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Comparing Two Inquiry Professional Development Interventions in Science on Primary Students' Questioning and Other Inquiry Behaviours

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Abstract Developing students' skills to pose and respond to questions and actively engage in inquiry behaviours enables students to problem solve and critically engage with learning and society. The aim of this study was to analyse the impact of providing teachers with an intervention in inquiry pedagogy alongside inquiry science curriculum in comparison to an intervention in non-inquiry pedagogy alongside inquiry science curriculum on student questioning and other inquiry behaviours. Teacher participants in the comparison condition received training in four inquiry-based science units and in collaborative strategic reading. The experimental group, the community of inquiry (COI) condition, received training in facilitating a COI in addition to training in the same four inquiry-based science units. This study involved 227 students and 18 teachers in 9 primary schools across Brisbane, Australia. The teachers were randomly allocated by school to one of the two conditions. The study followed the students across years 6 and 7 and students' discourse during small group activities was recorded, transcribed and coded for verbal inquiry behaviours. In the second year of the study, students in the COI condition demonstrated a significantly higher frequency of procedural and substantive higher-order thinking questions and other inquiry behaviours than those in the comparison condition. Implementing a COI within an inquiry science curriculum develops students' questioning and science inquiry behaviours and allows teachers to foster inquiry skills predicated by the Australian Science Curriculum. Provision of inquiry science curriculum resources alone is not sufficient to promote the questioning and other verbal inquiry behaviours predicated by the Australian Science Curriculum.

Keywords Collaborative philosophical inquiry · Community of inquiry · Inquiry behaviours · Questioning · Teacher professional development

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Introduction

Inquiry-based teaching and learning is now mandated by the Australian Science Curriculum as an approach to teaching science in order to support the development of science inquiry skills (Australian Curriculum, Assessment and Reporting Authority 2014b). Even throughout the development of the Australian Science Curriculum, models of learning based on student inquiry and the posing and investigating of questions were strongly emphasised (National Curriculum Board 2009). Despite this, there is little pedagogical guidance on how to best teach the Australian Science Curriculum in order that students "develop an understanding of the nature of scientific inquiry and the ability to use a range of scientific inquiry methods" (Australian Curriculum, Assessment and Reporting Authority 2014b). One of the possible approaches the Australian Curriculum Assessment and Reporting Authority presents for developing critical and creative thinking across all learning areas is based on Matthew Lipman's (1988) *Philosophy for Children*, which employs critical pedagogy centred on collaborative philosophical inquiry (Australian Curriculum, Assessment and Reporting Authority 2014a). Research has already identified many advantages of using the collaborative philosophical inquiry approach in science education to develop students' reasoning and problem-solving abilities, skills essential for engaging in inquiry (Garcia-Moriyon et al. 2005; Trickey and Topping 2004); however, there are still some doubts about the effectiveness of the approach (see Daniel and Auriac 2011). This paper describes a more focused analysis into the questioning and other inquiry behaviours that students develop from engaging in collaborative philosophical inquiry. It also examines how students use these skills to understand science in order to develop a broader understanding of the effectiveness of the collaborative philosophical inquiry approach for science inquiry learning.

To date, research on the effectiveness of embedding a collaborative philosophical inquiry approach for developing students' skills and behaviours outside of the cognitive domain in primary school science education is limited (Garcia-Moriyon et al. 2005). This study broadens the scope of the current body of research on investigating the effectiveness of the collaborative philosophical inquiry approach for improving inquiry teaching and learning, as it analyses a diverse range of specific skills and behaviours that the approach may indeed impact and locates this learning within the current aims of the Australian Science Curriculum. This study is unique as it explores the relationship between interventions, types and levels of questions, and the inquiry behaviours students use to understand science within the Australian schooling context.

Teacher Professional Development for Inquiry-Based Learning in Science

Crawford (2012) suggests that many current professional development initiatives are not effective in supporting teachers' understanding of the nature of scientific inquiry nor do they adequately prepare teachers to implement inquiry learning into their science classrooms, due to the focus on scientific curriculum concepts rather than pedagogical approaches. This finding indicates the need to review what is considered quality professional development around inquiry teaching and learning and what teachers require from professional learning experiences in order to design more effective interventions (Grigg et al. 2012).

Multiple studies have researched what teachers perceive to be useful aspects of professional development for improving their implementation of inquiry science. Most notable is the recent study conducted by Tseng et al. (2012), who interviewed 15 experienced junior high school teachers to gain an understanding of their perspectives of and recommendations for inquiry teaching. Also noteworthy is a seminal study by Supovitz and Turner (2000) that drew on a variety of published researchers and educators to identify widely accepted components of quality professional development. The findings from these studies outlined that an immersion approach to professional development is considered most effective where it immerses teachers in inquiry learning themselves; demonstrates how learning links to specific curriculum standards, involves concrete and practical resources, demonstrations, and strategies that can be connected to other areas of learning; and provides sustained support from research teams. Supovitz and Turner (2000) analysed data collected through self-reported teacher surveys and found that increased engagement in professional development that embodied these components was associated with both increased use of inquiry-based teaching practices and higher levels of investigative classroom culture. Lee et al. (2004) implemented a professional development intervention that embraced many of these components in its design and found teachers identified positive changes in their practices in alignment with an inquiry approach to teaching and learning.

Whilst these results are promising, there are limitations with these studies collecting data through teachers self-reporting on improvements to practice (Grigg et al. 2012; Lee et al. 2004). Furthermore, Supovitz and Turner (2000) indicate great variance in results depending on the length of time teachers engaged in the professional development. Impartial research is therefore needed to further examine the effectiveness of longitudinal professional development and the importance of incorporating content knowledge and/or pedagogical approaches in professional development interventions to improve science inquiry teaching and learning (Crawford 2012; Grigg et al. 2012; Keys and Bryan 2001; Lee et al. 2004). This study explores the impact of an immersion approach to professional development (Supovitz and Turner 2000) where the impact of collaborative philosophical inquiry (inquiry pedagogy) embedded in inquiry science curriculum is compared to collaborative strategic reading (non-inquiry pedagogy) embedded in inquiry science curriculum, on students' inquiry behaviours.

Collaborative Philosophical Inquiry

Influenced by Charles Peirce's notion of community of inquiry and John Dewey's thoughts on education, Lipman developed the Philosophy for Children programme. At the core of Lipman's Philosophy for Children are the classroom community of inquiry (COI) and a curriculum of purpose-written philosophical novels and instruction manuals for teachers. In Australasia, teachers and schools have embraced Lipman's COI pedagogy but use an assortment of curriculum materials adapted for the classroom, including children's literature and a growing body of purpose-written materials by Australasian authors. The term collaborative philosophical inquiry is used to broadly cover all educational approaches to teaching and learning through philosophical inquiry that have developed from or adapted Lipman's educational theory and practice. Collaborative philosophical inquiry is an inquiry approach "for the implementation of philosophy in the elementary and secondary school" that engages students in thinking about thinking as they discuss important concepts with the aim of improving their reasoning abilities and judgment (Lipman 1993, p. 296). Derived from the work of Lipman and colleagues in the 1960s and 1970s, collaborative philosophical inquiry focuses on capturing the curiosity and intrigue children have of the world around them and using this as a stimulus to engage students in posing and exploring questions (Vansieleghem and Kennedy 2011). Pedagogically, collaborative philosophical inquiry can "transform the classroom into *a community of inquiry* where children are engaged in doing philosophy" (Lipman 1993, p. 296).

