Transacting inquiry in middle school science classrooms: A study exploring the nature of discourse and a spectrum of outcomes

Synopsis of Ph.D. Thesis

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Abstract

Science involves reasoning about the world in particular ways that are shared by a scientific community (Lemke, 1990). Students are inducted into the practices of science through discourse in the science classroom. The teacher plays a pivotal role in guiding students into this emergent science community through the level and complexity of her questions, the environment created for questioning, and the patterns of teacher-student interactions. This study explores some of these ways in which teachers guide the discourse, activities and ways of thinking in the science classroom, how students appropriate them in their learning and how it affects not just students' understanding of science concepts but also the ways in which they engage with and perceive science and learning. For this purpose, science teaching and learning were studied in two sets of middle school science classes, one taught through inquiry and another through traditional teaching, in the context of an out-of-school science program. The study adopted a mixed methods research approach and is aligned with the social constructivist perspective (Vygotsky, 1978) that emphasizes how personally meaningful knowledge is socially constructed through shared understandings. Accordingly, open-ended methods (classroom observations, video-records, teacher reflections, student diaries questionnaires and semi-structured interviews) were used to gather data which were analyzed qualitatively and quantitatively to build a naturalistic account (Lincoln & Guba, 1985) of the science teaching that was observed. Different methods and elements of the study together portray a composite picture, leading towards a characterization of the complex process of teaching science as an inquiry; teachers interested in moving towards more constructivist teaching practices in their classrooms may find this description helpful. This study also attempts to explore a wide array of outcomes that may help in garnering further support for the teaching of science as an inquiry.

Chapter 1. Introduction

Sustaining and building on children's initial curiosity in the pedagogic space, and even evoking it, requires attention to some important design features. Such features that teachers need to "orchestrate to help children build a chain of inquiry rather than a succession of fleeting interests" (Lehrer, Carpenter, Schauble & Putz, 2000) are often left tacit. The teacher's decisions about how a concept would be introduced, the activities that would be used and how much and what type of guidance is needed while transacting the lesson affect how students engage with their science learning. As the teacher goes about creating and shaping the classroom dynamics, the nature of interactions between the teacher and students plays a crucial role in the process (Alexander, 2006). This study intends to understand such dynamics in the science classroom, exploring the ways in which teachers guide the discourse, activities and ways of thinking in the science classroom, how students appropriate them in their learning and how it affects students' understanding, views, participation and engagement with science in classes taught through inquiry vis-a-vis those involving the conventional, expository science teaching.

Before delving into the research background, context and motivation of the study, the research questions that it aims to address and the theoretical assumptions underpinning it, we find it necessary in the thesis, to engage in a prologue on what we as a science education community want students to learn in science at the school level. The intent, in this section, is not to draw up a comprehensive list of goals for science education but to highlight the wide spectrum of goals deemed important by different researchers in the field. As Biesta (2009, p. 33) argues, "there is a need to reconnect with the question of purpose in education in general and science education in particular, especially in light of a recent tendency to focus discussions about education almost exclusively on the measurement of educational outcomes". Instead of merely making a case for an effective way of teaching, we need to ask 'effective for what?' and 'effective for whom?', otherwise, there is a danger that we would end up valuing what is measured, rather than examining ways to measure what we value.

1.1 Towards a more complete picture of what teaching and learning of science entails

Educators have argued for a diverse range of goals for the teaching of school science that are conceptual, epistemic, social and affective in nature. We contend that these goals (discussed in detail in the thesis) are not necessarily mutually exclusive. They are interlinked with various components of teaching in a complex web, and albeit the primary focus of a particular teaching approach may explicitly be any one of the goals, de facto, students would most likely be affected in multiple, interconnected ways (Varelas, Kane, & Wylie, 2011). We, therefore, argue that studies exploring the dynamics and effectiveness of science teaching need to consider the larger goals of science education instead of just content acquisition and to dwell on what aspects of teaching affect the different outcomes, and how, and what could be the kind of evidences of students attaining those outcomes.

1.2 Research background and rationale

Across the calls for reforms proposed in science education throughout the world, there is a common emphasis on teaching science as inquiry, which would mirror the ways in which science works and facilitate students' active intellectual engagement (European Commission, 2015; National Council of Educational Research & Training [NCERT], 2006; National Research Council [NRC] 1996, 2012). Yet it is not commonly practised in classrooms (Akuma & Callaghan, 2019) possibly because it is challenging to prepare teachers to adopt inquiry practices in their classroom. As Bybee (2000, p.20) points out, although the teaching of science as inquiry has a long history in science education, there has been "an equally long history of confusion about what teaching as inquiry means and regardless of its definition, *its implementation*." Furthermore, it is unclear whether the outcomes justify the effort needed for transacting inquiry in the classroom, as educational and political debates continue over its effectiveness (Zhang, 2016). Researchers in science education have been trying to address this problem in two ways. Firstly, acknowledging the difficulty of visualizing inquiry in actual practice, studies (e.g. Martinez, Borko & Stecher, 2012) have attempted to characterize the complex process of inquiry in the classroom and provide real-life descriptions which would facilitate reform. Secondly, studies have aimed to probe the efficacy of inquiry-oriented teaching (e.g. Marshall, Smart & Alstone, 2016). This dissertation study seeks to contribute towards answering these two important questions that underpin the current research on inquiry-based science teaching: What does inquiry in the science classroom look like, in terms of the transactions that make it possible? And what, if any, is the comparative evidence for the effectiveness of inquiry across the conceptual, affective and epistemic domains of learning?

1.3 Research context

The present study was associated with the 'Middle School Science Curriculum Development Project' at the Homi Bhabha Centre for Science Education (HBCSE). The objective of this larger project was to develop an alternative, inquiry-oriented science curriculum at the middle school level. The curriculum development and testing processes involved in this project were so combined that the curriculum took shape within the classroom setting where students' ideas were elicited and probed and pedagogic strategies to address them were developed and tested simultaneously to develop curricular material for students and supporting material for teachers. Classes conducted as part of the curriculum development project from June 2009 to June 2010 were observed as inquiry classes as part of this dissertation study.

The instructional approach in the inquiry classrooms in this study was specifically that of guided inquiry (illustrated in Vijapurkar, Kawalkar & Nambiar, 2014). Discussions and activities were used to gauge students' prior knowledge and elicit their mental picture of the associated concepts. These insights aided the teacher in planning and developing the pedagogical sequences required to take students to the point where they could do a critical examination of their understanding and revisit their conceptions.

1.4 Motivation for the study

In the classroom trials conducted for the curriculum development project at the HBCSE, over several years, some conspicuous affective changes in students were noticed, although the focus of teaching in these classes was on conceptual understanding. A group of students attended these classes consistently for four years since the time they had passed Grade 4 until they had passed Grade 8 (2005 - 2009). At the end of the contact period with them, these outcomes were probed using questionnaires and follow-up interviews with the students. We also administered questionnaires to students' parents and peer group for triangulation of students' responses. Findings of this preliminary study (Kawalkar & Vijapurkar, 2011) included reported increase in students' engagement levels with the topic at hand, their self-confidence and participation in regular science classes at school as well as a change in the way they learned science and in their perceptions of science and scientists.

There were certain limitations of the preliminary study due to its *ex post facto* nature. Since questionnaires were administered only after the intervention, baseline information from students was not available for comparison. It could not address the effect of confounding variables like positive bias and maturation. We took up further research on this issue, in the form of this dissertation study, to address these limitations and also probe the characteristics of inquiry teaching that might play a part in bringing about such outcomes. Inputs from the preliminary study informed the design of this doctoral study. Possible confounding factors were addressed with measures like the inclusion of a comparison group, administration of questionnaires both before and after the instructional contact period and formal classroom observation. The questionnaires and interview schedules developed and piloted in the preliminary study were used for the dissertation study with a few additions and modifications. Building on the initial study, the present study attempts to explore the array of outcomes from multiple data sources as well as detail what happens in an inquiry classroom, compared to a traditional science classroom, particularly what the teacher does in terms of scaffolding science talk.

1.5 Theoretical framework

This study is aligned with the social constructivist perspective of Vygotsky (1978) which focuses on how personally meaningful knowledge is socially constructed through shared understandings. Social interaction, especially with more experienced members (teachers, usually, in the case of a classroom) provides children with ways of interpreting the world around them. Students thus become “enculturated into ways of thinking that are common practice in that specific community” (Palmer, 2005, p. 3). This highlights the importance of the teacher’s role in guiding students through ‘the zone of proximal development’ and of using talk as a means for joint reasoning.

The present study is in line with this sociocultural perspective in which discourse has various crucial functions: as a cognitive tool which children learn to use to process knowledge; as a social or cultural tool for sharing knowledge as well as values and attitudes; and as a pedagogic tool which one person can use to provide intellectual guidance to another (Mercer & Wegerif, 1999). Also, there are constant, implicit inputs from the teacher about what counts as knowing and about valid ways of knowing. Teachers’ choices in pedagogy also send messages about the nature of science and science learning (Berland & Hammer, 2012). Whether they are aware or not, teachers design the learning environment by setting norms for the kinds of questions worth pursuing, the forms of arguments that are persuasive and the criteria for an acceptable explanation (Lehrer, Carpenter, Schauble & Putz, 2000). Teacher’s questions thus play a crucial role as a design tool, helping them in ‘orchestrating and improvising' the classroom discourse (Jurow & Creighton, 2005).

Drawing on Vygotsky's cognitive zone of proximal development (ZPD), Brophy (1999) developed the idea of motivational ZPD. On the affective side, Brophy contends that the features of a learning domain or activity must gear up with the learner's prior knowledge and experiences in such a way as to stimulate interest in pursuing the learning. This would occur when the domain or activity is familiar enough to the learner to be recognisable as a learning opportunity and attractive enough to interest the learner in pursuing it. Also, there needs to be an optimal match between the difficulty level of a task and developing skills of the learner. The sociocultural theory extends this idea to include the role of the teacher in optimising this match with mediation via modelling, coaching and scaffolding.

1.6 Aims of the study and the guiding research questions

In this study, science teaching and learning were studied in two sets of middle school science classes, one taught through inquiry and another through traditional teaching, in the context of an out-of-school science program. We started the study with two broad aims. As the study design was not tightly predetermined but emergent (Suter, 2011), our strategies for collecting data were open to revisions and additions (for example, asking students to write a learning diary or interviewing teachers as detailed in Chapter 3). Along with the research foci, the research questions also evolved and got sharpened during the study, even as some new ones emerged along the way. This led us to explore the following questions and sub-questions that guided our analyses.

Aim 1. To contribute to characterising the teaching of science through inquiry, exploring the classroom interactions that make it possible, in comparison with traditional science teaching, through multiple perceptions of the researchers, teachers and students.

In this study, we were interested in several closely related aspects of science teaching. Specifically, we asked -

1. How does the teacher guide the discourse in the two sets of classrooms, one taught through inquiry, and the other taught the traditional way?

> How are the teachers' questions and classroom interaction patterns different? What are the teachers' views and strategies that guide the framing of their questions?

2. How does the structure of lessons, nature of tasks and their usage differ in the two modes of teaching?

3. How do students perceive the instruction? What may students' writing in the form of learning diaries reveal about their characterisation, if any, of the teaching methods they have experienced?

4. What are the perspectives of the teachers, participating in this study, on the teaching-learning that happened in these classes?

Aim 2. To explore a range of possible outcomes of learning science through inquiry and traditional teaching (conceptual understanding, students' conceptions of science, learning and themselves as science learners, their participation in class, and cognitive, affective and behavioural engagement) and explore methods to study them

1. What is the difference, if any, in students' understanding of science concepts gleaned from their learning diaries?

2. How do students think about what knowledge and learning entail? How do students in the two classrooms frame science learning?

3. What are students' feelings and reactions towards the teaching they experienced and their self-perceptions of their ability to learn science?

4. What is the difference in the nature and pattern of students' vocal participation in whole-class discussion?

> Who participates and to what extent? Over time, how does students' participation evolve in their classroom community?

5. Is there any change in students' interest in science in and beyond the science classrooms in the program? Is there any change in their participation in the science classes in their school?

1.7 Organization of the thesis

The introduction chapter attempts to give an overview of the study, outlining its purpose, context, and the theoretical perspectives framing it. The second chapter on literature review dwells on the barriers as well as dilemmas that teachers face while attempting to teach science as inquiry. It underscores the need for further characterization of classroom transactions involved in teaching science as inquiry and for comparative accounts of the outcomes and potential of inquiry teaching. Chapter 3 describes the methodological approach, the settings and the methods. The results are presented in the subsequent two chapters. Chapter 4 focuses on the characterisation of teaching science as inquiry, in comparison to traditional teaching, while Chapter 5 presents the outcomes of teaching science through the two modes. Chapter 6 contains the discussion and reflections on the findings.

