al. (2007), in a meta-analysis of 61 studies that examined the effectiveness of specific science teaching strategies on student achievement in science, reported that collaborative learning strategies where students worked cooperatively in groups had an effect size of 0.96, an effect size that is much greater than the 0.40 Hattie (2009) indicates makes a difference in educational interventions.

Many of the benefits attributed to cooperative learning are evident in the comments a number of the teachers made:

It gave them: "*…confidence and engagement…contribution to the discussion*" (1a);

> "*…there was a tremendous change in their whole notion of working as team*" (1b); and
> "*…it gave them a lot of ownership of the unit and, being that co-operative, they could sort of persuade which way it was going to go*." (1a)

Others noted *"… it did really breed a really nice environment of helping each other and the feeding off each other*" (2); students' "*ability to work in a team*" (5) was enhanced; and "*The team had to work together…it was great*" (6).

Another stated "*I really think that co-operative approaches to investigating concepts, content, whatever, should be a constant theme in the class*" (4) with one teacher further noting "*it's about constructing their own knowledge so they constructed their own knowledge of what* *cooperative learning was because they're capable of doing that…constructing their own knowledge really helped them* (to learn how to cooperate)" (1a).

Another teacher observed cooperative learning is a "powerful" technique that enables students to "*go and access other kids in the class…and I'm just the facilitator of them taking them on a journey.*" (7).

Cooperative learning provides opportunities for students to work together, to investigate topics, affirm and disconfirm conceptions, and construct new understandings. In so doing, it enables them to talk and reason among themselves and build relationships that promote group cohesion, confidence and trust (Johnson and Johnson 2002). It is this reciprocal interaction between students and the respect they develop for others' perspectives that enables the exchange of knowledge and the co-construction of meaning to occur (Mercer 2010), enhancing the development of problem-solving, reasoning, and learning (Gillies and Boyle 2010).

Challenges of Teaching Inquiry Science

Current developments in science education promote inquiry learning in science (Bybee 2006; Osborne 2007), however, successful enactment requires teachers to be able to understand the fundamental concepts of the discipline and scaffold and guide students' learning as they confront challenging ideas (Loucks-Horsley 2003). Teachers often grapple with students taking scientific discussions in different and extended directions as it challenges their science content knowledge. One teacher dealt with this problem by observing her colleague's teaching:

"*I'm observing "Melissa"* (pseudonym) *a lot more, like with, like inquiry and cooperative learning that we're doing this year, Melissa's been running it and I've sort of been observing a lot more on what kind of strategies she's putting in place …*" (1b).

A second teacher when reflecting on her lack of science knowledge commented:

"*there were moments in that DNA unit where I just went, ahh, which way do I go here, you know, there was few times when we went off tangent.*.". (2)

Teaching elementary science can be a challenge if teachers feel they are not well qualified to teach science (Appleton 2003; Fulp 2002a) or they lack the confidence to do so (Marshall et al. 2009). However, this is not to say that these challenges cannot be overcome. Buczynski and Hansen (2010) found that when elementary teachers are provided with professional learning in inquiry science content and pedagogical practices, it increased their science content knowledge and their implementation of inquiry learning activities in their classrooms.

The professional learning opportunities the current project afforded lead one teacher to reflect:

"*You know, for me, because I'm really only a beginning teacher, learning specifically how to do the inquiry method and how to, you know, do the cooperative learning roles, that was good for me … having really specific instruction on it, how to put that into the classroom, that was good because I was like, okay, I've got another, you know, another trick in my bag of tricks that I can use in the classroom.*" (5)

Other challenges the teachers confronted included the physical resources available to put students into groups, with one teacher commenting:

"*Obviously…the environmental restrictions, is the hardest one. When you are restricted to that small space and you've only got this size desk and you only get just enough desks and chairs, it causes problems. But you have to deal with what you've got. You've always got a different mix of kids but you treat them the same as anyone else. You do what you have to.*" (6)

A further challenge confronting the teachers was the time available to schedule inquiry. In discussing the difficulties with timetable restrictions, one teacher noted:

"We could go way off over here left field, but I've got this to do. So, I was torn. Especially when we got within the 3 or 4 weeks to go and I was like… having to make sure we covered our curriculum requirements." (2) School organisational structures (e.g., physical layout of the rooms; curriculum) and teaching strategies (e.g., group work) are critically important in supporting inquiry as they affect students' ability to engage in inquiry science learning and become self-directed learners (Schroeder et al. 2007; Van Deur 2010).

Summary and Conclusions

This study reports on the reflections of nine grade 6 teachers who taught two inquiry science units. In particular, the study focused on investigating their perceptions of teaching inquiry science as well as the processes they employed. Additionally, because inquiry science adopts a student-centred approach to teaching and learning, the study also investigated the benefits and challenges this posed.