This central idea, that learning must come through doing and that knowledge is active, builds on John Dewey's description of constructivist learning (Lipman 1993). The teacher's role is to facilitate collaborative philosophical inquiry where students engage in constructing dialogue to clarify, explore and develop a shared understanding that builds on existing knowledge and practice (Burgh and Nichols 2012; Lipman 1993; Millett and Tapper 2012; Vansieleghem and Kennedy 2011). The recommended pedagogical process, developed by Lipman (1991), starts with introducing students to the stimulus for initiating inquiry. This involves the introduction of a problematic situation to stimulate students to wonder and think about what is unclear. As a group, students then generate questions based on what they find problematic. Following this, students offer suggestions in response to a central question by expressing their opinions, exploring ideas, stating conjectures and generating hypotheses in order to find possible answers, solutions or explanations. This leads to the analysis of concepts and reasoning to develop arguments, in order to gain deeper understanding of the problems, issues or topics into which students are inquiring. Interest in constructing learning experiences that promote these inquiry behaviours and develop students' capabilities to participate as active and informed citizens continues to grow (ACARA 2014b; Cam 2006; Millett and Tapper 2012; Trickey and Topping 2004; Vansieleghem and Kennedy 2011). The effectiveness of engaging students in the collaborative philosophical inquiry approach during inquiry-based science education has been prominent in research for many decades (Garcia-Moriyon et al. 2005; Millett and Tapper 2012).

In a recent longitudinal study, Scholl et al. (2009, 2014) found that teachers trained in facilitating the COI approach in the primary classroom demonstrated improved pedagogy that the teachers themselves perceived to have improved the types of questions and complex thinking and reasoning with which their students engaged. The research to date provides strong evidence that teaching students to pose and respond to questions through collaborative philosophical inquiry improves students' cognitive abilities, their ability to reason and problem-solve, and their ability to critically engage in classroom discussions (Garcia-Moriyon et al. 2005; Millett and Tapper 2012; Topping and Trickey 2007b; Trickey and Topping 2004). Despite these findings, Trickey and Topping (2004) and Garcia-Moriyon et al. (2005) found, when undertaking meta-analyses of studies looking at the effectiveness of implementing collaborative philosophical inquiry, that few studies follow up on the participants' progress or gather data for more than a year, and a large number of studies failed to include adequate control measures such as comparison conditions. They noted that minimal empirical studies have been conducted recently, with a focus more on qualitative methods based on participant self-reporting. Both analyses, therefore, indicated the need for longitudinal quantitative studies in order to establish with validity the effectiveness of embedding collaborative philosophical inquiry in primary classrooms.

Inquiry Behaviours and Inquiry Learning

Several researchers have discussed categories of inquiry behaviours, skills or processes that align with an inquiry approach. Many identify five to six phases of inquiry that promote or develop different inquiry skills specific to the needs of each phase. For example, Facione (1990) described six inquiry phases: interpretation, analysis, evaluation, inference, explanation and self-regulation. Lipman's model of the classroom as a COI has been described variously as a pattern of inquiry that involves students initiating inquiry, generating suggestions, reasoning, engaging in conceptual exploration, evaluating and concluding to explore a problem (Burgh et al. 2006; Cam 2006; Splitter and Sharp 1995). Seraphin et al. (2013) outline five inquiry phases that include initiation, invention, investigation, interpretation and instruction.

While these authors describe the phases of inquiry differently, each is very similar in the inquiry skills or behaviours students are expected to develop throughout the inquiry process. These similar descriptions emphasise the importance of the inquiry process for developing students' scientific understandings and highlight the importance of supporting students to make predictions, pose questions, explore ideas, communicate their findings and use this information to inform future learning; in other words, to develop students' abilities to engage deeply in their own learning (Mercer et al. 2009). This is vital in order to prepare students to be successful, confident learners and citizens in the twenty-first century (MCEETYA 2008).

This study explores the impact of inquiry pedagogy through collaborative philosophical inquiry alongside an inquiry science curriculum on the inquiry behaviours that have consensus in the literature, including developing ideas, exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions. These inquiry behaviours, skills or processes also align well with the Australian Science Curriculum.

Questioning and Inquiry Learning

The role of questioning within inquiry-based learning has long been recognised (Cam 2006). Explicitly teaching questioning strategies plays a role in supporting students to engage in the inquiry process. In a previous study (Gillies et al. 2014), we analysed small group discussions during upper primary science inquiry lessons to determine differences in the types of discourse students engage in after they had been trained in questioning strategies. The findings were reported for a combined student cohort whose teachers were trained in *either* a COI or an Ask-to-Think-Tell-Why approach. We found that a combined cohort of students who were taught how to ask thought-provoking questions using either of these approaches to stimulate and clarify information and elicit reasons engaged in more sustained discussions with their peers and used questioning as a method to develop explanations. While these results indicate that teaching students to question does in fact increase student engagement in learning science, we believe there is a need to focus a deeper analysis on the types of questions and other inquiry behaviours used in classroom discussions when following an inquiry-based COI approach. Therefore, we sought, in this study, to carry out a finer grained analysis in order to investigate the specific types of questions that are impacted as well as the level of thinking students engaged with during discussions around science phenomena. This required a careful consideration of previous studies that explored questioning during inquiry learning.

Reinsvold (2011) explored the frequency of students using closed-ended, open-ended and task-oriented questions to seek feedback and develop understanding of the science content and processes during classroom discourse, finding that closed-ended questions dominated primary classrooms with task-oriented questions being displayed the least. While these results provide some insight into very broad types of questions students engage with in an inquiry science classroom, the results still only provide minimal understanding of the cognitive level of the questions posed and their impact on the inquiry process. There is a need for studies that focus on the impact of inquiry on questioning with a clear theoretical classification of these behaviours.

Splitter and Sharp (1995) outline two types of questions that are integral to inquiry learning that can be used to consider the purpose behind students' use of questions: procedural and substantive questions. Procedural questions are used "to inquire into meaning and the underlying logic or structure of thinking" (Burgh et al. 2006, p. 154). These types of questions are derived from the Socratic questioning taxonomy, developed by Paul (1990), and are used for the purpose of clarifying, exploring viewpoints and perspectives and establishing the procedure of an inquiry. Substantive questions are those aimed at developing a deeper understanding of the subject matter and are used for the purpose of inquiring into the nature of reality, knowledge and values. Using a combination of these questions during the inquiry process allows students to question both the process and substance of their learning and classifying questions within these categories provides insights into the purpose students have for posing the questions (Burgh and O'Brien 2002).

While these procedural and substantive question categories describe the purpose behind the questions, they do not provide a complete understanding of the level of thinking students engage in when they pose a particular question. There are many classification systems that use a hierarchy to classify questions based on the cognitive processes they involve that could provide deeper analysis of the thinking with which students engage (Gall 1970). Gall analysed the research knowledge surrounding many of these systems to develop broad definitions representing the similar categories of each classification system, most of which are still at the forefront of current approaches (Australian Curriculum, Assessment and Reporting Authority 2014a). These questioning categories include (i) recall questions, which require low-level recognition and remembering of facts; (ii) analytic thinking questions, which involve logical reasoning, comparisons and explanations; (iii) creative thinking questions, which entail synthesising and conjecturing information; and (iv) evaluative thinking questions that comprise judging information. Questions classified within the final two categories, creative and evaluative thinking, are together regarded as higher-order thinking questions.

The complexity of questioning makes it difficult to fully understand the context and level of thinking that questions require and to be able to identify the difference between the types of questions presented in discourse (Gall 1970; Reinsvold 2011). Combining type (procedural, substantive) and cognitive engagement (recall, analytic thinking, higher-order thinking) question categorisation methods provides a set of criteria to identify characteristics of questions posed during discourse and enables a finer grained analysis of the contributions questioning makes to students' engagement with science inquiry skills and learning. These criteria were used in this study to assess the impact of collaborative philosophical inquiry embedded in inquiry science curriculum on students' types and levels of questioning.