Chapter 2. Literature Review

2.1 What does it mean to teach and learn science as an inquiry?

Though views on what exactly is involved in inquiry-based science teaching (IBST) have varied historically (Haury, 1993), most of them converge on conceiving it as a pedagogical approach that reflects the nature and practice of science, in that learners engage with scientifically oriented questions, formulate explanations from evidence, connect explanations to scientific knowledge, and communicate and justify explanations (NRC, 1996, 2000). However, what exactly inquiry might look like in practice is frequently left implicit with no precise operational definition (Anderson, 2002). For some educators, it is just one among the many recommended instructional methods. For instance, the position paper on ‘Teaching of Science’ by the National Focus Group (NCERT, 2006), posits that a “good pedagogy must essentially be a judicious mix of approaches, with the inquiry approach being one of them” (p. 5). Many other educators adopt a broad perspective, arguing that “when education as a whole is viewed as inquiry, it is not a method to be used on particular occasions, but a particular orientation to learning, in which the task of teaching becomes that of supporting the inquiry process” (Harste, 1993 quoted in Wells, 2007, p.155). We are inclined towards this broader view in which inquiry is multi-faceted and subsumes the use of different strategies. As NRC (1996) puts it “Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry” (p. 23). It would be valuable to examine inquiry-based teaching-learning to identify its core elements further (Pedaste et al., 2015). Further, the *Next Generation Science Standards* framework of the USA (NGSS Lead States, 2013), often cited in recent science education research as the gold standard in reform goals, recognised that reform efforts should be centred on classroom practice and, with the intention of better explaining and extending what is meant by inquiry in science teaching and learning, articulated (in addition to the disciplinary core ideas) a range of cognitive, social, and physical practices.

2.2 Complexities in teaching through inquiry: need for further characterisation

Even where the curriculum explicitly requires them to adopt inquiry-based approaches, many science teachers find it difficult to implement it in their classrooms (Choksi, 2007; McNeill & Pimentel, 2010). Many barriers to implementing inquiry – personal, cultural and technical - have been described in the literature (Akuma & Callaghan, 2019; Anderson, 2002; Crawford, 2007). Speaking particularly of classroom practice, it is messy, requiring that teachers attend to students, materials, tasks, and ideas, often simultaneously, as well as to the social context that serves to shape the overall climate of the learning environment (Bevins & Price, 2016). Inquiry requires that teachers choreograph the sequence and flow of activities in a manner that guides students to move towards understanding the key science ideas in an investigation. This involves building and sustaining coherence within and across lessons. Teachers may struggle to engage students in complex reasoning (Driver, Newton, & Osborne, 2000); it is challenging to focus not just on students collecting data or completing procedures but more on analysing the data, generating conclusions or synthesising new findings with students' previous ideas (Donnelly et al., 2013). Empirical studies (Capps, Shemwell & Young, 2016) have shown that even when teachers believed they were enacting inquiry, their practice indicated that they struggled to interpret and enact inquiry-based teaching and needed support distinguishing inquiry from non-inquiry practices.

One among the many areas of science education research that has attempted to diagnose and address the challenges in implementing inquiry at the instructional level is discourse analysis. With its analytical lens zooming in and out of macro- and micro-level structures in classroom discourse, researchers have attempted to use discourse analysis to identify the discourse moves, conversational turns and linguistic features that appear to either promote or constrain science teaching and learning. Smart and Marshall (2013) explain that though discourse is "broadly defined as the use of language in the social context... within science education research, the concept of discourse is more complex in meaning... Discourse is more than classroom talk; it is a complex interaction between teacher, students, and these individuals' unique perspectives manifested in verbal communications" (p.250). As Gee (2001) defines it, discourse is an interplay between ''words, acts, values, beliefs, attitudes, and social identities'' (p. 526) among individuals who jointly attempt sense-making.

The seminal work on classroom discourse like those of Mehan (1979) and Lemke (1990) highlighted the ways in which norms of communication are constructed in the classroom through discourse moves that the teacher makes and how these often implied rules for verbal interactions may constrict student talk. The teacher's role in orchestrating discussions continues to be one of the salient foci of science education research, especially teacher questioning and their level, complexity, and ecology (Chen, Hand, & Norton-Meier, 2017; Chin, 2006) and classroom communication patterns (Mortimer & Scott, 2003; Jin, Wei, Duan, Guo, & Wang, 2016).

Traditional, teacher-centred discourse patterns are inconsistent with an inquiry-learning philosophy (Polman & Pea, 2000) wherein the role of the teacher is to encourage student voice and dialogical argumentation. In inquiry, teachers are required to relinquish some interactional rights such as being the exclusive one in class to initiate an interaction and give feedback to students' utterances through her talk moves. Parallelly, students need to give up, at least in part, their novice roles and take on expert interactional rights such as asking questions, responding to others in the classroom and proposing an argument or a counter-argument (Oliviera, 2008). Conducting such inquiry-based instruction is complex (Anderson 2002; Assay & Orgill, 2010), and teachers require concrete illustrations of its implementation in various forms and contexts as also rich descriptions of their roles in the process (Crawford, 2000). Given the importance of sustained dialogue, there is another clear gap and opportunity in current research to study the ways in which whole-class dialogue and students' social interactions in a science classroom develop over a period (Ellwood & Abrams, 2018).

2.3 Teacher questioning

Teacher questioning is a major contributing factor shaping the role of teachers in facilitating classroom discourse (Chen, Hand & Norton-Meier, 2017; Chin, 2007) and although considerable amount of research has been done on teacher's questions, there is a limited amount of literature investigating teacher questioning in constructivist learning environments such as inquiry (Erdogan & Campbell, 2008) where it is pivotal. Previous studies have shown that the purpose of teacher questioning in traditional science classes is often to evaluate what students know and the predominant pattern of discourse is Initiation–Response–Evaluation (IRE) (Mehan, 1979; Sinclair & Coulthard, 1975) or the triadic dialogue (Lemke, 1990) in which the teacher typically initiates (I) an interaction with a question, a student responds (R), and the teacher evaluates (E). However, in inquiry-oriented science classrooms, the role of teachers' questions is to move away from this simple recollection of the 'right answer' towards coherent explanations of the phenomena in context. Therefore, instead of the evaluation move, there is often a feedback move (F) from the teacher, which serves a variety of functions and leads to IRF sequences (Mortimer & Scott, 2003; O'Connor & Michaels, 2017). In the present study, we look closely at the various ways in which the teacher initiates dialogue as well as sustains it through her feedback and guidance in the form of questions.

2.4 Potentials of teaching science as inquiry and the need for comparative studies

While much research has been done on the effectiveness of inquiry-based science teaching - see meta-analyses, for example by Furtak et al. (2012), and review studies such as those by Zhang (2016), the results are not definitive. In general, the evidence from studies on outcomes of inquiry teaching suggests that the support for it is well grounded (Sadeh & Zion, 2009), although this evidence is not unequivocal – there are reports of negative results (Cairns & Areepattamannil, 2019) and claims of no difference, at least in terms of content learning (Cobern et al., 2010). The researchers who have reported negative results have interpreted these findings as possibly being a consequence of inquiry instruction not being implemented effectively or appropriately. This again points to the importance of characterising the day-to-day transaction involved in inquiry-based instruction. Further, these studies assessed performance on standardized tests and we feel that there is a need to explore more measures discernible of different aspects of science learning.

Supporters claim that positive effects on cognitive as well as attitudinal outcomes have been linked with IBST (Smart, Marshall & Alston, 2017). Another significant finding reported is that it may lead to narrowing the achievement gap in science (Marshall & Alston, 2014) suggesting that it might have a potential to make science accessible for all learners. However, there are also critics (Kirschner, Sweller & Clark, 2006) who have questioned the effectiveness of inquiry, looking at minimally-led inquiry approaches like the discovery method (Kirschner, Sweller & Clark, 2006). Researchers have responded to this argument by detailing the kind of guidance and support involved in inquiry-based science teaching (Hmelo-Silver, Duncan, & Chinn, 2007). However, what kind of guidance is adequate, and for whom? These questions need further investigation (Lazonder & Harmsen, 2016). There are also doubts whether the outcomes justify the time and effort (Jenkins, 2000). Cobern et al. (2010) argue, therefore, that comparison of the two modes of instruction cannot be simply based on content acquisition alone; the concomitant outcomes need to be studied in research designed for these purposes. There is also a paucity of research involving comparable classroom situations to assess and juxtapose the impact of learner-centred teaching with more traditional ones, on students' perceptions of learning, actual content learned and depth of thinking about (and understanding of) the conceptual underpinnings of science (Wohlfarth et al., 2008).

2.5 Considering students' and teachers' perspectives in characterising inquiry-based teaching-learning

In order to gain further insights into scaffolding students' co-construction of conceptual knowledge and bolster their ownership of learning, we need to deepen our understanding of what ignites and sustains students' full engagement in inquiry. Missing from many narratives of inquiry-based classrooms are the details of student-teacher interactions during the course of teaching (Reinsvold & Cochran, 2012); especially, the affective dimension of these interactions has been mostly left unattended (Oliviera, 2008). Other aspects that require more attention include the beliefs and pedagogies of teachers who appear successful in engaging students in inquiry-based lessons (Crawford, 2000). On the other hand, Zhai, Jocz, and Tan (2014) outline the need to investigate students' perceptions of their inquiry learning experiences and how these shape their conceptions of school science. It is important to know what students think they know and how their learning is changing.

2.6 Summary and conclusions of the review

It is surprising that though inquiry has been an increasingly prominent theme in multiple science education reform movements worldwide, being a central theme in significant international reform documents, the transition from theory and advocacy to practice has been unsatisfactory. The probable reasons seem that the practices associated with inquiry teaching involve complex interactive experiences and roles for both the teacher and the student (NRC, 2012), and as Oliviera (2008) points out, the literature mostly describes these with simplistic and over-generalised instructional metaphors like 'teacher as facilitator' and 'active learner', which fail to convey the interactional expertise that inquiry teaching requires. Few research studies have explicitly examined teachers' instructional practices in inquiry-based classrooms (McNeill & Krajcik, 2008), leaving details of day-to-day events of classroom life to the imagination, and often, the frustration of the teacher striving to use inquiry-based strategies (Crawford, 2000). This may have contributed to the gap between research and practice. Hence we need concrete examples to understand better how inquiry science is enacted in the day-to-day milieu of the classroom (Bevins, Price & Booth, 2019), especially in terms of the discursive moves that teachers use to guide the lesson (Henderson et al., 2017). Also, we need the voices of the teacher and also the students as we attempt to develop a holistic understanding of the nature of an inquiry-based classroom. Further, we need to look across the conceptual, affective and epistemic domains of learning, as we compare the outcomes of inquiry vis-a-vis traditional science teaching.

Chapter 3. Methods

3.1 Research design and methodological approach

This study has a nested or embedded mixed methods design (Creswell, Plano Clark, Gutmann & Hanson, 2003) with a quantitative strand nested within a predominantly qualitative study. The qualitative approach guided the study, in the sense that not only qualitative research methods were predominantly used for collecting data but the theoretical framework and the philosophical assumptions undergirding the study, which shaped the kind of research questions, methods and nature of claims involved in the study, are more aligned with the naturalistic, qualitative paradigm (Lincoln & Guba, 1985). The quantitative methods were used to seek information from different levels and to corroborate and consolidate the findings from qualitative explorations. The qualitative component of the study adopts a 'comparative qualitative research' approach (Silverman, 2004) which involves accessing multiple data sources in looking for patterns within and across cases, providing means to understand and explain diverse outcomes and processes.

Science teaching and learning were studied in two sets of middle school science classrooms - one taught through inquiry and another through commonplace, expository or direct teaching. Open-ended research methods were used (classroom observations, students' learning diaries, formal and informal interviews and discussions with teachers and students, video recordings of classes, class summaries and reflections by teachers, and researcher's field notes) to build a naturalistic account (Lincoln & Guba, 1985). From these multiple sources of data representing perspectives of the researchers, teachers and the students, the study analyzed the processes of the day-to-day science instruction to elucidate crucial aspects of inquiry-based instruction as compared to traditional science teaching. The methods were mixed both at the data collection and analysis level.

3.2 Data collection

Data collection was conducted in two phases. Phase I mainly involved after-school classes conducted over an academic school year (from July 07, 2009 to April 27, 2010). This included week-long intensive “camps” conducted during short school vacations in October and December. Phase II was held during the summer vacation (from May 17, 2010 to July 14, 2010). During vacations, the classes were held at the centre for two hours a day. Figure 3.1 summarizes the details of data collection.