All teachers spoke positively about their experiences teaching the inquiry science units, particularly because the topics not only captured the students' interest but the inquiry process also allowed them to take ownership over how they learned and it helped them to think outside the box. Teachers perceived that cooperative learning was a driver for the inquiry and for taking ownership of the learning process. The teachers also appreciated the opportunity to be creative in the way they taught so the students were engaged in discussing real world topics which made their learning meaningful. However, the teachers did emphasise that it was important for them to structure the inquiry process to challenge students' thinking and scaffold their learning to encourage discussion. These findings are consistent with Tseng et al. (2013) who interviewed junior high school teachers who were very experienced in inquiry science teaching. Just like the primary teachers in this study, teachers that Tseng et al. interviewed felt it was important to highly structure and scaffold the inquiry experience and that the major benefit of inquiry was that it was student-centred. Teachers in this study found that the inquiry structure with the use of the graphic organisers scaffolded each step of the scientific inquiry for the students and helped students to see where they would take the next phase of the inquiry.

Tseng et al. (2013) report that the very experienced teachers claimed that their persistence in implementing inquiry science in their classrooms was due to their positive experiences in inquiry during their own learning. They strongly advocated that training teachers to implement science in the classroom should include inquiry learning experiences because through these experiences they came to recognise that inquiry is meaningful for students and that it is a powerful way to construct an understanding of science concepts. During the professional development days, the teachers in the current study experienced first-hand the same inquiry that they were to implement in their own classrooms, and they enjoyed this experience. This may have contributed to their willingness both to implement the inquiry as well as to see the benefits inquiry brought to their students.

The opportunity to work cooperatively with others was also viewed as a very positive feature. The teachers observed that it gave students confidence to stay on task and contribute to the discussions and to work together as a team to co-construct new understandings and knowledge. The opportunity to seek help from each other and the feedback they provided, both to their peers and their teachers, was "brilliant" and "fantastic" (1a).

Although the teachers reflected positively on their experiences teaching the two inquiry science units, they also expressed concerns about the challenges that inquiry imposes, such as dealing with student direction of discussions when they go off on a tangent, and the constraints imposed by the demands of the curriculum and the assessment requirements.

Limitations of the Study

There are two limitations to our study. First, we only interviewed nine teachers who agreed to participate in the interviews, limiting the generalizability of the insights gained. Second, we did not collect observational data of the teachers' implementation of their cooperative, inquiry units so no information is available on how they implemented these science units in their classrooms. These are issues that need to be addressed in future studies.

Implications for Teacher Education

This study has implications for inquiry science teaching in primary schools. First, it highlights the challenges some primary teachers experienced in implementing inquiry science. Primary teachers are expected to teach inquiry science but often believe that they lack the "tools" to enable them to do so, particularly the skills required to help extend students' discussions and questions as they endeavour to engage in scientific thinking and reasoning. These concerns, though, are not insurmountable as this study demonstrates. Buczynski and Hansen (2010) found that professional development in specific science content and pedagogical strategies led teachers to not only improve their science content knowledge and practices but it also contributed to modest gains in students' standardised science achievement exams.

Similarly, Sinclair et al. (2011) reported on a professional development program in science that led to significant changes in teachers' content knowledge and self-efficacy for teaching science. In short, teachers do transfer knowledge and skills gained in professional learning experiences to their teaching, and these studies highlight the benefits that can accrue to primary teachers, and ultimately students, from implementing professional learning programs on science education.

In this study, explicit modelling of activities, use of graphic organisers, and other resources within the researcher-designed inquiry units were provided during the professional learning days. The teachers were able to act as students and as inquirers and experience what the students in their classrooms would experience. Alongside this training, teachers received professional development around the science content and how to integrate cooperative learning strategies within their inquiry units. The findings of this study suggest that this training resulted in positive attitudes towards teaching the inquiry science units and using cooperative learning as a strategy to facilitate the inquiry process. We have previously reported the positive student learning gains (Gillies et al. 2012).

Second, the study draws attention to the key role the teacher plays in implementing inquiry science. The teacher's role in inquiry science learning is to encourage exploratory investigations and talk, to work with students' ideas, scaffolding and challenging them to think critically and reflectively so they can draw evidence-based conclusions about topics under discussion (Hmelo-Silver et al. 2007; Tytler 2007).

Third, the study underscores the importance of embedding cooperative learning experiences in inquiry science to provide opportunities for students to seek information and opinions from others, solicit and provide explanations and reasons, share their thoughts, and evaluate proposals in a context that is supportive of members' endeavours (Mercer 2008). The teachers in the study found that cooperative learning strategies naturally fit within a context of inquiry learning in science and that they foster constructive group discussions about science. They were especially pleased with the development in students' abilities to share and exchange ideas and explore the content in more depth. The training in cooperative learning in this study further enabled teachers to facilitate and engage students in inquiry science in their teaching, and they recognised this very important addition to their pedagogical repertoire.

Statement of Ethical Approval This study was approved by the relevant ethical clearance committee at our university, and a written informed consent was obtained by the participants who were interviewed in this study.

Appendix 1. Interview Questions

1. What were the issues you had to contend with as you taught the inquiry-based science units?
2. So how did you feel about the units as you were doing them?
3. Tell me about your previous experiences in teaching science.
4. What are the sorts of issues you consider when you're getting the students ready to work on the science activities?
5. How did you set up the tasks for the students?
6. What sorts of strategies do you like to use?
7. How did the children respond to the science units?
8. How did the children respond to the group activities?
9. Reflecting on your experiences of teaching the units: How would you describe them? Has it changed the way you teach?
10. Are there any other issues that you'd like to discuss?

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