Research Problem and Questions

Students' engagement with questioning and inquiry behaviours is largely influenced by how they are introduced to inquiry processes. To examine the effectiveness of implementing a collaborative philosophical inquiry approach, or COI pedagogy, within science inquiry curriculum, in comparison to implementing science inquiry curriculum without inquiry pedagogy (but with a collaborative strategic reading pedagogical approach), the following research question was posed. In reference to professional development delivered as either a combined pedagogical- and curriculum-based inquiry intervention (including training in the collaborative philosophical inquiry approach and science inquiry curriculum) or a science inquiry curriculum-based intervention with a non-inquiry pedagogical intervention (including training in science inquiry curriculum and collaborative strategic reading), what impact does the intervention have on the types of questions and verbal inquiry behaviours students use during small group collaborative inquiry activities to understand science? Structured observations were undertaken of student discourse during small collaborative inquiry group activities in order to address the research question.

The hypothesis posed by this study is that students who are part of the COI condition pose more substantive questions that are creative and evaluative in nature than those in the comparison condition. It also hypothesised that being exposed to the COI condition enhances students' engagement with inquiry behaviours.

Method

Setting and Participants

The purpose of this study was to investigate the impact of embedding a collaborative philosophical inquiry approach into inquiry science classrooms on student questioning and other verbal inquiry behaviours. It focused on comparing student discourse between groups of students during four units of inquiry science taught over 2 years. The study used an experimental case-controlled design where hypothesis-testing occurred through the manipulation of a variable (Gay and Airasian 2000; Neuman 2004). The independent variables included the intervention and time. The dependent variables included questioning categories and other verbal inquiry behaviours. As there were multiple dependent variables included in the analysis, multivariate analysis of variance was used to analyse the data (Kraska 2010).

Teacher participants were drawn from nine state and independent primary schools within one district of Brisbane, Australia. There was a mix of both state and Catholic metropolitan schools with similar demographic and socioeconomic profiles. Schools were recommended based upon their involvement with continuing professional development in inquiry-based science learning, with principals from these schools then nominating the teacher participants if they agreed to the school participating in the large scale study, from which this data has been drawn. Teachers within the school were then asked to volunteer to participate in the first year of the study, providing they met the following inclusion criteria:

1. they were year 6 teachers in year 1 of the study.
2. there was a commitment to participate for a 1-year period.
3. they agreed to follow the strategies presented in the professional development interventions.

As students were followed from year 6 to year 7, the teachers for year 2 of the study were selected only if they were teaching the students already involved in year 1. In the COI condition, two teachers who participated in year 1 of the study also participated in year 2 with one new teacher being introduced to the study. For the comparison condition, one teacher remained participating over both year 1 and year 2 of the study with three new teachers being introduced to the study in the second year.

A total of 18 teachers participated in the study over the 2 years. There were four male and fourteen female teacher participants, which is broadly representative of the current ratio of male to female teachers in primary schools in Australia. The participating teachers varied in their teaching experiences (1–20 years) but all were highly regarded by their supervisors for their commitment to professional development and their willingness to trial new teaching approaches in their classrooms.

The inclusion of students within the study was based on the initial cohort of teachers who volunteered. Students were provided with information sheets and consent was obtained from their parents if they agreed to be video and audio recorded on four occasions throughout the 2-year study. Two hundred and twenty-seven students (106 boys, mean age=12.5 years; 121 girls, mean age=12.5 years) participated in this study over the 2-year period. While all students participated in the inquiry-based science units that were taught as part of their regular classroom curriculum, two groups of students from each class were randomly selected by their teacher to be filmed for data collection purposes as they worked on the specific inquiry-based activities.

Study Design and Procedure

This is a longitudinal comparative study that employed an experimental design to examine the effectiveness of embedding a collaborative philosophical inquiry approach to inquiry-based science learning where students worked cooperatively in small groups on assigned tasks (Neuman 2004). This study involved two conditions: the COI experimental condition and the comparison condition. The aim was to determine if there were differences in students' questioning and other verbal inquiry behaviours between the two conditions and analyse the maintenance of the skills by both conditions into the second year of the study. As outlined in Fig. 1, the study involved four phases.

Phase 1 involved delivering the professional development interventions to one cohort of 11 teachers, five teachers in the COI condition and six teachers in the comparison condition. Teachers for both the experimental and comparison conditions received training in how to implement two inquiry-based science units (units 1 and 2) and embed cooperative learning into the inquiry science activities. The experimental group was also trained in the use of the philosophical COI approach to engage students in collaborative philosophical inquiry-based learning, thus receiving a combined pedagogical- and curriculum-based inquiry intervention.

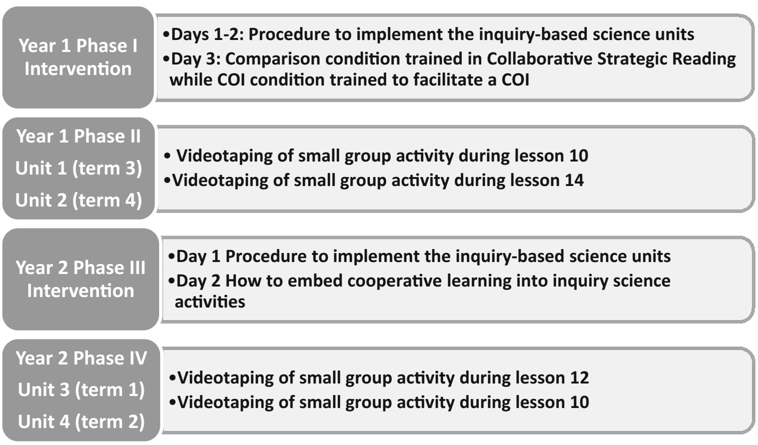

Fig. 1 Outline of procedure for the study

Year 6 teachers in the comparison condition received training in collaborative strategic reading thereby receiving a science curriculum-based inquiry intervention and a non-inquiry pedagogical intervention. Following the intervention, teachers randomly assigned students to four-person, gender-balanced, mixed-ability groups, as previous research has indicated that this grouping arrangement is more likely to promote interaction and learning than other gender and ability combinations (Lou et al. 1996). Phase 2 involved teachers implementing the strategies introduced during the interventions to teach two inquiry-based science units (units 1 and 2) across two consecutive school terms while the students (106 boys and 121 girls, 10–11 years of age) were in year 6.

Phase 3 involved training a cohort of seven year 7 teachers, three teachers in the COI condition and four teachers in the comparison condition, who would be teaching students who had already been involved in the study during year 6. Teachers received training in two science inquiry units (units 3 and 4). Following the interventions, teachers once again randomly assigned students to four-person, gender-balanced, mixed-ability groups. Only students that were part of the study in year 6 were included in the study. Phase 4 involved year 7 teachers implementing the strategies introduced during the interventions to teach two inquiry-based science units (units 3 and 4) across two consecutive school terms.

Within phases 2 and 4, data collection was undertaken by video-recording student discourse during the small group discussions at four time-points (within the last 2 weeks of the unit) over the 2-year period (see Fig. 1). The study was designed in this way to embrace the recommendations stipulated by Morris and DeShon (2002) and Garcia-Moriyon et al. (2005) that studies should test an experimental and control group at various time-points and where possible be conducted as a longitudinal study in order to ensure results regarding the effectiveness of a collaborative philosophical inquiry approach are as valid and unbiased as possible.