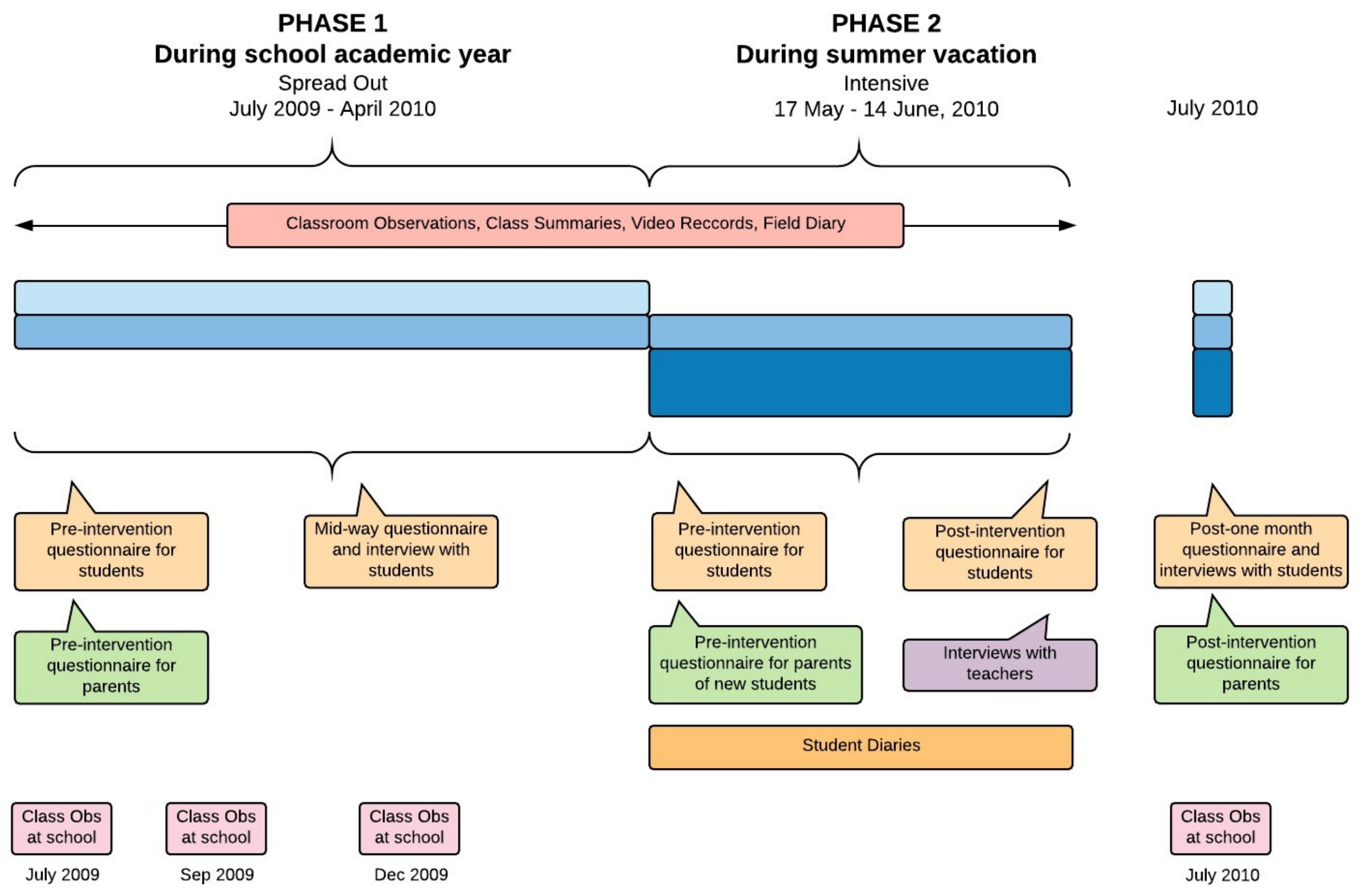
3.3 Participants in the study

3.3.1 Phase I: Students of Grade 7 (average age 11.8 years) were invited to attend voluntary, after-school science classes held within their school premises. The students belonged to an urban school in a cosmopolitan setting of Mumbai. The school had English as the medium of instruction and followed the national curriculum in India, brought out by the National Council of Educational Research and Training (NCERT). Students came from varied linguistic and socioeconomic backgrounds but mainly from lower to middle-income groups. This school was chosen for its varied student profile and because of its ease of access and proximity to the centre. Students who were interested in joining were randomly divided into two groups, each of about 25 students. Analysis confirmed that there was no significant difference between the two groups in terms of their academic performance at school, socio-economic status (gauged through family income and parents’ education levels) or in students’ reports of out-of-school activities related to interest in science. The classes were mainly held in English but the students and teachers sometimes switched to Hindi.

Two teachers from the research group taught (individually, not together) a group of students through inquiry. Both the teachers (referred to as Teacher IJ and Teacher IK) had at least a Masters degree in science but were not formally trained teachers. One of the teachers had over 10 years of experience in research and in teaching science in the inquiry way at the school level in the context of the curriculum development project. She coached and supported Teacher IK, who had a couple of years of experience in lecturing at college level but was a relative novice in inquiry teaching.

Two teachers (referred to as Teacher TN and Teacher TP) from nearby schools, nominated as among their best science teachers by the school authorities, taught another group. Although they taught in the traditional way, they reported that they could do fuller justice to their

Figure 3.1 A snapshot of the study design and its timeline



		Inquiry group	Comparison group
Phase 1	One hour classes, twice a week, in school, along two week-long camps at HBCSE which were for two hours each day	58 hours	43 hours
Phase 2	Two hour classes each day, days a week for a month, at HBCSE	37 hours	33 hours

	Inquiry group	Comparison group
Students who participated only in Phase I (more than 20 hours)	7	10
Students who participated both in Phase I and Phase II	10	9
Students who participated only in Phase II (more than 20 hours)	24	21

teaching in these classes as they were not constrained by time limits for transacting material as demanded by the school schedules, nor were they limited to the content of prescribed textbooks. They also put in considerable effort to prepare for these classes and make them more interactive than their usual school classes. Both these teachers had a Masters degree in science and were formally trained teachers with four to five years of teaching experience.

3.3.2 Phase II. In addition to students from the school in Phase I, students from three other nearby schools from the same school system were invited to attend a science summer camp at our centre. This was done to get enough number of students for the two groups in the vacation. Students had just entered Grade 8 (average age about 12.50 years). The new students who volunteered to participate were randomly assigned to the two groups so that each of them had around 30 students each. The two groups were found to be similar in terms of academic and socio-economic profiles.

The same two teachers from the research group, who taught the inquiry classes in Phase I, taught in this phase too. However, the school teachers who taught the comparison group in Phase I, were unavailable in the summer. Hence, two other teachers (referred to as TS and TA), each with a formal degree in teaching and at least a Masters' degree in science taught the comparison group in Phase II. One of them had over four years of experience in teaching in middle school; the other was a relative novice.

3.4 Data sources

3.4.1 Classroom observations: The researcher (AK) observed the classes conducted for this study along with a research associate (referred to as AF), using an observation sheet that was developed to record the classroom interactions in detail. Additionally, some science classes at students' school were also observed, firstly, with the intent of understanding the nature of experience the students have in their science classes at school and secondly to note changes, if any, in the way students participated in them after attending the classes in this study.

3.4.2 Field notes were made during observations to note any critical events, interactions and impressions of individual classes. Also, a **field diary** was maintained by AK to note her out-of-class interactions with the teachers, her reflections and observed trends over several class observations, the methodological dilemmas and the choices we made along the way.

3.4.3 Video records: Video recording of the classes in the study were used to examine the content and structure of the lessons and details of classroom interactions, as well as details such as the exact instructions for diary writing and contexts of particular student diary entries. Video recording was not possible for classes observed in the school.

3.4.4 Teachers' reflections: Discussions with the teachers before and after class, lesson plans and class summaries written by them served as valuable data sources for making explicit the teachers' instructional strategies. Additionally, self-reports by teachers on their motivations and purposes for questioning were obtained which helped us build a better understanding of teachers' purposes and practices related to questioning. Further, semi-structured interviews with them were done after the program to get their overall reflections.

3.4.5 Students' diaries: In Phase II, we asked students if they could briefly write a daily diary entry noting what they had learned each day in the camp and anything else that they found significant or interesting. Our analysis of these optional learning diaries brought to light many aspects of the teaching and learning in these classes and served several purposes: (a) the amount (and kind) of voluntary diary writing served as an indicator of their engagement with the learning experience (b) candid feedback could be obtained from the students and (c) students' emerging understanding of the content after teaching in each class could be captured.

3.4.6 Students' interviews and self-reports by students and parents: The questionnaires administered at the outset of the program helped us understand the characteristics of the two groups as they entered the program and served as a baseline for changes, if any, reported by students and parents in the post-intervention questionnaire (components of the questionnaires and interviews are summarised in the Appendix).

3.5 Data analysis

Mainly two qualitative methods of analysis were used:

(1) A microethnographic analysis (Garcez, 2008) of data from classroom observation sheets and video-recordings enabled us to describe and illustrate patterns in classroom talk and how teachers scaffolded this talk. Bogdan and Biklen (2003) describe microethnographies as case studies of very specific organizational activity (e.g., teacher questioning) with small organizational units (e.g., inquiry science lessons), aiding in investigating in detail what participants do in real-time as they co-construct talk-in-interaction.

(2) An emergent or bottom-up approach (Thomas, 2006) was used for qualitative analysis of data from the classroom observation sheets, student diaries, questionnaires and interviews;

that is, instead of predetermined codes, tentative categories emerged and were gradually grouped, regrouped and refined based on close examination of meanings and patterns in the data.

After we analysed individual data sources, we realised that there were common themes and trends across and within a data set. For example, indications of students' level of engagement with their science learning were evident from their diary writing, class participation as well as from reports from students themselves (in responses to different questions in questionnaires and interviews) and reports from their parents, peer, teachers and the observers. We did a cross-comparison of the data sources and collated the evidence according to the themes that emerged. Such a triangulation helped us arrive at a more robust picture of the outcomes and differences in them across the two groups in the study.

The quantitative analysis mainly consisted of descriptive statistics; further tests of significance of differences were used where required. Details of the process of coding and efforts taken to address issues of credibility and trustworthiness of the analysis are discussed in the thesis.

3.6 Content of the instructional units

A few topics, being developed for the curriculum project (for example, units on immediate environment and taxonomy referred to in the Results section) were novel and had no direct parallel to the standard textbook for the particular grade the students were in. Other topics (for example, human circulatory system and reproductive system in plants) were chosen from the standard, central board (NCERT) textbook for which parallel units were already developed or were being refined for the curriculum project; these topics were not necessarily dealt with in the same manner as in the textbook and were taught in the program before students had been taught these topics at school. The content of the units and the time taken to transact them in the two modes are detailed in the thesis.

3.7 Methodological considerations

3.7.1 Out-of-school context of the study

The study could not be conducted within the school settings for logistical constraints. Hence we needed to conduct an after school/ summer program. This context had several advantages as well as disadvantages as detailed in the thesis.

3.7.2 Conundrums involved in having different teachers for the two groups

A crucial methodological issue that is a concern in comparative studies such as this one is whether both groups in the study should be taught by the same or different teachers. Both approaches have been taken in different studies by researchers. Our stance is that the same teacher cannot do justice to teaching in both the modes and outcomes would be affected by bias due to the teacher's disposition. Furthermore, the focus in this study is on what the teacher does in class; after all, the often intangible qualities of a teacher's personality mediate outcomes through the way they are manifested in the teaching practice. Having two different teachers in each of the modes takes care of the influence of the teacher's personality to some extent. Also, as expressed in students' diaries and self-reports, teachers of both groups were well liked by their students and were perceived as friendly and good at teaching.

3.7.3 Difference in the two teaching modes in the study

Teachers of both the groups in the study had the same starting point in terms of content, resources, teaching time available and support available for lesson planning and conducting hands-on activities. However, transaction of the material was left entirely to the teachers. The essential difference between the two modes of teaching for us was, as Cobern et al. (2010) put it, 'how students come to the concept', that is, whether students grapple with and develop the concepts from exploration, with the teachers' guidance and support or whether the concepts are explained to them by the teacher.