Interventions and Conditions

The teachers who participated in the study agreed to teach an inquiry-based science unit each term to provide students with opportunities to develop verbal inquiry skills including questioning behaviours over four consecutive terms across 2 years. These units were created in alignment with existing curriculum requirements and were introduced to all teachers during the professional development interventions. The units were designed using a guided level 2 inquiry approach (Blanchard et al. 2010) and aligned with a 5E's instructional model (Bybee 2006). The following sections provide a description of the content and activities that made up each inquiry unit.

Unit 1 The focus of the first unit was identifying the differences between living and non-living things. This was achieved by engaging students in exploring their own pre-conceptions of the characteristics of living things, coming to a decision on a suite of characteristics that identify living things and then applying the new found knowledge to a novel situation. The unit consisted of 12 lessons, taught over 6–8 weeks, that enabled students to draw on their prior knowledge to define a living thing; generate a list of inquiry questions; and explore how living things acquire energy, move, reproduce, respond to stimuli, respire, grow and develop. Students were videotaped in lesson 10 working in their groups on the problem, the Martian and the car. This problem stipulated Marty Martian had been sent to Earth by his government to find life and had captured a car, which he took back to Mars as an example of life on Earth.

The Martian government, however, did not believe that the car was alive and Marty had to stand trial for failing to perform his Martian duties. The students, in their groups, were required to make a case for both the defence, arguing that the car was alive, and the prosecution, identifying why it was a non-living thing. Students listed their reasons and shared them with the class, where other students could challenge the reasons.

Unit 2 The focus of the second unit was on guiding students to arrive at a personal stance on whether or not Australia should grow GM crops. The unit consisted of 17 lessons which were taught over 8–10 weeks, designed to enable students to understand the purposes of science, practice generating questions, learn the foundational content of the unit, synthesise new understandings and dispel misconceptions, engage in laboratory experiments designed to illustrate the processes of DNA extraction and gel electrophoresis as part of the procedures used in genetic modification, and develop arguments for and against growing GM crops. All lessons involved students working in groups to investigate key ideas and topics, share their information with others, challenge others' perspectives, and present their groups' ideas to the class where they were expected to provide reasons and justifications for their position. Students were videotaped during lesson 14 as they discussed the environmental, social, health and economic reasons for and against the growth of GM crops. The purpose of this session was to have the children agree on three or more arguments that contributed to the debate on the value or otherwise of GM crops. The students then prepared their oral presentation for the class, which involved them presenting the arguments for their stance and identifying any environmental, social, health or economic arguments that supported their position. Once again, students could be challenged to provide reasons or justifications for their position.

Unit 3 The third unit was taught during the second year of the study and focused on investigating how forces and energy create motion. In particular, the unit focused on how the motion of objects changes as the result of opposing or supporting forces, how renewable and non-renewable energy sources can be identified and used, and how energy can be transferred and transformed. The unit consisted of 15 lessons that were taught across 10 weeks. Students' knowledge was developed through students designing different bicycles for different purposes and justifying their choices with scientific explanations of the forces, motion and energy acting on the bicycle. Students were videotaped in their groups in lesson 12 as they discussed how they would design a bike, based on a predetermined scenario. In their discussions students were expected to identify and discuss the components of their bike, the forces acting on it during operation and, finally, present their design to the class and justify their decisions.

Unit 4 The fourth unit focused on helping students to investigate the difference between animal and plant cells, including the structure of the cells, the functions of the different parts and how these different cells and their structures could be represented. The unit consisted of 12 lessons that were taught across 8 weeks. The students examined different cells under the microscope and prepared specimens for the microscope to enable them to examine the different cell structures and represent them through the construction of a model. In lesson 10 students were videotaped in their groups as they discussed how they would represent the structure and the function of the various parts of a cell.

All teachers participated in 2 days of professional learning workshops prior to teaching the science units, which provided them with the background information on the inquiry-based science units that they had agreed to teach and the procedures they needed to follow to implement these units. Additionally, all teachers received information on how to embed the key elements of cooperative learning into their inquiry science activities. These elements included ensuring that all students contribute, exhibit the social skills required to facilitate cooperation, promote each other's learning, and reflect on their own and the group's progress with the task at hand (Johnson and Johnson 1990). Teachers who participated in the study were then randomly allocated by school to either the COI (eight teachers) or the comparison condition (ten teachers) and provided with an additional day of professional development in accordance with the process outlined in Fig. 1.

Comparison Condition In addition to the training delivered on implementing the inquiry science units, teachers in the comparison condition were provided with an additional day of training on collaborative strategic reading pedagogy as a way of helping students to analyse texts (Vaughn et al. 2001). Collaborative strategic reading consists of four basic strategies that are designed to enhance students' comprehension of text. These strategies include learning to make predictions prior to reading (preview strategy), monitor reading and learning to enhance vocabulary development (click and clunk strategy), identify main ideas (get-the-gist strategy) and summarise key ideas (wrap-up strategy). Additionally, teachers were supported in discussing and exploring the resources they would need to implement the units. This intervention was considered pedagogical because of the focus on classroom strategies to support learning.

COI Condition During Phase 1 teachers in the COI experimental condition received an additional day of training around using the COI approach (Lipman 1988) to engage students in collaborative, inquiry-based learning, in addition to the two day intervention on implementing the inquiry science units. Examples of activities and content from units 1 and 2 were used as a context for the COI training. The COI approach emphasises the classroom as a pluralistic community where students actively engage in dialogue, learn to listen to one another, share and build on each other's ideas, consider different opinions and perspectives, and explore disagreements (Lipman 1988).

Teachers were trained to engage their class using a COI pedagogy through using specific procedures and practices, particularly the five stages articulated by Lipman (1991), to guide and reinforce engagement in a COI. Teachers were also trained to facilitate substantive discussion through the use of open-ended questioning and the introduction of exercises, discussion plans and other classroom activities that compel students to inquire further and to connect their questions with the philosophical questions of the tradition. To this end, training for the COI condition focused on modelling the skills required to facilitate communities of inquiry, including immersing teachers in a COI in line with research on quality professional development, in order to ensure teachers had sufficient understanding of how to facilitate classroom discussion in their own schools (Supovitz and Turner 2000; Tseng et al. 2012).

Data Analysis

The coding schedules were developed based on previous research looking at questioning and inquiry behaviours. The questioning behaviours framework was used to code students' discourse based on two types of questions, procedural and substantive, as outlined by

Splitter and Sharp (1995), and three levels of cognitive engagement, recall, comprehension and high-level thinking, as outlined by Gall (1970). Five inquiry behaviours that students employ while working together to achieve a common goal, as outlined by Cam (2006), were also coded in accordance with the verbal inquiry behaviours framework. These behaviours are classified as skills used to critically explore ideas and include verbal behaviour that reflects developing ideas, exploring alternatives, exploring key concepts, testing hypotheses or drawing conclusions. Both of these coding schedules were utilised to analyse behaviour during discourse and based on the research that validated coding of these behaviours (Burgh et al. 2006; Cam 2006; Gall 1970; Splitter and Sharp 1995).

Student discourse was analysed to identify the type and cognitive engagement of students' questioning throughout the small group discussions. Understanding the types of questions students asked was achieved by identifying the instances of procedural or substantive questioning (Burgh et al. 2006) in student discourse and coding this behaviour. The discourse was then coded based on the cognitive engagement it required, defined by Gall's (1970) levels of recall, analytic and high-level thinking questions. The frequency of questions coded within these categories during student small group discussions around the inquiry tasks was further analysed to calculate the differences in frequency between the two groups and the maintenance of these behaviours within each condition over the 2-year period.

As outlined above, procedural questions are questions posed by students "to inquire into meaning and the underlying logic or structure of thinking" (Burgh et al. 2006, p. 154). Questions probing simple clarifications, simple explanations and simple operations or persuading an act were coded as procedural questions. These questions were then categorised based on the cognitive engagement the questions required. Questions that required low-level recognition and remembering of facts were coded as recall questions (P1); those involving logical reasoning, comparisons and explanations were coded as analytic thinking questions (P2); and questions that entailed synthesising, conjecturing and judging information were coded as higher-order thinking questions (P3) (Gall 1970). Table 1 summarises coding for procedural questions with examples of student discourse displaying these questioning behaviours.

Substantive questions are those questions posed by students to develop a deeper understanding of the subject matter and inquire into the nature of reality, knowledge and values (Burgh et al. 2006). Questions about science content that required effortful thinking to answer were coded as substantive questions. These questions were then categorised based on the cognitive engagement the questions required. Questions that required low-level recognition and remembering of facts were coded as recall questions (S1); those involving logical reasoning, comparisons and explanations were coded as analytic thinking questions (S2); and questions that entailed synthesising, conjecturing and judging information were coded as higher-order thinking questions (S3). Table 2 summarises coding for substantive questions with examples of student discourse displaying these questioning behaviours.

The process of inquiry requires students to engage in and develop a variety of inquiry skills and behaviours in order to deepen their engagement with the inquiry process (Australian and Reporting Authority 2014b). There are many versions of the process of inquiry; however, the desired inquiry skills and behaviours are similar across the models, as can be seen in Table 3. To analyse the inquiry behaviours students engaged with, students' discourse was analysed and coded for five types of inquiry verbal behaviours drawn from each phase of inquiry outlined in Cam's (2006) Basic Pattern of Inquiry. These behaviours include developing ideas,

Table 1 Examples of coded procedural (P) questions during small group activities

Question category	Example
P1 factual questions	S1: For environment, do you know how you said bananas clone themselves, anyway, where did you get that information?
	(T_3, comparison group 2, unit 2)
	S1: I think we should be told (about GM food) because we've got to know what we're buying. We're paying all this money and if we don't know what we're buying…
	S2: Yes. Next topic.
	S1: Can we get off that subject?
	S3: Can we do health? (T_4, COI group 1, unit 2)
P2 analytic thinking questions	S1: You do the first one. You do the second one. I'll do the third one. You do the fourth one and then we'll get on to this one.
	S2: That's being silly. Why don't we just do it all at the same time? (T_2, comparison group 2, unit 1)
	S1: Do I say water train to mitochondria? (T_6, comparison group 1, unit 4)
P3 high-level thinking questions	S1: Stupid scientists.
	S2: The good thing about GM crops is they may grow faster. Did you think about that? (T_4, COI group 1, unit 2)
	S1: Let's write health. (Pause) I think the next one should be social or political. S2: Do you think social because they don't tell us if they're eating it or not? (T_3, comparison group 1, unit 2)
	S1: Are we going to explain the safety features that help with Newton's law? (T_7, COI group 2, unit 3)

Teachers (T_1, T_3), student group (1 or 2), condition (COI or comparison) and unit number (1–4) are denoted for each example

Table 2 Examples of coded substantive (S) questions during small group activities

Question category	Example
S1 factual questions	S1: We'll all think of some for defence and we'll do that afterwards. S2: What's a defence against it? (T_2, comparison group 2, unit 1)
	S1: Does a car have DNA? (T_8, COI group 1, unit 1)
S2 analytic thinking questions	S1: What is mitochondria going to be? (T_6, comparison group 1, unit 4)
	S1: We definitely know it (car) gives off waste.
	S2: Would that make it living? (T_1, COI group 2, unit 1)
	S1: Maybe we should colour this in because you can't really see it. (Pause) So are the handlebars going to be the normal straight ones? Because the normal ones are like that… (Demonstrates) And the ones up high are for freestyle "thing". (T_5, COI group 2, unit 3)
S3 high-level thinking questions	S1: But still the PM has no choice. S2: Do we have a choice in this at the supermarkets? (T_3, comparison group 1, unit 2)
	S1: Even they have wheels. They drink that stuff petrol. S2: Do you reckon that it is living because it drinks? (T_8, COI group 1, unit 1)
	S1: What if the cell wall is like a fence and cell membrane is the big entry and exit? (T_{10}, COI group 2, unit 4)

Teachers (T_1, T_3), student group (1 or 2), condition (COI or comparison) and unit number (1–4) are denoted for each example

Table 3 Alignment of inquiry phases across different inquiry models and the associated inquiry behaviours. Italicized inquiry behaviours were coded in this study

Basic pattern of inquiry	Scientific inquiry steps	Cognitive skills	Associated behaviours
Initiating inquiry	Initiation	Interpretation	Questioning, predicting, planning, clarifying, gathering ideas, decoding, *developing ideas*
Generating suggestions	Invention	Inference	*Exploring alternatives*, analysing information, comparing and contrasting, forming hypotheses, gathering information
Reasoning	Investigation	Self-regulation	*Testing hypotheses*, conducting investigations, searching for evidence, self-correcting, providing counter-examples
Conceptual exploration	Investigation	Analysis	Processing and analysing data/information/ arguments, *exploring concepts*, making distinctions, identifying relationships, forming criteria
Evaluating concluding	Interpretation	Evaluation inference	Assessing claims/arguments, evaluating results, *drawing conclusions*
(Cam 2006)	(Seraphin et al. 2013)	(Facione 1990)	

exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions, with each being important to engage students in critically exploring ideas. Table 4 summarises coding for these inquiry behaviours with examples of student discourse.

The five verbal inquiry behaviours align with the five sub-strands of the Australian Science Curriculum and include inquiry skills from the Science Inquiry Skills strand. These verbal inquiry behaviours are important to the inquiry process and focus on the skills students require to successfully undertake each phase of the inquiry process, providing insights into how well students are engaging with science inquiry learning (Cam 2006). The frequency of these behaviours in students' small group discussions around the inquiry tasks in each unit and group was then calculated to determine the differences between the two groups and the maintenance of these behaviours within each condition over the 2-year period.

In this study, 58 student groups (approximately 39 h) over the 2-year period were filmed. The digitally recorded discussions were transcribed and then coded for student questioning and verbal inquiry behaviours to produce quantitative data. Students' verbal behaviours during small group inquiry activities were coded according to frequency across recorded group sessions and represent 100 % of the students' group discussions during these sessions. To check for inter-rater reliability, two coders, one blind to the purposes of the study, coded a common 2 h (three group sessions) of recording. For the categories coded, inter-rater reliability ranged from 83 to 96 %. To maintain confidentiality, examples of student discourse are distinguished by the group within which the student was participating and that group's teacher, who was de-identified using a number representing the group and unit they taught.