3.8 Trustworthiness of the study

Measures taken for improving the trustworthiness of claims made in the study involved prolonged engagement/ immersion in the field (observation over a long period), independent classroom observations by two researchers (AK & AF), triangulation using multiple sources of data, debriefing with the participants (informal and formal lesson conversations with teachers helped the researchers better understand what the teacher did during the class and why), maintaining an audit trail in the form of a field diary by the researcher and providing detailed description of the data analysis including measures taken to establish inter-rater reliability and expert validation. Also, we have attempted to provide 'rich, thick descriptions' (Lincoln and Guba, 1985) which contribute to transparency and credibility of the findings.

Chapter 4. Characterising Science Teaching through Inquiry and Traditional Teaching Modes

4.1 An overview of the teaching modes observed in this study

As part of this research, science teaching was observed in three settings, namely (a) science classes in the study that were taught through inquiry (b) those of the comparison group in the study and (c) science classes in the school attended by students of Phase I.

We start this chapter with a descriptive account of science teaching at the school. Subsequently, the two modes of teaching transacted in our study are illustrated with sketches of the teaching-learning sequences for a unit titled ‘What makes a fish a fish?’ (Figures 4.1 and 4.2). These were derived from video records and transcripts of the classes.

4.1.1 Traditional science teaching at school

This account is based on 24 classes observed over a year, in three different divisions of Grade 7 of the school to which students of Phase I belonged. It was an urban school affiliated to the Central Board of Secondary Education. It had good infrastructure in terms of classrooms and laboratories. There were about 35 students in a class.

Our observations in school are similar to those noted in accounts of mainstream schooling and science teaching in India, reported in the literature (Kumar, 2005; Sarangpani, 2003; Vijaysimha, 2013). The teaching was highly structured around the study of prescribed textbooks and examinations conducted on the basis of these textbooks. Each chapter from the science textbook took five to six classes, of 35 minutes each, to be transacted. Teaching a chapter involved three activities: the teacher or one of the students read the chapters (for around three classes) a few paragraphs or sentences at a time, the teacher explained some parts wherever she felt the need to and asked some comprehension questions, and finally questions given at the end of the chapter (around three classes) were answered and written in the notebooks. The students tried to answer the questions from what they had understood, but finally, the teacher dictated the answers (or sometimes, wrote them on the blackboard) and students noted them neatly in their notebooks. This was followed by a revision of the questions and answers as exams approached. The whole focus of teaching was thus on establishing and endorsing the right answers to be written in the examinations.

Students hardly had a choice in any of the matters related to teaching-learning. Nevertheless, they generally seemed very accepting and compliant. The exercise of authority was palpable for all teacher-student interactions; the teacher asked the questions, almost all of the time, nominated which student will talk and evaluate the answers as right or wrong. Notably, there were many activities and experiments in the textbook, but they were discussed and done separately; also, they were framed in a way that did not warrant student investigation. We also elicited and analysed students' descriptions of science teaching at school through a few questions in a post-instruction questionnaire. Students' responses served as a window into their experience of school science.

4.1.2 Traditional science teaching in the study (comparison group)

In the comparison group, the teacher usually began the lesson with an interesting question, setting the stage for the instructional sequence and getting students' attention. She kept the class interactive with a lot of question-answer exchanges and included hands-on activities and demonstrations. For example, in the vignette depicted in Figure 4.1 she made an effort to bring actual specimens of animals and used them as an aid while explaining about the features of a fish. However, though the teacher asked the driving question, she gave away the explanation herself very soon. The activities remained as an add-on, with hardly any discussion taking off from them. The level of interaction and student participation was illusory since the rights, roles and responsibilities of students were limited. There were very brief answers, mostly in unison, from students.

The interactions in these science classes were similar to those observed in students' school in that they were made of typical IRE sequences, disconnected from each other. The teacher asked a lot of questions to keep interactions going but these were factual, closed-ended, rarely placing high cognitive demand on students. There was hardly any attempt to probe students' answers or convince them of the correct answer with evidence or justifications. She tightly controlled the interactions and was the sole authority to ask questions and to respond to what students said. Thus, though it was interactive and activity-based, the teaching in this group was essentially authoritative (Mortimer & Scott, 2003) and transmissive.

4.1.3 Science teaching in the inquiry way

Here, the explanations were co-constructed by the students, guided and supported by their teacher, as illustrated in teaching-learning sequence in Figure 4.2. The teacher consistently explored students' thinking on the topic, asked them to elaborate and justify their responses, helped them to articulate and reflect on their own and their peers' thinking and drew their attention to aspects they had missed. The observations from the activities served as anchor points for the class discussion, and this, in turn, led to the students making far richer observations when they went back looking for more ideas to back their propositions.

Even when there were incorrect responses initially (like whales and starfish being considered as fish in the illustrated sequence), the teacher did not rush to correct them but posed further questions to make students think ("Are they all fish? Why or why not?"). On getting correct but brief answers, she re-framed her question in an alternate way to get reasoned responses. Even better, she responded to students' answers by guiding students to observe and giving them time to think and discuss it amongst themselves before resuming the whole class discussion. Thus, the teacher's questions in this class continually challenged as well as supported students' thinking and progressively built on students' responses. This resulted not just in multiple, individual student voices in the class, but the direction and pace of the lesson were contingent on students' ideas and questions.

4.2 Teachers' questions and their purposes

In our class observations, teachers' questions in each of the two modes of teaching seemed to manifestly serve different roles and the pattern of questioning brought about a difference in how the lesson progressed. Considering the significance of teachers' questions, we attempted a characterisation of inquiry teaching that focused on them.

4.2.1 Teachers' questions in inquiry classrooms

Our analysis of teachers' questions led to five broad categories, apart from management questions, as given below. The sub-categories within the categories and their examples are given in the thesis. For clarity in illustrating and explaining these questioning strategies, the purpose most prominent for each question has been noted for the analysis although one uestion can and many a times does serve more than one purpose.

***Exploring prerequisites/ setting the stage*.** These questions basically gave feedback to the teacher about the familiarity and difficulty level of the topic, students' prior experiences with it and presence of prerequisites needed for teaching the intended concept. Teachers used these questions as wonderment questions - as starters for discussions.

Figure 4.1: "What makes a fish a fish?": teaching sequence in the traditional mode: Explaining the concept with the help of activities

Key: **Bold text: Teacher's speech summarised**
Text in Box: Students' speech summarised
Text in Italics: Descriptions of events

Interesting introduction by the teacher using hand gestures to depict a fish

⇩

What is this?

⇩

Fish	*In chorus*

⇩

How is it a fish?

⇩

Fins, Streamlined body	*The class excitedly answers in chorus.*

⇩

Paired fins, elongated streamlined body shape... also swimming implies being aquatic, so gills – with or without operculum

Teacher elaborates and adds other features.

⇩

Teacher shows some fishes (specimen of pomphret, sardine and seahorse) as well as a prawn and starfish

⇩

Which are fish? And which are not fish?

⇩

Seahorse is not a fish	*In chorus*

⇩

Teacher explains how prawn and starfish are not fish while seahorse is a fish

⇩

Teacher explains features of fish (such as gills, scales, different kinds of fins) with the help of a labelled picture of gold-fish

⇩

For being a fish what are the important features?

Teacher assigns homework.

Figure 4.2: Teaching sequence for the unit “What makes a fish a fish?” in inquiry group

Note: ‘Sn’ indicates student ‘n’, Ss indicates multiple, overlapping student responses.

Key: **Bold text: Teacher’s speech summarised**
Text in Box: Students’ speech summarised
Text in Italics: Descriptions of events

Draw a fish. ⇒ *Teacher sees that there are some stylised drawings.* ⇒ **Name at least one fish you know.**

⇓ *Every student gives an example of a fish.*

Some examples of fish, some of others (starfish, whale, octopus)

⇐ **Are they all fish? Why? Or why not? What features do you see in an animal to call it a fish?**

⇐ *Very few responses from students; teacher tries another approach.*

⇓ *Teacher shows photographs and specimens of different fishes.*

⇒ **How could all these be fishes?** ⇒ S1: Is seahorse a fish?

⇓ *Class discussion: Students come up with criteria for what is a fish.*

S2: Fins, gills, snout, peculiar tail

⇐ **What about a prawn? It has gills, tail and it swims? Is it a fish? Why not?**

⇓ *Class discussion: Students add to the criteria*

S3: Streamlined body, body covered by scales and not hard shell
S4: It doesn’t have fins

A brief student generated discussion on what is meant by dorsal and ventral sides and sense organs in aquatic animals

⇓ *Teacher gives counter-examples: for a particular criteria there would be some fishes that don't clearly have it and some other animals that do. Students too add to such examples.*

Next class: **Some fishes, like the seahorse, do not have a streamlined body; some fishes have lungs too...**

Some salamanders have gills and retain them for life; some reptiles have scales.

⇓ *Class discussion leading to more questions*

S4: Are dolphins fish or not? Why?
S5: What about jellyfish? What will we call tadpoles – they have many of these features?

S6: If jellyfish and starfish are not fish, why are they named that way?

⇓ *Teacher answers with history of classification of animals*

⇓ *Question tossed back to students*

S3: Gills, scales, cold-blooded
S6: Streamlined body S4: Lateral line Ss: Snouts, tail

⇒ *Summing up of criteria*

Exceptions: some larger fishes like white sharks can maintain a higher body temperature.

Generating ideas and explanations. These questions further stimulated interest and provoked thought. They were usually in the context of activities, immediately preceding or following them; they helped students to articulate their observations and make further close observations. They solicited initial attempts at explanations from students. This was crucial for the teacher to gain further insights into students' preconceptions and decide at what level to pitch her questions and the amount of guidance needed. This category of questions also included those through which teachers encouraged wider participation asking for students' opinions, guesses, examples and questions.

Probing further. These questions probed students' initial ideas. In the discussions that followed, often there were spontaneous questions from students. More often than not, the teacher responded to these questions with a question - a 'reflective toss' (van Zee & Minstrell, 1997). We found such reflective tosses serving a variety of purposes - asking for clarification, elaboration and justification of students' comments, pointing out contradictions with what has been observed or discussed in class, and, in the true spirit of inquiry, asking the student if they can think of a way to find out the answer.

Refining conceptions and explanations. There was a rich variety of ways in which the teachers' questions provided scaffolding to extend and refine students' thinking . In the thesis, this important category of questions is illustrated with an episode from a lesson on measurement of rain, describing how the teacher responded to students' observations and conjectures and helped them get a grasp of the difficult and abstract concepts of randomness and averaging (in the context of rain-drop sizes over space and time). To achieve this the teacher asked nested questions which supported students in refining their explanations in various ways like providing hints, making connections with earlier observations and directing attention towards aspects missed by students.

Guiding the entire class towards the scientific concept. In an inquiry classroom, where students express their own opinions and come up with their own explanations which could be different from the canonical scientific knowledge, conclusion of the discussion is a very significant phase. The teacher has to steer the course of discussion and direct it to the goal of reaching the scientific conceptions. This is an important phase and disabuses the mistaken notion of inquiry teaching as 'freedom to come to any conclusion' or 'no conclusion having a privileged epistemic position'. The questions in this category helped the teacher to build consensus in the class. At times, specially at turning points of conceptual change, a show of hands was invited - “How many of you agree/ disagree/ are unsure ...?” This not only served to take stock of how prevalent a particular conception was but also nudged students to weigh the pros and cons of the options in order to do so.

Classroom management questions. These questions aided the teacher to build the classroom culture for inquiry, for example by asking if students want more time to think or want to discuss among themselves before answering, monitoring their progress during activities or cajoling students to respond to each other or gauging their readiness to do a task. Teachers also used these questions as invitations instead of commands to direct student actions for example, “Would you like to do it?” or “Can you answer?” and to create a positive emotional climate “Did you enjoy the debate yesterday?”.

4.2.2 Teachers’ questions - in traditional science classrooms

Contrary to reports in the literature and perhaps to our expectations, there were as many teachers’ questions in the traditional science classes as in the inquiry classes, perhaps because the teachers made extra efforts to make these classes more interactive than their usual classes. Nonetheless, there was a stark difference: only 15% of the questions in TN’s class and 19% in TP’s class were open-ended compared to 92 % and 86 % in IJ and IK’s class. As seen in the distribution of question types in Table 4.1, the traditional teachers started a unit or even each class interactively with a variety of questions. However, they slipped into the transmission mode soon and then used questions mainly to evaluate what students have learned and keep the class attentive.

A huge number of revision questions (based on what was taught in the same class) and rhetorical questions (where the teacher asked and herself answered the questions) led to a large number of questions in these classes. Another typical kind of closed-ended question in these classes was that of asking for sentence completion which was usually answered in chorus by the class. Other questions included managerial questions, those asking for prerequisites and a smaller proportion of open-ended questions eliciting experiences and asking for elaboration, instances, and rarely, explanations.