Preliminary assumption testing was conducted before analysing each set of data to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices and multicolinearity, as recommended by Kraska (2010), with no serious violations noted. A one-way between groups multiple analysis of variance (MANOVA) was

Table 4 Examples of coded verbal inquiry behaviours during small group activities

Inquiry behaviour	Example
Developing ideas	S1: With social, will they turn the job market upside down in making GM food? S2: Is it possible that GM may be our future? S3: Is it possible that GM is our next future food? What about economic? S2: Is it benefitting us or only the farmers? S3: The government and farmers. (T_3, comparison group 1, unit 2)
	S1: It needs a knobbly tread remember. Do you know those little things that stick out of the tyres? S2: The spikes he means not the knobbly things. (T_5, COI group 2, unit 3)
Exploring alternatives	S1: So do we have a second point on economic? Well what's good angle for GM crops? S2: I don't see any good angles. I'm against it. But I suppose there are some good… S3: But haven't tomatoes developed resistance to antibiotics… (T_3, comparison group 1, unit 2)
	S1: What if you're allergic to bananas? S2: Then they'll make bananas that are allergy free. (T_4, COI group 1, unit 2)
Exploring key concepts	S1: So, is it (GM) beneficial to us? Are the farmers the only ones that are benefitting from the economic—from money? S2: For the environment—cross-pollination. What happens when there's cross-pollination? S1: The plant that is cross-pollinated to… S2: It changes its DNA and then that becomes GM. (T_3, comparison group 1, unit 2)
	S1: Basically, it's non-living. S2: Cars don't have babies. S1: Is Marty saying it's alive? S2: They run on fuel like petrol. (T_1, COI group 2, unit 1)
Testing hypotheses	S1: It doesn't have blood so…. S2: He wants to put the person in jail. S3: No, he's trying to put him in jail to show that he was right in it being not alive. No form of blood. That's better because trees have sap. (T_{11}, comparison group 1, unit 1)
	S1: But it doesn't break… (Pause) Does the car have cells? S2: How do we know that? You can't stick a needle into it. Otherwise the needle would break. And it has cells, gas cells, molecules. S1: That's from petrol. (T_1, COI group 2, unit 1)
Drawing conclusions	S1: He's got a point. S2: But also, it's a robot basically. Robots are non-living. S3: OK. Everyone give us an answer, OK. S2: It's a robot. S3: Is that why? S2: It's non-living. It's non-living because it's a robot. (T_2, comparison group 2, unit 1)
	S1: But what happens when they (cars) crash? If it can break, what does that mean? S2: If it breaks and it doesn't work again, that would tell that it isn't living. S1: That is true. (T_1, COI group 2, unit 1)

Teachers (T1, T3), student group (1 or 2), condition (COI or comparison) and unit number (1–4) are denoted for each example

performed to investigate differences in students' procedural and substantive questioning behaviours and differences in students' discourse reflecting the different categories of inquiry behaviours between the two conditions over the 2 years of the study. A within group MANOVA was also performed to analyse the impact of the interventions on student questioning behaviours and other verbal inquiry behaviours over the 2 years within each condition separately. In these analyses, three main categories of procedural and substantive questioning (recall—P1, S1; analytic thinking—P2, S2; high-level thinking—P3, S3) and five categories of verbal inquiry behaviours (developing ideas, exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions) were used as dependent variables. Results for dependent variables were considered separately using a Bonferroni test.

Results

Questioning

Comparison Condition Within Group Comparisons Students' questioning behaviours within the comparison condition during both years of the study were coded and the mean frequency of the specific behaviours was calculated. There was no statistically significant difference in either student procedural or substantive questioning between year 1 and year 2 for the comparison group, F (6, 24)=1.433, p>0.243; Wilk's Lambda=0.736; partial eta squared=0.264.

COI Condition Within Group Comparisons Students' questioning behaviours within the COI condition during both years of the study were coded and the mean frequency of the specific behaviours was calculated. There was a statistically significant improvement in student procedural and substantive questioning between year 1 and year 2 for the COI condition on the combined dependent variables, F (6, 18)=11.549, p<0.001; Wilk's Lambda=0.206; partial eta squared=0.794. When the results for the dependent variables were considered separately, Table 5 shows that there was a significantly higher frequency of P1, P2, P3, S1 and S2 questioning in the COI group across year 2 compared to year 1.

Between Groups Comparisons Across the Two Conditions The mean scores for the frequency of student questioning in both the comparison and COI conditions were calculated. In the first year of the study, there was no statistically significant difference between the comparison and COI conditions on the combined dependent variables, F (5, 30)= 0.704, p>0.625; Wilk's Lambda=0.895; partial eta squared=0.105. In the second year of the study, however, there was a statistically significant difference between the

Table 5 COI condition mean scores and standard deviations (in parentheses) for procedural (P1, P2, P3) and substantive (S1, S2, S3) question categories in the first and second year of study

Question category	Year 1 (N=16)	Year 2 (N=9)	F (1, 23)	p	Effect size
P1	3.25 (1.183)	7.67 (4.00)	17.344	*<0.001*	*0.430*
P2	1.44 (1.031)	4.11 (1.453)	28.849	*<0.001*	*0.556*
P3	0.13 (0.500)	1.33 (1.323)	10.897	*0.003*	*0.321*
S1	3.00 (1.932)	5.78 (2.224)	10.698	*0.003*	*0.317*
S2	2.94 (2.081)	7.22 (1.922)	25.739	*<0.001*	*0.528*
S3	2.06 (2.792)	3.78 (1.922)	2.661	0.116	0.104

Testing for normality and univariate/multivariate outliers revealed that one group was an outlier and was removed from the dataset across year 1 and year 2

P1 procedural recall questions, *P2* procedural analytic thinking questions, *P3* procedural high-level thinking questions, *S1* substantive recall questions, *S2* substantive analytic thinking questions, *S3* substantive high-level thinking questions, *N* number of student groups (each with four students) across two units. Italicized p values and effect sizes denote significance and large effect sizes respectively.

Table 6 Mean scores and standard deviations (in parentheses) for procedural question categories P1, P2, P3 and substantive question categories S1, S2, S3 in the second year of study

Question category	Comparison (*N*=12)	COI (*N*=9)	*F* (1,19)	*p*	Effect size
P1	4.83 (1.267)	7.67 (4.00)	5.385	*0.032*	*0.221*
P2	1.42 (1.505)	4.11 (1.453)	16.969	*0.001*	*0.472*
P3	0.17 (0.389)	1.33 (1.323)	8.489	*0.009*	*0.309*
S1	3.50 (1.168)	5.78 (2.224)	9.293	*0.007*	*0.328*
S2	4.00 (1.809)	7.22 (1.922)	15.476	*0.001*	*0.449*
S3	2.50 (1.931)	3.78 (1.922)	2.261	0.149	0.106

P1 procedural recall questions, *P2* procedural analytic thinking questions, *P3* procedural high-level thinking questions, *S1* substantive recall questions, *S2* substantive analytic thinking questions, *S3* substantive high-level thinking questions, *N* number of student groups (each with four students) across two units. Italicized p values and effect sizes denote significance and medium to large effect sizes respectively.

comparison and the COI conditions in student procedural and substantive questioning categories, F (6, 14)=7.189, $p<0.001$; Wilk's Lambda=0.245; partial eta squared= 0.755. Table 6 shows that, in the second year of the study, the COI group demonstrated significantly higher mean scores for P1, P2, P3, S1 and S2 questioning within small group discussions than the comparison group.

Inquiry Behaviours

Comparison Condition Within Group Comparisons Students' verbal inquiry behaviours within the comparison condition during both years of the study were coded and the mean frequency of the specific behaviours was calculated. There was a statistically significant difference in student verbal inquiry behaviours across year 1 and year 2 for the comparison condition on the combined dependent variables, F (5, 25)=5.856, $p<0.001$; Wilk's Lambda= 0.461; partial eta squared=0.539. Table 7 shows that in the second year of the study, the comparison condition demonstrated a significantly higher frequency of verbal inquiry behaviours classified as developing ideas compared to the first year of the study. However, in the first year, the comparison condition demonstrated a higher frequency of exploring alternatives and testing hypotheses than in the second year.

Table 7 Comparison condition mean scores and standard deviations (in parentheses) for the inquiry verbal behaviours: developing ideas, exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions in the first and second year of study

Inquiry verbal behaviour	Year 1 (*N*=19)	Year 2 (*N*=12)	*F* (1, 29)	*p*	Effect size
Developing ideas	4.11 (1.853)	6.17 (1.749)	9.495	*0.004*	*0.247*
Exploring alternatives	2.26 (1.996)	0.83 (2.870)	4.992	*0.033*	*0.147*
Exploring key concepts	5.68 (2.668)	5.17 (2.209)	0.314	0.579	0.011
Testing hypotheses	2.53 (2.568)	0.42 (0.793)	7.555	*0.010*	*0.207*
Drawing conclusions	3.58 (2.714)	2.42 (1.240)	1.927	0.176	0.062

N number of student groups (each with four students) across two units. Italicized p values and effect sizes denote significance and medium to large effect sizes respectively.

Table 8 COI condition mean scores and standard deviations (in parentheses) for the inquiry verbal behaviours: developing ideas, exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions in the first and second year of study

Inquiry verbal behaviour	Year 1 (*N*=17)	Year 2 (*N*=10)	*F* (1, 25)	*p*	Effect size
Developing ideas	4.24 (3.251)	10.00 (3.367)	19.298	*<0.001*	*0.436*
Exploring alternatives	3.12 (2.870)	3.40 (2.503)	0.067	0.798	0.003
Exploring key concepts	6.35 (2.760)	8.80 (2.573)	5.194	*0.031*	*0.172*
Testing hypotheses	3.76 (3.509)	2.60 (3.204)	0.738	0.399	0.029
Drawing conclusions	3.59 (2.320)	4.30 (2.406)	0.577	0.455	0.023

N number of student groups (each with four students) across two units. Italicized p values and effect sizes denote significance and medium to large effect sizes respectively.

COI Condition Within Group Comparisons Students' verbal inquiry behaviours within the COI condition during both years of the study were coded and the mean frequency of the specific behaviours was calculated. There was a statistically significant difference in student verbal inquiry behaviours between the first and second year of the study for the COI group on the combined dependent variables, $F\,(5, 21)=8.611$, $p<0.001$; Wilk's Lambda=0.328; partial eta squared=0.672. The mean scores and the standard deviations in Table 8 show that the COI condition had a significantly higher frequency of verbal inquiry behaviours classified as developing ideas and exploring key concepts in the second year of the study compared to the first year (see Table 8).

Between Groups Comparisons Across the Two Conditions The mean scores for the frequency of student verbal inquiry behaviours in both the comparison and COI conditions were calculated. In the first year of the study, there was no statistically significant difference between the behaviours demonstrated by students in the comparison and COI conditions on the combined dependent variables, $F\,(5, 30)=0.704$, $p>0.625$; Wilk's Lambda=0.895; partial eta squared=0.105. However, in the second year of the study, there was a statistically significant difference between the comparison and COI conditions on the combined dependent variables, $F\,(5, 16)=3.307$, $p<0.031$; Wilk's Lambda=0.492; partial eta squared=0.508. Table 9 shows that in the second year of the study, the COI condition demonstrated a significantly higher frequency for all verbal inquiry behaviours when compared to the students in the comparison condition.

Discussion

This study investigated the effectiveness of training teachers in the COI approach on a broad scope of student inquiry behaviours. Through doing so, this study sought to find out how implementing a COI approach during primary science inquiry-based lessons impacted on the nature of the questioning and other inquiry behaviours with which students engaged. The results have shown that the pedagogical- plus curriculum-based inquiry professional development intervention (COI condition) had a statistically significant positive impact on many variables of students' questioning behaviours and significant impacts on all verbal inquiry

Table 9 Mean scores and standard deviations (in parentheses) for the inquiry behaviours developing ideas, exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions in year 2 of the study

Inquiry verbal behaviour	Comparison (*N*=12)	COI (*N*=9)	*F* (1, 20)	*p*	Effect size
Developing ideas	6.17 (1.749)	10.00 (3.367)	11.816	*0.003*	*0.371*
Exploring alternatives	0.83 (1.193)	3.40 (2.503)	9.972	*0.005*	*0.333*
Exploring key concepts	5.17 (2.209)	8.80 (2.573)	12.714	*0.002*	*0.386*
Testing hypotheses	0.42 (0.793)	2.60 (3.204)	5.236	*0.033*	*0.207*
Drawing conclusions	2.42 (1.240)	4.30 (2.406)	5.606	*0.028*	*0.219*

N number of student groups (each with four students) across two units. Italicized p values and effect sizes denote significance and medium to large effect sizes respectively.

behaviours when compared to the comparison condition. There was a corresponding improvement in both students' questioning and other inquiry behaviours over the 2 years of the study within the COI condition and, when compared to the comparison condition, the results clearly show that inquiry-based pedagogical interventions helped to provide teachers with the necessary understanding to foster questioning and other inquiry behaviours in students.

Across the 2 years of the study, the comparison condition showed a significant decline in inquiry behaviours, exploring alternatives and testing hypotheses, an improvement in developing ideas and no significant change in questioning or other inquiry behaviours. A science curriculum-based inquiry intervention (with a non-inquiry pedagogical intervention) provided in both years of the study was largely insufficient to improve, or maintain in some cases, questioning and other inquiry behaviours. The between groups comparisons found that the students in the COI condition demonstrated a significantly higher use of all types and levels of questioning than those in the comparison condition within the second year of the study, with significantly higher frequencies of procedural recall, procedural analytic thinking, procedural high-level thinking, substantive recall and substantive analytic thinking questions. In addition, the COI condition demonstrated a significantly higher engagement with all inquiry behaviours (developing ideas, exploring alternatives, exploring key concepts, testing hypotheses and drawing conclusions) within year 2 of the study.

Impact of Collaborative Philosophical Inquiry on Questioning and Other Inquiry Behaviours

The within groups comparisons revealed that the COI condition experienced significant improvements on all questioning variables and corresponding improvements on all verbal inquiry behaviours, with the exception of testing hypotheses, where students were strong in year 1 and maintained this skill into year 2. These results show that implementing collaborative philosophical inquiry does not only promote critical thinking in students, as evidenced by the meta-analyses conducted by Garcia-Moriyon et al. (2005) and Trickey and Topping (2004), but significantly improves the specific questioning and verbal inquiry behaviours the Australian Science Curriculum stipulates as central to students' science learning. The findings show a more fine-grained picture of the questioning and other verbal inquiry behaviours that collaborative philosophical inquiry fosters and indicates that students not only ask more questions, as we reported (Gillies et al. 2014), but students ask a variety of types of questions that engage high cognitive levels of thinking. Students in this condition also demonstrated a significantly higher incidence of other inquiry behaviours in year 2. In this study, the pedagogical- and curriculum-based inquiry intervention improved students' abilities to engage in discussions to understand science, to undertake collaborative philosophical inquiry, and to pose a broad range of questions through the development of verbal science inquiry behaviours. These findings indicate that the COI approach to teaching science is effective in improving students' abilities to engage with and examine science content at a deeper level, as it equips them with the necessary inquiry skills. Therefore, they provide strong evidence for the inclusion of collaborative philosophical inquiry as a preferred approach to teaching science inquiry.