The management questions were limited in scope and helped retain the teacher’s authority with questions like “Are you paying attention?”. There were a few classes taught by Teacher TN which had a wider variety of questions but these were only the introductory classes.

Table 4.1 A comparison of the number of questions in each category of the progression in teaching

Kinds of Questions and their codes	IJ	IK	TN	TP
Exploring pre-requisites/ Setting the stage	19+2*	13+3*	32+11*	29+9*
Generating ideas	28	12	4	4
Probing further	7	10	7	0
Refining conceptions	20	10	1	0
Guiding the entire class	13	28	3+19**	4+7**
Classroom management	4	3	3	3
Total	**93**	**79**	**80**	**56**

*Rhetorical questions **Revision questions

4.2.3 Teachers' reflections on their questioning

When asked to explicitly deliberate on what purposes questions serve in their classrooms, what was common in all the teachers' responses was the need to know what prerequisites students had for the topic to be taught. Consistent with the oft reported findings in literature (Chin, 2007), the traditional teachers in this study too said that they "ask questions to test students' knowledge" and "if they (students) have learned the material".

Both the inquiry teachers reported that their further teaching plan would be dependent on students' responses. They wanted to understand not only where the students were but also whether the level of difficulty of the topic they had planned suits the students. Both of them reported that they actively tried to stretch students' thinking to draw out answers from them whenever it was possible and thought that additionally this would also increase student engagement and curiosity. One of them, Teacher IJ articulated a much more nuanced understanding and awareness of her questioning practices and the many crucial roles they play in inquiry - ranging from directing students' thought to the topic at hand to probing difficulties students have in understanding the topic and tracing the roots of these difficulties. She also pointed out an important purpose of questions - that of involving the entire class.

4.3 Discourse patterns

The variety of teachers' questions and feedback to students' answers and questions, in the inquiry classes, resulted in discourse patterns other than the typical the IRE or IRF sequence. The discussions often involved IRFRF chains, with several students responding to a given question, typical of discourse that supports dialogic interaction (Mortimer & Scott, 2003). Also, in addition to the student-teacher-student pattern of interaction, over time, we observed a variation of this pattern: student-teacher-other students. Rarely, but towards the end of the program students themselves responded to each other leading to a dialogue among the students rather than merely with the teacher (for instance, at the end of the teaching sequence in Figure 4.2). Out of the ways of speaking during science instruction described by van Zee, Iwasyk, Kurose, Simpson and Wild (2001), we found that lectures and recitations were more common in the traditional classes while guided discussions as well as student-generated discussions were characteristic of inquiry classes.

4.4 Comparing the nature of tasks and use of activities

The nature of the learning activities and sequencing of events by the teacher determine the opportunities for participation and the kind of participation which can occur. The different approaches used by the teachers of the two groups were associated with different patterns of activity and engagement by the students. In the inquiry classes, activities and experiments were an integral part of the teaching and were investigative in nature, with students' observations leading to classroom discussions; further development of the lesson depended on what students concluded from the experiment. In traditional teaching, they were most often verificatory in nature. Vignettes from the classroom illustrate how differences in sequencing and incorporating differing levels of student participation led to the same activities ending up as verificatory or investigative.

4.5 Characterisation of the two modes of teaching from students' perspective

4.5.1 Characterisation implicit in students' diaries

Students' perceptions of the learning environment within each class were consistent with the observers' field records of the patterns of learning activities and engagement in each classroom.

Traditional teaching (comparison group). Diary entries of students in this group provide evidence that the instruction in these classes was different from the commonplace science teaching in that there were many activities, the class was kept interactive through teachers' questions, and audio-visual material was used: "Teacher showed us many experiments and examples. She asked us many questions". "This is the reason I like the camp because the same topics of school taught with experiments and practicals seem more interesting".

However, it is also evident through students' descriptions that the teaching was in the transmissive mode consisting of exposition from the teacher, with an emphasis on definitions and formulae: "We studied about buoyancy and wrote laws of floating", "Teacher taught us about volume and gave definition", The way students wrote about the activities is indicative of these being verificatory and not investigative in nature: "We learned about density and *did some activities to clear the concept"*[1] "We learned that thicker the wire in size, the lesser the resistance it has and the longer the wire, the more the resistance it has. *We did an experiment to see the difference"*. The teachers were perceived as friendly and many students said that they "explained nicely".

Inquiry teaching. Students' entries in this group prominently reflect the focus on inquiry. Many a time, students wrote about a lesson or activity as a question to be pursued "Is that the seahorse is a fish? We were asked to reason why it is fish [sic]". Learning through inquiry involved higher-level cognitive demands as described by students and was contingent upon observations and discussions in class: "*We did an experiment to find out if* the water fell out [overflowed] because of the mass or size [of the object]", "The crown battle had started ... *we were thinking* how Archimedes had decided which crown is of gold and which is of silver". The teacher helped them meet these high cognitive demands by being responsive to their ideas and difficulties and providing the necessary scaffolding. There was an explicit, gradual building of the lessons - subsequent activities and discussions were based on the earlier one and teacher elicited the answer from students through a series of questions and counter-examples to students' statements. These aspects were also reflected in students' diary entries: "She asked a question which in the end almost all could answer." We note the absence of definitions reproduced verbatim in the diaries of the inquiry group, a reflection of the teaching-learning not being centred on factual information and its reproduction.

4.5.2 Characterisation reflected in students' responses to questionnaires

In the questionnaire administered at the end of Phase II, students were asked to place science from easy to difficult on a semantic differential scale. Their responses indicate that students in inquiry recognized the high cognitive demand placed on them but also found it manageable - not very easy but not very difficult either. Thus, instruction in inquiry seemed to provide an optimum level of challenge. These self-reports from students corroborate what they tacitly

1 The emphasis in students' quotes are added by the researcher.

indicated in their diaries about challenging yet manageable level of cognitive demands in the teaching-learning involved in an inquiry classroom. There was no difference between the groups in other dimensions that students were asked to reflect, namely how important, interesting and related to daily life students found science to be.

In another question, students were asked to compare their regular science classes at school with the classes conducted in this program. This was a direct way for asking students of characteristics of the two modes of teaching that they found significant. There were fewer responses from both groups stating similarities between science teaching at school and in the program than those pointing out the differences. Similarities were seen at the broader level - both sets of science classes included experiments to some extent, were interesting and teachers were good-natured.

The starkest difference between the science teaching at school and in the program, for both groups, was that the classes in the program included relatively more activities. For students in the comparison group, other significant differences were the use of audio-visual aids (videos, slides) and actual biological specimen for observations, and that the teaching was comparatively spaced out and not hurried. Students in the inquiry group appreciated the “way of teaching” or “way of explaining”; this has been a common phrase even in the diaries and in responses from the parents in this group indicating that students perceived the teaching as distinctively different from commonplace science teaching, though they did not have a term to describe it. Note that the term ‘inquiry teaching’ was not used at all in interactions with the students. The overall range of characteristics of the two modes deemed significant by the two groups of students and their relative prominence in students’ responses is similar to those reported in the analyses of diaries.

4.6 Insights into the teaching from teachers’ interviews

The interviews intended to get teachers’ reflections on their implicit strategies for teaching, their views that inform their teaching practice and get them to explicate moments salient to them in a narrative form (e.g., high points and low points, turning points, what they found interesting or challenging). Specifically, we probed teachers’ ideas on (a) their purposes of questioning in their science classes, (b) nature and amount of active student participation in their class (how and how much did students - participate, need for student talk and teachers’ strategies to promote it), (c) orientation towards science teaching (objectives for teaching-learning of science, perceived role of activities and experiments in the science class), (d) reflections on their teaching in the classes in this study in general and overall on their self-efficacy, and (e) any change they perceived in the class or in particular students. These reflections gave insights into the strategies that teachers in the two groups used to guide students' learning and participation in the science learning in these two classes, the different meanings learning and participation meant for these teachers and thus further provided another perspective to our characterization of the two modes of teaching.

4.7 Summary of findings in the chapter

In this chapter, we described the ways in which teachers scaffolded the classroom talk, activities and ways of thinking in the two sets of classrooms. Considering questions and prompts that teachers use to structure classroom interactions as significant forms of scaffolding, we attempted a characterisation of science teaching that focuses on them. A fine-grained analysis of the teachers' questions revealed a rich variety in terms of their roles in the inquiry science classroom. From a sequential typology of questions, emerged a progression in the inquiry lesson from eliciting, diagnosing and probing students' ideas to refining them and guiding the entire class towards accepted scientific knowledge. It is this progression that truly characterised the inquiry classes, and differentiated it from the traditional ones. To further our attempt in making explicit teachers' tacit strategies employed in inquiry teaching, we examined, through teachers' self-reports, their motivations for questioning, the need for student talk in their classes, their strategies to promote it, their views on the nature and amount of student participation and engagement in their class and their views related to their orientation towards science teaching. Students' reflections about the teaching they experienced, depicted implicitly in their diaries and expressed explicitly in response to questionnaires and interviews added another perspective to our attempt to characterise the two modes of teaching, corroborating and adding to the researchers' perspectives.

Chapter 5. Exploring learning along different axes

In this chapter, we present the gamut of learning outcomes that we gleaned from multiple data sources. We present them as overarching themes from the data, themes that are interconnected and overlapping, which entails that some of the data indicate more than one outcomes and therefore would be discussed under more than one theme.

5.1 Content learning – difference gleaned from students' diaries

A large proportion of instances of what was learned, written by the comparison group indicated a lack of conceptual clarity and several instances of misunderstanding of the concepts. This was particularly stark in situations when there were inverse relations or more than two variables involved in understanding a concept such as density. When conclusions of an experiment were recorded by students of the comparison group, they were often incorrect.

In the inquiry group too, students arrived at incorrect conclusions although there were fewer such instances. and they were were made in the initial stages of a sub-topic, as opposed to the errors by students in the comparison group that were made even after instruction. As the unit progressed, there were opportunities for such errors to surface in the inquiry class and be addressed by the teacher. This might account for the fewer number of content errors in the diary entries.

5.2 Difference in students' conceptions of science and learning

A clear pattern emerged in how students in both groups viewed science differently and how they engagedd in the learning of science. Though the difference in each of the category of evidence may not be quantitatively large in each instance, together they consistently point to students in inquiry adopting a frame of 'doing science' (Jimenez-Aleixandre et al., 2000). In the diaries, they wrote what they had learned in their own, personalised manner and based it on evidence and arguments. Students' diary entries such as "*We were deciding* which kinds of objects float and which ones sink", "Then we raised doubts [sic] *which teacher and we answered"* reflect students' internalisation that they shared epistemic authority with the teacher. In the questionnaires, many of them described science as processes, reported participating in the classes by way of asking questions and discussing with friends instead of taking to answering; significant outcomes for them out of this program was 'increase in interest and asking questions' rather than 'answering more and getting to know more'. They asked more wonderment questions based on their observations and experiences.

On the other hand, students in the comparison group seem to have adopted a 'doing the lesson' frame of learning. More students from this group wrote what they had learned, in the diaries, in the form of mere recall of facts, definitions, and laws taught by the teacher, expressed through formal statements indicating uncritical acceptance of canonical knowledge and authority. These students' responses in the questionnaires reflect that they conceived of science as merely an academic subject they have to study at school, their participation in science class was mostly restricted to answering teacher's questions rather than asking their own, the significant outcome of attending this program for them was being able to answer more in their science classes at school since they got to know more and paid more attention. More students in this group indicated an extrinsic motivation for learning science (like scoring good marks), asked factual questions mostly restricted to what they had read in a book or what had been taught in a science class and hardly made an observation beyond the classroom. When the data were collated (details in the thesis), we found that 30 out 40 students in the inquiry adapted a frame of 'doing science' while 18 out of 41 students in the comparison group show some aspect of this frame of learning.

5.3 Students' engagement with the science learning they were experiencing

We found evidence of different aspects of students' engagement with the learning they were experiencing in the various data sources we explored.

5.3.1 Reflections from students' diaries

Students' diary entries in the two groups differed in both the number of entries as well as in how detailed they were. Students in the inquiry group wrote almost twice the number of entries on an average, compared to the group taught traditionally. Also, their journal entries were significantly longer than those of the comparison group. Moreover, diary writing was voluntarily sustained over the four-week period of the camp in the inquiry group. Students in the inquiry group clearly had more to say (and made the effort to do so) than the comparison group. Additional evidence for the higher level of engagement in the inquiry group comes from the higher amount of spontaneous notes by students during teaching and the large number of self-generated, spontaneous students' questions written in the notebooks.

5.3.2 Indications of engagement from students' responses in questionnaires and interviews

Many students from the inquiry group and their parents reported that students began to discuss what was learned in science with their friends and at home. While reporting changes students found in themselves as a result of attending the science classes in this program, students in inquiry, mainly talked about increase in interest in learning science, "*Science easy* *lagta hai, mazaa aata hai, connect kar sakte hain to what we know"* (I find science easier, enjoy it and can connect it to what we know).

5.3.3 Reports on students' engagement from interviews with the teachers

While teachers in inquiry talked about how students participated in their class and commented on the change in students' participation over time in the camp, they gave indications of how, and how much, students were involved in their class -

> Eventually, many students participated in the class discussions. But some did not speak up much, especially girls though they did come to the teachers' desk in the break or after class to tinker around with the activities and materials kept on the desk, and to ask a question or to discuss. (Teacher IJ)

Teachers from the comparison group also reported that students were very engaged in their classes, but the nature of this engagement that they reported was starkly different - indications for students' involvement in the comparison class were answering teacher's questions, taking down notes diligently and finding related content in reference books.

In summary: Data corroborated from across reports of students, parents, teachers, and observers indicates that most students in inquiry (37 out of 40) were engaged with the science learning they had experienced, in at least in one aspect while 18 out of 41 students in the comparison group reported an aspect of the engagement.

5.4 Culture of collective, co-operative learning against competitive, individual learning

As reported earlier, for many students in the inquiry group, continuing discussion beyond the classroom on what was learned in science, was a major change for them as a result of undergoing teaching in these classes. Also, participation in class for them predominantly entailed asking questions and discussing with friends. This also points to a culture of learning collectively, of trying to solve a problem or find an explanation collaboratively instead of a stress on individually vying to answer teacher's questions or getting to know more, as reported by students of the comparison group.

Another indication of a cohesive culture building up in the inquiry classroom comes from the data in the interviews. When students were asked if they saw a change in any of their friends or classmates who also attended these classes in the program, many students in inquiry (7 out of 15), unlike only 2 from the 14 in the comparison group had noticed and described changes in their friends which were supportive of what the students had said about themselves. The researcher had also noticed this change in the classroom culture; this observation is illustrated in the thesis using notes from her field diary.

5.5 Self-efficacy and self-confidence

There were indications of an increase in students' self-confidence and self-efficacy in learning science from an equal number of students from both groups. However, this increase was reported by students in the comparison group in terms of ease in answering questions especially when the topic is familiar, getting more marks and rarely in terms of asking questions, again pointing to their frame of 'doing the lesson'. Responses from the inquiry group indicated that students felt confident in engaging with the science learning in these classes even when they found it challenging, they tried to answer difficult questions in class without the fear of being wrong, and that they felt that they were getting better in learning science since they were putting in more efforts due to their increased interest in science.

5.6 Indications of more self-reflection

Instances from students' diaries in inquiry show that these students reflected on their self-understanding, reporting not only what they found difficult but also what intrigued them and what they were able to do well. Some students also explicitly noted that they had become more observant and reflective. As in the diaries, we found more glimpses of reflective thinking in the responses to the questionnaires and interviews too from the inquiry group.

5.7 Students' participation in whole class interactions

According to sociocultural perspectives on learning, participation in discourse is a primary characteristic of learning and knowing (Lave & Wenger, 1991). In this sense, enhanced participation in discursive practices is the improvement in learning itself and not just something that supports learning (Yun & Kim, 2015). We analysed whole class interactions (which formed a major part of the lessons in the study in both the groups) and how actively students participated in them.

5.7.1 Nature of students' participation

The classroom vignettes (Figures 4.1 & 4.2) illustrate a stark contrast in the way students in the two classrooms participate. Teachers in the comparison group often started the class with questions, solicited students' responses questions . Indeed, they had explicitly told students at the beginning of the intervention not to hesitate to speak or ask questions. However, as evident in the illustrated episode (Figure 4.1), rarely was a discussion developed or sustained in the class unlike in inquiry classes. In the inquiry class, there were elaborate responses from students sharing their ideas and opinions, identifying reasons for and against claims. Note how towards the end of the episode in the inquiry classroom (Figure 4.2), students responded to each other, critiquing or presenting an alternate viewpoint. More interestingly, students' participation did not remain merely as responses, they initiated a discussion with their own questions and observations. There were several instances in inquiry when students articulated their difficulties or disagreements with a concept or claim put forward by the teacher or other classmates or pointed out a seeming contradiction.

5.7.2 Amount, patterns and change over time

Overall, there was a high amount of student participation in the inquiry group in terms of spontaneous student contributions to class discussion. A higher number of student responses and questions in the inquiry classes was noted in Phase I (in the sub-sample of classes analysed for teacher's questions, presented in section 4.2). A detailed quantitative analysis of student talk from Phase II was done to capture the patterns - which are the students who participate in class interactions and how much and what is the change in students' vocal participation over time? We found that in this phase too, there were more spontaneous student contributions to the class discussion in inquiry on an average (38 ± 17 spontaneous student turns at talk in a class) compared to the comparison group (14 ± 9 spontaneous student turns at talk in a class). Also, the average number of students who individually and voluntarily contributed to discussions was greater in the inquiry classes (13 ± 4 students) than the comparison classes (7 ± 3 students). Notably, the participation was not only sustained over time in the inquiry classroom but it increased while there was a dip in the comparison classroom both in terms of the proportion of student talk and number of students speaking out. Participation in the inquiry class was broad-based and most students, though not all of them, participated to some extent over time; in stark contrast, the same set of a select few students eventually took the floor in the comparison group.

There were noteworthy within-group differences in both the classrooms. In the comparison group, students who vocally participated more frequently in the whole class interactions were those with higher academic scores and came from higher-income families. Higher participation in class discussions in the inquiry group, on the other hand, came from a more diverse range of students from across the academic and socio-economic spectrum. However, participation was skewed based on gender in the inquiry classroom, with boys taking much more of the discussion space than girls. Only two of the fifteen students who were most vocal in the class were girls, in the inquiry group, while in the comparison group three of the five most vocal students were girls. Towards the end of the program there was a slight increase in the number of girls speaking up in class in the inquiry group. We note that this marked gender difference in students' vocal participation in class discussions in the inquiry classes was peculiar to this particular group of students. Most girls in the previous classes (conducted over the years, as part of the curriculum project, with several cohorts of students) either did not show such diffidence or grew out of it quickly. One of the possible reasons may perhaps be that they were younger when they joined these classes (Grade 5 or 6) and had less inhibitions than adolescent girls.

5.7.3 Students' self reports on their vocal participation

We asked students to pick a reason if they reported being hesitant to talk in the class. A greater proportion of students in inquiry (many of them girls) reported their fear that other students would laugh at their response or think that their answer or question was silly. The most common reason that students in the comparison group gave was that other students usually gave the answer first. This pattern was recurrent in the responses to both the mid-way questionnaires and those administered at the end of the program.

We again note that this particular group of students seemed comparatively more shy to participate in class discussions; this was not the case in earlier classes conducted as part of the curriculum development project. Perhaps, students' adolescent age, their specific context and the relatively shorter duration of contact are possible reasons.

This difference in the patterns of participation in the two groups and students' reports also makes sense in light of the negotiation of 'what counted' as science ideas between the teacher and their students in the two classrooms, reflected in the kinds of questions asked, the level of cognitive demands placed and the kind of participation expected from students in the two teaching modes. Teachers' questions asked in the comparison classroom, being more fact-based and placing low cognitive demand, would be less threatening as compared to open-ended responses that involved individual guesses, justifications or premature ideas as required in an inquiry class. This points to the difficulty many students initially had in speaking out during a class discussion in the inquiry mode, pronouncedly so for girls. Kumar (2010) notes that attribution of agency to the active learner, the main ingredient of child-centred education, is at odds with girlhood in India and although it is not easy to implement it in the case of boys too, in the case of girls, "the teachers' attempt, if it were to be made, is pitted against the full force of culture." (p. 81). However, as it usually happens as a result of traditional discourse practices in science classes over time (Lemke, 1990), many students got eventually alienated and demotivated from the class interactions in the comparison group as only a few privileged students were provided with the 'wind beneath their wings'. In inquiry, a variety of thinking processes, ideas, experiences – knowledge bases and resources that students bring to the class - were valued, making science seem more accessible to a wider range of students as the classes progressed.

5.8 Summary of findings in this chapter

This study brought out a variety of differences in the learning outcomes in the two sets of classrooms. Our analysis of students' diaries proved to be a useful tool for the comparison of the teaching-learning between the two groups. A large number of instances of what was learned, written by the comparison group indicated a lack of conceptual clarity, and several instances of misunderstanding of the concepts. Further, students in inquiry demonstrated a frame of 'doing science' (Jimenez-Aleixandre et al., 2000) This was in stark contrast with the frame of 'doing the lesson' adopted by students in the comparison group, wherein, more often than not, they described the learning in their diary entries through formal, conventional statements and involved a recall of facts, definitions, and laws explained by the teacher. There was evidence, on the other hand, that students in inquiry internalised that they shared epistemic authority with the teacher to construct and articulate explanations and steer the course of the discussion. There was also evidence of increased student engagement, self-efficacy, self-confidence, self- reflection, in the inquiry classroom as well as a developing classroom culture of co-operation with more equitable participation from students. Thus, we explored the outcomes across the conceptual, epistemic, affective domains, and also looked at how the teaching in both the modes affected students individually and at the collective level. Except for content learning (which was studied only through students' diary writing), rest of the outcomes were corroborated through various sources.

Chapter 6. Discussion and Conclusions

6.1 Role of teachers' questions in co-ordinating classroom discourse

Teachers' scaffolding of students' thinking in the various ways described in this study brought the quality of exploratory talk (Barnes, 1976; Mercer & Wegerif, 1999) to the inquiry classrooms. The teachers' questions aided in stimulating students' thinking and guided it through successively higher cognitive levels. The essence of scientific inquiry in the classroom, as Marshall et al. (2009) point out, is that students critically engage in investigating questions regarding the world around them, come up with explanations and evidences, then communicate conclusions with convincing arguments. This study portrays how teachers can facilitate such an inquiry through the categories of questions we have detailed.

We wish to emphasize that the inquiry lessons themselves necessarily had a progression - from the initial ideas, observations and questions students have to the forming of a coherent picture or concept. The progression of questions the teacher asks (Figure 6.1), whether embedded in an activity or building upon students' responses in a discussion, reflects this aspect of inquiry teaching and enables students to arrive at a conclusion without the teacher going into the explanation mode. This is a significant difference between inquiry and traditional modes of teaching.

In order to bring about such a progression, teachers' questions in the inquiry classes were necessarily contingent on students' responses, as is reflected in the high proportion of teachers' questions asked as a direct follow-up of students' responses. Their lesson plans were tentative and changed even within the duration of a single class, in response to what the students' ideas were. Sometimes the questions also branched off to delightful and necessary digressions taking students' interests into consideration or pursuing an odd alternative conception. In fact, many activities in the inquiry classes were sparked off by students' questions, conjectures, and suggestions.

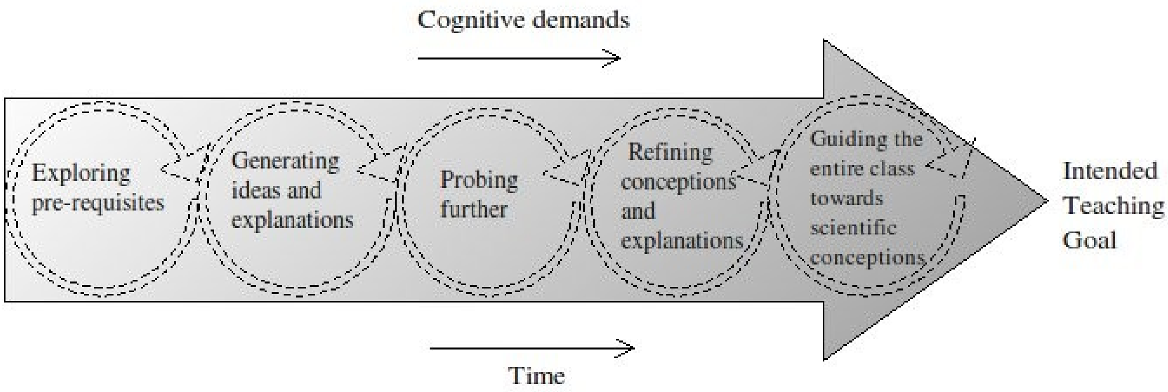


Figure 6.1 Progression of questioning in inquiry teaching

Also, the inquiry teachers made active attempts to engage all the students in the discussions and move them towards conceptual understanding. They continually assessed and adjusted the elements of the task at hand, taking into account students' abilities and curiosities and to promote continued student interest and efforts which is necessary in carrying the inquiry ahead. This high level of teacher's engagement with students' ideas and their responsiveness helped the teacher bring out and deal with students' existing conceptions and their concerns. Invariably, in the inquiry classes, the teachers repeated or rephrased students' responses and questions. This 'revoicing' (O'Connor & Michaels, 2017) served not only to affirm students' contribution and make it available to the social plane of the classroom but also acknowledged students' ideas as important topics to be pursued further. As students' responses were treated in a respectful manner and actively solicited, they formed a substantial part of the classroom talk in inquiry. Thus, teachers' questions (including those for classroom management), their response moves and directives aided in creating a supportive environment in the inquiry classrooms. Thus, in addition to cognitive scaffolding, questions also provided affective scaffolding - motivating, engendering confidence, giving respect.