The within groups comparisons also revealed that the positive impacts on students' questioning and other verbal inquiry behaviours was fostered over the 2-year period. This provides a much needed insight into the longitudinal impacts of implementing a collaborative philosophical inquiry approach in science inquiry learning (Crawford 2012; Supovitz and Turner 2000) and indicates that the positive short-term impacts reported by Garcia-Moriyon et al. (2005) and Trickey and Topping (2004) are maintained by students over a longer period of time. The maintenance of behaviours demonstrated by students in this study supports the findings of Topping and Trickey (2007a) that exposure to collaborative philosophical inquiry can have long-lasting positive impacts on students' learning. While their study showed that students taught through collaborative philosophy inquiry in primary school maintained cognitive gains into their second year of secondary school, the present study indicates that the maintenance of cognitive gains was likely to be associated with the the improvement of questioning and other inquiry behaviours that support students to think deeply about subject matter and therefore improve students' learning. Explicitly teaching students to ask strategic questions enables them to infer and predict, and promotes the transformation of information through fostering the development of explanatory answers to those questions (see Woolley 2007). This is further supported by a case study conducted with 25 teenage students in Singapore (Laxman 2013), which showed that students involved in formulating their own questions through an inquiry-oriented, student-authored questioning pedagogy improved in their ability to problem solve and generate questions and explanations.

The findings presented here attest to the students' abilities to transfer the behaviours and skills they learnt through the collaborative philosophical inquiry approach to other contexts, with this study showing that students were able to transfer questioning and other inquiry behaviours they had developed to support their engagement across four diverse science topics. The development of these behaviours over time and across contexts is significant as this finding indicates that students who learn science through a collaborative philosophical inquiry approach are more likely to internalise the questioning and verbal inquiry behaviours they developed for use in other contexts and thus are more likely to apply the behaviours and skills they develop in class in the real world and later on in life (Lucas et al. 2005). Indeed, previous studies have shown that engaging students in elaborate and higher-order questioning and discussion enhances their language and comprehension skills as well as their ability to store verbal information in working memory (see Woolley 2007). In light of the continuing discussion around how to best shape school science to provide students with "the competence to act intelligently in a future dominated by science and technology" (Brickhouse 2008, p. 287), this study, alongside the work by Topping and Trickey (2007a), indicates that collaborative philosophical inquiry may indeed be a way of supporting students to develop science behaviours and skills that will support them to successfully engage in the future world.

Do Teachers Need Inquiry Pedagogy Professional Development?

Previous studies focusing on training teachers to implement inquiry in the classroom have examined teachers' perceptions and have uncovered many aspects of inquiry that teachers find difficult to implement (Crawford 2012; Grigg et al. 2012; Supovitz and Turner 2000; Tseng et al. 2012). These particular studies implemented the comparison intervention included in the current study, where teachers are involved in unpacking what to teach but are not supported in how or why they should teach it—common of many professional development interventions (Edelson 2008). Perhaps this, alongside the conflicting advice that still surrounds how inquiry should be implemented in the classroom (Abd-el-khalick 2008), is why teachers find it difficult to implement inquiry in the science classroom. Given this information, it is important to consider the value of providing interventions for teachers on inquiry pedagogy and the impact these interventions have on students' science behaviours.

In this study, the two interventions were clearly defined. The comparison condition received an inquiry science curriculum-based intervention alongside a non-inquiry pedagogical intervention. This included training in collaborative strategic reading pedagogy and in the inquiry-based science units with a focus on mapping out the unit; teachers learned about the content as they participated in the activities themselves and also discussed appropriate cooperative learning strategies that could be used within the unit to foster student learning. The experimental group, the COI condition, also received the inquiry science curriculum-based intervention but additionally received an inquiry pedagogy intervention. The pedagogical intervention focused on facilitating collaborative philosophical inquiry within the classroom, which supported the teachers to understand how to foster student discussion and deep thinking about the content and knowledge required. The study was structured in this way to find out whether providing teachers with a set of instructions on what they should teach (an inquiry science unit), through a curriculum-based intervention, was sufficient to foster inquiry and questioning behaviours in students, as per the aims of the Australian Science Curriculum (Australian Curriculum, Assessment and Reporting Authority 2014b).

The between groups comparisons for this study showed that, when compared to the comparison condition, students in the COI condition demonstrated a significantly higher frequency of procedural (recall P1, analytic thinking P2, high-level thinking P3) and substantive (recall S1 and analytic thinking S2) questioning categories and all of the other types of verbal inquiry behaviours during year 2 of the study. These results show that an inquiry pedagogy intervention alongside an inquiry science curriculum intervention is essential to foster higher engagement with questioning and other inquiry skills in students. Even with training in cooperative learning strategies, the inquiry curriculum-based intervention (alongside a non-inquiry pedagogical intervention) provided to the comparison condition was insufficient in improving students' engagement with questioning and other verbal inquiry behaviours. These findings show that teachers need more than curriculum support to effectively implement inquiry-based learning, as proposed by Crawford (2012), Gamoran et al. (2003), Grigg et al. (2012) and Reinsvold (2011). This has large implications for how educational organisations choose to support teachers in adopting inquiry-based learning in the science classroom and indicates more pedagogical support is required for teachers to successfully utilise inquiry curriculum resources that are commonly provided.

In this paper, we have explored the link between inquiry-based learning through inquiry science curriculum and inquiry-based teaching through COI pedagogy as an approach to teacher professional development and its impact on student inquiry behaviours. This approach to professional development has a sustained (2 years) impact on students' levels of procedural and substantive questioning and inquiry behaviours. The question arises as to why we see this significant impact on students' inquiry behaviours? The embedding of COI into inquiry science curriculum fosters pedagogy that develops and supports practitioner inquiry. Integrating a COI approach into inquiry science units of work requires teachers to focus on or emphasise the inquiry learning processes around science concepts. This promotes classroom interactions that enable teachers and students to move conceptually deeper into science concepts through critical inquiry (Baumfield 2006). We have shown in a previous study that teachers trained in the COI approach show a significant change in their pedagogy around fostering intellectual quality in the classroom compared to their untrained colleagues (Scholl et al. 2014). Their pedagogy becomes more open, critical, interactive and constructivist. They engage students in questioning, in problematizing and constructing knowledge, and in expressing differing perspectives.

Implications and Conclusions

This study has shown two clear results. First, learning through a collaborative philosophical inquiry approach to science inquiry improves students' questioning and verbal inquiry behaviours and supports students to transfer and apply these skills across contexts. The results showed that the students in the COI condition maintained these behaviours and demonstrated significant improvements in the 2 years of the study. The inference drawn is that implementing a collaborative philosophical inquiry within inquiry science develops questioning and science inquiry behaviours within students that will support their engagement with science and society into the future and allows teachers to foster the skills predicated by the Australian Science Curriculum within their students. Secondly, the study shows that no matter the quality of a science inquiry unit, providing only curriculum resources to teachers is not sufficient in supporting teachers to promote the questioning and other verbal inquiry behaviours predicated by the Australian Science Curriculum. Teachers require quality inquiry pedagogy interventions that require them to think about the topics they are teaching and inquire themselves into the content they are teaching.

Collaborative philosophical inquiry through a COI approach is widely discussed in the educational community; however, there is still resistance to embedding this approach in classroom teaching (see Daniel and Auriac 2011). The results of this study offer evidence that could assist the educational community to understand how to embed collaborative philosophical inquiry learning successfully into science education. To implement collaborative philosophical inquiry into science curriculum requires explicit pedagogical-based interventions that support teachers to understand how to teach the content through inquiry and how to engage students in inquiry about science content. This study shows that through engaging in an inquiry pedagogy intervention, teachers can successfully implement an inquiry-based approach and positively impact the development of inquiry behaviours and science learning in their students.

Future studies need to investigate exactly how engaging students in collaborative philosophical inquiry impacts students' questioning and other verbal inquiry behaviours. How does philosophising about the science curriculum transform student thinking to result in a significant shift in their skills to question and inquire?

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