At the same time, teachers' discursive moves played crucial pragmatic and epistemic roles - aiding the teacher relinquish, at least partially, her science expert role by forfeiting some interactional rights such as providing the right answers, imperatively telling students what to do and evaluating their ideas. At the same time, these questions encouraged students to partially relinquish their science novice roles and take on expert interactional rights (such as asking their own questions and responding to other students) thus contributing to form a more symmetric interactional structure. This did not lead, however, to a complete loss of control for the teachers, as is often feared; the teachers while encouraging and responding to students' ideas, exercised subtle control in deciding which lines of thought need to be pursued and how elaborately so that the discussion/ lesson remained on track in spite of digressions.

In the traditional science classes, there was not much difference in the questions asked or their sequence in the class from what had been planned prior to class. Though there were questions that explored students' prerequisites - ones that elicited students' experiences and observations - and occasionally questions that encouraged students to give explanations, there were hardly any questions to probe and refine students' thinking. Also, though many a time the teacher asked "Clear? Understood?" students were given little or no time to respond before the teacher moved on. Students' responses were rarely followed up with further probes to explore and extend the responses. Thus, the sequence in the teaching here (Figure 6.2) was of a different kind than the one seen in the inquiry classes. The traditional teachers, despite markedly greater efforts than their regular classes, led an authoritative, transmissive discourse, arguably because they paid less attention to the multi-functional role that teacher talk serves, mediated by questions.

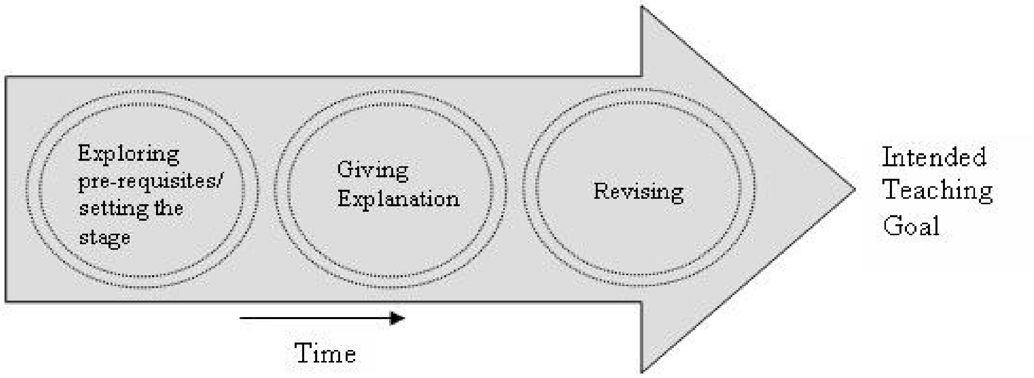


Figure 6.2 Progression of questioning in traditional teaching

The practice of questioning in the inquiry classroom also brought an added advantage - as reported by the teachers, it made teaching interesting for the teachers themselves and engaged them in an inquiry into what goes on in children's minds - something they enjoyed thoroughly. The inquiry teachers affirmed that the high level of interest that questions bring about in them, the level of engagement they demand, the challenge of thinking on their feet and the sheer fun of figuring out what is going on in children's minds, made inquiry worthwhile for them and they believed that this attitude transfers to the children.

It is pertinent to note here that enjoying this kind of pedagogical challenge necessitates, and indicates, a high level of preparedness and comfort with the content involved in teaching, which the teachers in the inquiry mode in this study had. Both teachers not only had robust subject expertise in the areas they taught, they also researched the topics well before and during the teaching. As Gess-Newsome (1999) asserts, teachers need to have deep and highly structured content knowledge (which is not fragmented or compartmentalized) in order to craft instruction that represents science as an inquiry. However, she maintains that content knowledge alone does not guarantee it. This was evident in the case of teachers in the comparison group who had expertise in the subject area they taught and yet resorted to didactic teaching.

6.2 Outcomes of teaching-learning through the two modes

The open-ended and reflective nature of the entries enabled a more nuanced look at the meaning and outcomes of the classroom experience for students in these groups. A spectrum of outcomes, and clear differences in those outcomes between the two modes of teaching emerged through this analysis - conceptual, affective and epistemic.

Students' conceptual understanding and the classroom events that led to their conceptual clarity became evident from diary entries, as did the nature of their difficulties with a particular concept. While most assessments test a concept after the teaching, that is, the final stage the student arrives at, regular diary entries of what students are learning provided information about students' emerging conceptions. Although diary writing is not a common practice at all in India, this artefact was easy to introduce and yielded rich results on several aspects of teaching and learning science.

The diaries, serving equally well as evidences of such concurrent affective outcomes, indicated that inclusion of activities and demonstrations in the class led to a high degree of self-reported enjoyment by students of both groups. However, genuine emotional and cognitive engagement with the content taught was observed to a markedly greater extent in students taught through inquiry. Our analysis also brought to light other important outcomes of inquiry: the development of a conscious awareness of learning, a questioning attitude and a learning approach in which they based their explanations on evidence and argument rather than on authority.

Beyond conceptual clarity and affective outcomes discussed above, researchers have pointed out that the inquiry vs. direct teaching debate is also about “a ‘feel’ for science and hence some appreciation of the nature of scientific inquiry” (Cobern et al., 2010, p. 92). Our study provides support to their proposition that though traditional, direct instruction might require less time for some topics, it does risk sending the message that science is simply a body of knowledge to be learned, which is encyclopedic, impersonal and non-negotiable. Teaching through inquiry models scientific inquiry and the diaries of students taught through inquiry reflected that they have internalized, implicitly, the inquiry approach to learning science. Thus students’ diaries of the two groups reflected an epistemic difference in their conceptions of learning science - whether it is “explained nicely” or it is “thinking how” and “to figure out [something]”. We believe this is particularly significant because these aspects were not explicitly verbalized to students but were picked up by them from the way the classes were taught thereby underscoring the need for discursive awareness for science teaching.

Our analyses of students’ class participation and their self-reports additionally complemented this array of outcomes students’ diaries and further helped elucidate the dynamics of teaching-learning in the two sets of classrooms.

6.3 Some limitations of the study

There are several limitations of this study stemming from its exploratory nature, settings and the methods employed. The specific situational context of voluntary, out-of-school classes is an important limitation of the study, reducing generalisability or transferability of the findings. However, we have attempted to provide rich, thick descriptions of the classroom interactions which attempt to contribute to the transparency and credibility of our findings and help the reader decide on the transferability of the findings to other settings. We have also tried to corroborate our findings using multiple data sources incorporating different perspectives of the various participants of the study.

We acknowledge the limitation of small sample sizes in our study especially for the quantitative part of the study. Moreover, though we intended to conduct a longitudinal study across a year with the same set of students, due to logistical reasons, the duration of the study was much shorter than intended and split into two phases, making the contact period with the cohorts of student shorter. Consequently, just when the classroom environment, especially in the inquiry group was getting established, it was time for the classes to end.

6.4 Concluding remarks and implications

One of the hurdles teachers face in adopting inquiry-oriented teaching practices has been that they have few operational models of teaching science as inquiry, and of what their own roles might be in helping students develop scientific understanding through inquiry (Asay & Orgill, 2010). As noted by Erdogan and Campbell (2008) it is important to identify mechanisms employed by teachers as they strive to implement effective teaching strategies in their classrooms. This study is just such an attempt to make explicit teachers' tacit strategies employed in inquiry teaching. It contributes to building a clearer, more nuanced picture of the complex processes, possibilities, and difficulties involved in inquiry teaching and learning developed from multiple sources of data incorporating perspectives of the researchers, teachers, students, and parents. Studies of this kind can help science education researchers, teacher educators and practicing teachers to understand both how environments conducive to inquiry are created and the central role teachers' questions and interactions play in establishing these environments. We believe that the teachers' self-reports, along with our analysis of questions and their progression would be useful to teachers who want to frame questions that aid in making a science lesson into an inquiry one. This study also contributes to the research on how teachers' discursive practices affect the kinds of learning, epistemologies, affective responses and self-concepts that enhance or limit students' participation in science. We hope that the varied outcomes reported in this study contribute to garnering support for teaching science as inquiry.

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Some publications related to the thesis

Kawalkar, A. & Vijapurkar, J. (2015). Aspects of Teaching and Learning Science: What students' diaries reveal about inquiry and traditional modes, *International Journal of Science Education*, 37(13), 2113-2146. **(mainly Chapter 4, 5 and 6)**

Vijapurkar, J., Kawalkar, A. & Nambiar, P. (2014) What do Cells Really Look Like? An Inquiry into Students' Difficulties in Visualising a 3-D Biological Cell and Lessons for Pedagogy, *Research in Science Education*, 44 (2), 307-333. **(Section 1.3)**

Kawalkar, A. and Vijapurkar, J. (2013) Scaffolding science talk: The role of teachers' questions in the inquiry classroom, *International Journal of Science Education*, 35 (12), 2004-2027. **(mainly Chapter 4 & 6)**

Kawalkar, A. & Vijapurkar, J. (2011) Several Lines of Inquiry Into Inquiry Teaching and Learning: Exploring the Affective Outcomes of Inquiry-Oriented Science Teaching. In D. Mogari, A. Mji and U. I. Ogbonnaya (Eds.), Proceedings of ISTE International Conference on Mathematics , Science and Technology Education, p. 265-276. South Africa: University of South Africa. **(Section 1.4)**

List of References

Akuma, F. V., & Callaghan, R. (2019). A systematic review characterizing and clarifying intrinsic teaching challenges linked to inquiry-based practical work. *Journal of Research in Science Teaching*, *56*(5), 619-648.

Alberts, B. (2000). Some thoughts of a scientist on inquiry. *Inquiring into inquiry learning and teaching in science*, 3-13.

Alexander, R. (2006). *Towards dialogic thinking: Rethinking classroom talk*. York: Dialogos.

Anderson, R. D. (2002). Reforming Science Teaching : What Research says about Inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12.

Areepattamannil, S. (2012). Effects of inquiry-based science instruction on science achievement and interest in science: Evidence from Qatar. *The Journal of Educational Research*, *105*(2), 134-146.

Asay, L.D., & Orgill, M. (2010). Analysis of essential features of inquiry found in articles published in The Science Teacher, 1998–2007. *Journal of Science Teacher Education*, 21(1), 57–79.

Bansal, G. (2014). Analysing middle grades science textbooks for their potential to promote scientific inquiry. *Journal of Indian Education*, 39(4), 5-21.

Barnes D. (1976). From communication to curriculum. Hammondsworth: Penguin.

Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of research in science teaching*, *49*(1), 68-94.

Bevins, S., & Price, G. (2016). Reconceptualising inquiry in science education. *International Journal of Science Education*, *38*(1), 17–29.

Bevins, S., Price, G., & Booth, J. (2019). The I files, the truth is out there: science teachers' constructs of inquiry. *International journal of science education*, *41*(4), 533-545.

Biesta, G. (2009). Good education in an age of measurement: On the need to reconnect with the question of purpose in education. *Educational Assessment, Evaluation and Accountability (formerly: Journal of Personnel Evaluation in Education)*, *21*(1), 33-46.

Brophy, J. (1999). Toward a model of the value aspects of motivation in education: Developing appreciation for particular learning domains and activities. *Educational Psychologist*, *34*(2), 75–85.

Bogdan, R. C., & Biklen, S. K. (2003). *Qualitative research for education: An introduction to theory and methods* (4th ed.). Boston, MA: Allyn and Bacon.

Bybee, R.W. (1997) Achieving Scientific Literacy. Portsmouth, N.H.: Heinemann.

Capps, D. K., J. T. Shemwell, and A. M. Young. 2016. "Over Reported and Misunderstood? A Study of Teachers' Reported Enactment and Knowledge of Inquiry-Based Science Teaching." *International Journal of Science Education* 38 (6): 934–959.

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

Chen, Y. C., Hand, B., & Norton-Meier, L. (2017). Teacher Roles of Questioning in Early Elementary Science Classrooms: A Framework Promoting Student Cognitive Complexities in Argumentation. *Research in Science Education*, *47*(2), 373–405.

Choksi, B. (2007). *Evaluating The Homi Bhabha Curriculum for Primary Science: In Situ*. Technical Report No.1 (2007-08). Homi Bhabha Centre for Science Education.

Cobern, W. W., Schuster, D., Adams, B., Applegate, B., Skjold, B., Undreiu, A., … Gobert, J. D. (2010). Experimental comparison of inquiry and direct instruction in science. *Research in Science & Technological Education*, *28*(1), 81–96.

Crawford, B. A. (2000). Embracing the Essence of Inquiry : New Roles for Science Teachers, *Journal of Research in Science Teaching, 37(9),* 916–937.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, *44*(4), 613–642.

Creswell, J. W., Plano Clark, V. L., Gutmann, M., & Hanson, W. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social & behavioral research* (pp. 209–240). Thousand Oaks, CA: Sage.

Donnelly, D., O'Reilly, J., & McGarr, O. (2013). Enhancing the student experiment experience: Visible scientific inquiry through a vir- tual chemistry laboratory. Research in Science Education, 43, 1571–1592.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84, 287–312.

Ellwood, R., & Abrams, E. (2018). Student's social interaction in inquiry-based science education: how experiences of flow can increase motivation and achievement. *Cultural Studies of Science Education*, *13*(2), 395-427.

Erdogan, I., & Campbell, T. (2008). Teacher Questioning and Interaction Patterns in Classrooms Facilitated with Differing Levels of Constructivist Teaching Practices.

International Journal of Science Education, 30(14), 1891–1914.

European Commission. 2015. Science Education for Responsible Citizenship. Report to the European Commission of the Expert Group on Science Education. Luxembourg: Publications Office of the European Union.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of educational research, 82*(3), 300-329.

Garcez, P.M. (2008). Microethnography in the classroom. In K.A. King & N.H. Hornberger (Eds.), *Encyclopedia of Language and Education,* Vol.10, (2nd ed.) (pp. 257-271). New York: Springer.

Gee, J. P. (2001). Literacy, discourse, and linguistics: Introduction and what is literacy? In E. Cushman, E. R. Kintgen, B. M. Kroll, & M. Rose (Eds.), *Literacy: A critical sourcebook* (pp. 525–544). Boston, MA: Bedford/St. Martins.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In *Examining pedagogical content knowledge* (pp. 3-17). Springer, Dordrecht.

Harste, J. (1993). Literacy as curricular conversations about knowledge, inquiry and morality. In M. R. Ruddell & R. B. Ruddell (Eds.), *Theoretical models and processes of reading (4th ed.)* (pp. 1220–1242). Newark, DE: International Reading Association.

Henderson, J. B., McNeill, K. L., González-Howard, M., Close, K., & Evans, M. (2017). Key challenges and future directions for educational research on scientific argumentation. *Journal of Research in Science Teaching*, 55(1), 5-18.

Jenkins, E. W. (2000). Constructivism in School Science Education: Powerful Model or the Most Dangerous Intellectual Tendency, *Science & Education, 9(6),* 599–610.

Jimenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). “Doing the lesson” or “doing science”: Argument in high school genetics. *Science Education*, 84, 757–792.

Jin, H., Wei, X., Duan, P., Guo, Y., & Wang, W. (2016). Promoting cognitive and social aspects of inquiry through classroom discourse. *International Journal of Science Education*, *38*(2), 319–343.

Jurow, A. S., & Creighton, L. (2005). Improvisational science discourse : Teaching science in two K-1 classrooms. *Linguistics and Education*, *16*, 275–297.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75–86.

Kumar, K. (2005). *Political agenda of education: A study of colonialist and nationalist ideas.* New Delhi, India: Sage.

Kumar, K. (2010). Culture, state and girls: An educational perspective. *Economic & Political Weekly*, 45(17), 75-84.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Lazonder, A. W., & Harmsen, R. (2016). Meta-Analysis of Inquiry-Based Learning: Effects of Guidance. *Review of Educational Research*, *86*(3), 681–718.

Lehrer, R., Carpenter, S., Schauble, L., & Putz, A. (2000). Designing classrooms that support inquiry. In J. Minstrell & E.V. Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 80–99). Washington, DC: AAAS.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood: Ablex.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. London: Sage.

Loyens, S. M. M., Rikers, R. M. J. P., & Schmidt, H. G. (2006). Students' conceptions of constructivist learning: A comparison hetween a traditional and a problem-hased learning curriculum. Advances in Heatth Sciences Education, 11(4), 365-379.

Magnussen, S. J., & Palincsar, A. S. (1995). The learning environment as a site for science education reform. *Theory Into Practice*, 34(1), 43–50.

Marshall, J. C., & Alston, D. M. (2014). Effective, Sustained Inquiry-Based Instruction Promotes Higher Science Proficiency Among All Groups : A 5-Year Analysis. *Journal of Science Teacher Education*, 807–821.

Marshall, J. C., Smart, J. B., & Alston, D. M. (2017). Inquiry-based instruction: A possible solution to improving student learning of both science concepts and scientific practices. *International journal of science and mathematics education*, *15*(5), 777-796.

Marshall, J.C., Smart, J., & Horton, R.M. (2009). The design and validation ofEQUIP: An instrument to assess inquiry-based instruction. International Journal ofScience and Mathematics Edu- cation, 8(2), 299–321.

Martínez, J. F., Borko, H., & Stecher, B. M. (2012). Measuring instructional practice in science using classroom artifacts: Lessons learned from two validation studies. *Journal of Research in Science Teaching*, *49*(1), 38-67.

McNeill, K. L., & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. Journal of Research in Science Teaching, 45(1), 53–78.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203–229.

Mehan, H. (1979). *Learning lessons*. Cambridge, MA: Harvard University Press.

Mercer, N., & Wegerif, R. (1999). Children's talk and the development of reasoning in the classroom. *British Educational Research Journal*, 25(1), 95–111.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction-what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms.* Maidenhead: Open University Press.

National Council for Educational Research & Training (NCERT) (2006). *Position paper of the National Focus Group on Teaching of Science.* New Delhi: NCERT.

National Research Council. (1996). *National science education standards.* Washington, DC:

National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academy Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts and core ideas.*.Washington, DC: The National Academies Press

NGSS Lead States. (2013). Next generation science standards: For states by states. Washington, DC: The National Academies Press.

O'Connor, C., & Michaels, S. (2017). Supporting teachers in taking up productive talk moves: The long road to professional learning at scale. *International Journal of Educational Research*.

Oliveira, A.W. (2008). *Teacher-student interaction: The overlooked dimension of inquiry-based professional development.* Indiana University: Unpublished doctoral thesis.

Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections* (Vol. 13). London: The Nuffield Foundation.

Palmer, D. (2005). A Motivational View of Constructivist-informed Teaching. *International Journal of Science Education*, *27*(15), 1853–1881.

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., … Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61.

Polman, J. L., & Pea, R. D. (2000). Transformative communication as a cultural tool for guiding inquiry science. *Science Education*, 85, 223–238.

Reinsvold, L. A., & Cochran, K. F. (2012). Power Dynamics and Questioning in Elementary Science Classrooms. *Journal of Science Teacher Education*, *23*(7), 745–768.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching*, 46(10), 1137–1160.

Samarapungavan, A., Mantzicopoulos, P., & Patrick, H. (2008). Learning science through inquiry in kinder-garten. *Science Education*, 92(5), 868–908.

Sarangapani, P.M. (2003). *Constructing school knowledge: An ethnography of learning in an Indian village.* New Delhi: Sage Publications.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: a fundamental characteristic of meaning making interactions in high school science lessons. *Science Education*, 90, 605–631.

Sinclair, J. M., & Coulthard, M. (1975). *Towards an analysis of discourse: The English used by teachers and pupils*. Oxford Univ Pr.

Silverman (2004). *Qualitative Research: Theory, Method and Practice.* Sage, New Delhi.

Suter, W. N. (2011). *Introduction to educational research: A critical thinking approach*. SAGE publications.

Thomas, D. (2006). A general inductive approach for analyzing qualitative evaluation data.

American Journal of Evaluation, 27(2), 237–246.

van Zee, E., & Minstrell, J. (1997). Reflective discourse: developing shared understandings in a physics classroom. *International Journal of Science Education, 19*(2), 209–228.

Varelas, M., Kane, J. M., & Wylie, C. D. (2011). Young African American children's representations of self, science, and school: Making sense of difference. *Science Education*, *95*(5), 824-851.

Vygotsky, L.S. (1978). Interaction between learning and development (M. Lopez-Morillas, Trans.). In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), Mind in society: The development of higher development of higher psychological processes (pp. 79–91). Cambridge, MA: Harvard University Press.

Vijaysimha, I. (2003). 'We are Textbook Badnekais!': A Bernsteinian Analysis of Textbook Culture in Science Classrooms. *Contemporary Education Dialogue*, 10(1), 67-97.

Wells, G. (2007). Forum: The linguistic construction of expert identity in professor–student discussions of science. *Cultural Studies of Science Education*, *2*(1), 151–170.

Wohlfarth, D., Sheras, D., Bennett, J. L., Simon, B., Pimentel, J. H., & Gabel, L. E. (2008). Student Perceptions of Learner-Centered Teaching. *Insight: Journal of Scholarly Teaching*, *3*, 67–74.

Yun, S. M., & Kim, H.-B. (2015). Changes in Students' Participation and Small Group Norms in Scientific Argumentation. *Research in Science Education*, *45*, 465–484.

Zhai, J., Jocz, J. A., & Tan, A.-L. (2014). "Am I Like a Scientist?": Primary children's images of doing science in school. *International Journal of Science Education*, *36*(4), 553–576.

Zhang, L. (2016). Is inquiry-based science teaching worth the effort? *Science & Education*, *25*(7-8), 897-915.

Appendix: Components of questionnaires and interviews

1. Pre-instruction questionnaire for students explored -

1. Interest in school science:
   a. Favourite subjects and least favourite subjects – where does science figure?
   b. Topics in science that they liked and did not like
2. Motivation for joining the program

2. Mid-way questionnaire administered during winter camp probed -

1. Any changes students noticed in themselves in the time they attended the intervention
2. Self-reports of participation level in science classes at school and in the intervention
3. Students' out of class questions and observations

3. Post- instruction questionnaire administered at the end of the summer camp probed -

1. Participation in the science classes in the intervention
2. Comparing science classes at school and those in the intervention and feedback for both
3. Dispositions towards learning science – how interesting/ important/ relevant/ difficult it feels

4. Students' self-reports one month post the summer camp attempted to explore

1. Students' interest in science outside of the program -
   a. Did they ponder about any questions, make any puzzling/ interesting observation?
   b. How was their participation in school science classes this year?
2. Any change they had felt about themselves in how they learned/ talked/ behaved?
3. Disposition towards learning science - did they start liking/ disliking any particular topics?
4. Conceptions of science

5. Components of the pre- instruction questionnaire for parents

1. Parents' reports on factors related to students' interest in science
   a. Students' discussion with parents about learning science at school
   b. Watching popular science programs/ channels on television
   c. Participating in science related co-curricular activities (quizzes, science fairs etc.)
   d. Reading science related books/ magazines
   e. Asking questions about events in daily life
2. Information related to students' routine outside school hours
   a. Academic support outside of school
   b. Activities engaged in out of school hours
   c. Number of hours of watching television
3. Perceived level of self-confidence of their child
4. Students' academic achievement and socio-economic status

6. Components of post- instruction questionnaire for parents

1. Whether, and how much, the child discusses, at home, about the classes in the program
2. Parents' impression of what happens in these classes
3. Any perceived change in their child after attending these classes
   a. Open-ended prompt
   b. Perceived change in the level of students' interest in science
   c. Perceived change in self-confidence level of the child
   d. Interest in making observations about the natural world
   e. Change in asking questions
   f. Any negative or undesirable change
4. Probable role of these classes in any of the changes observed
5. Request for feedback/ comments on science teaching in the program

7. Interviews with teachers aimed to document teachers' reflections on -

1. Students' participation in their class
2. Their questioning practices
3. Strategies to get students involved
4. Conceptions of science teaching and learning
5. Experience of teaching in the classes in this study
6. Perceptions about the particular group of students they taught