

Understanding student questioning

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Abstract Our investigation focusses on a group of eleven lower-middle-class students from classrooms in which the teachers did most of the talking and students rarely asked any questions. We have examined whether spontaneous discussions among the students in a less structured setting would include questioning, and what kinds of questions they might ask. Our study is based within a historical dialectical materialist framework. We particularly wanted to find out whether, given a material context—an unusual variegated tree—the students would spontaneously ask questions about the tree, or whether they would need some sort of teacher’s guidance in order to do so. We were motivated to raise these research questions partly by worries that a culture of an unquestioning student passivity may exist and that such a culture may be an expedient way of maintaining social norms. Rather than testing out a teaching strategy, our broader aim was to understand the students and find out whether or in what sense they might practice science. We explored the role of the teachers and the context in the students’ questioning process by analysing student talk and interactions with each other and with the tree. We found that, in the course of their spontaneous discussions, even with very little teacher guidance, the students engaged in questioning and asked each other a surprising number of investigatable science questions. Their questioning was mainly authentic, and was both explicit and implicit. We claim that their questioning was a dialectical process in which conflicts arose due to interactions between students, as well as between students and the tree. Even though the students had never done practical science activities in their classrooms, they spontaneously performed some experiments to

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find answers to their own questions. We present evidence that they did this despite thinking that they were not supposed to do so. We discuss how and why the students engaged in questioning and investigating. We also discuss possibilities for how student questioning could flourish, even if not officially encouraged, at least as a subversive activity.

Keywords Student questioning · Historical dialectical materialism · Open-beginning explorations · Explicit and implicit questioning · Investigatable questions

विद्यार्थ्यांच्या प्रश्नांची समज

असे दिसून येते की भारतीय शाळेतील वर्गात अशा चर्चा फार क्वचितच होतात ज्यात विद्यार्थी प्रश्न विचारतात. आणि दुसरीकडे असेही दिसून येते की लहान मुल खूप सारे प्रश्न विचारतात. मग काय जेव्हा मुलं मोठी होतात तेव्हा ते कमी प्रश्न विचारतात? का ते एकमेकांना प्रश्न विचारतात पण कोणा अधिकारी किंवा तज्ञांना नाही? किंवा ते प्रश्न विचारतात, पण वर्गात नाही विचारत? अनेक शिक्षक आणि संशोधक हे मानतात की विद्यार्थ्यांनी प्रश्न विचारण्याला हवेत. मग जर ते नाही विचारत, तर अस का? हे असे आहे कारण मुलांचा स्वभावच तसा आहे वा हा संस्कृतीचा भाग आहे ज्यात मुले वाढतात आणि जो बदलला जाऊ शकत नाही? का अशा काही शिकविण्याच्या पद्धती आहेत ज्यात विद्यार्थी जास्त प्रश्न विचारतील? हे काही व्यापक प्रश्न आहेत ज्यातून आमच्या संशोधनास प्रेरणा मिळाली आहे. आम्ही इयत्ता सातवीत शिकणाऱ्या अशा ११ विद्यार्थ्यांसोबत ही तपासणी केली ज्यांच्या शाळेत बोलण्याचे काम केवळ शिक्षकच करतात आणि फार क्वचितच हे विद्यार्थी काही प्रश्न विचारतात. इथे, आम्ही एका अनौपचारिक वातावरणात विद्यार्थी कशी उत्स्फूर्त चर्चा करतात, त्यात प्रश्नांचा कसा समावेश असतो आणि ते कोणत्या प्रकारचे प्रश्न विचारतात याचे परीक्षण केले आहे.

विद्यार्थी प्रश्नांवर यापूर्वी झालेल्या संशोधनाचे पुनरावलोकन केल्यावर आम्ही हिस्टोरीकल डायलेक्टिकल मटेअरीलीस्ट या विचारसरणीचा सदर अभ्यासात कसा वापर केला आहे याची चर्चा या लेखात करत आहोत. या विचारसरणीनुसार, निसर्ग आणि समाज हे नेहमी जसे दिसतात तसे नसून ते परस्परांशी डायलेक्टिकल आहेत: विरोधाभास आणि विरोधी संवादातून ते सतत बदलत असतात. तसेच या विचारसरणीनुसार विज्ञान हे केवळ एक ज्ञान-भांडार नसून ते डायलेक्टिकल आहे, एक सतत बदलणारी प्रक्रिया आहे ज्यात प्रश्न विचारणे, निरीक्षण करणे आणि भौतिकी प्रत्यक्षाची तपासणी करणे या सर्वांचा समावेश आहे. याचा अर्थ असा होतो की विज्ञान आणि प्रश्नात्मक चौकशी हे दोन्हीही विरोधाभास आणि अनिश्चिततेद्वारा समर्थित होतात. म्हणून, शिक्षकांनी प्रश्न विचारा किंवा निरीक्षण करा असे सांगितले नसतानाही, पानाच्या रंगात विविधता असलेल्या एका असामान्य भेंडीचे झाड पाहून अचंबित होऊन विद्यार्थी प्रश्न विचारतात का हे शोधायचे आम्ही ठरवले. हे झाड थोडे गोंधळात टाकणारे आहे कारण पानांचे रंग विलक्षण आहेत (जसे काही पाने पांढरी आहेत), काटे जी खरीतर मुळे आहेत, पानांचे अंकुर जे फुलांसारखे दिसतात आणि झाडाला फळ नाही आहे. अनौपचारिकपणे निरीक्षण करताना आणि हे झाड हाताळताना विद्यार्थ्यांनी एकमेकांशी केलेल्या संवादाची नोंद आणि विश्लेषण आम्ही इथे केले आहे.

आम्हाला असे आढळून आले की शिक्षकाचे अत्यंत कमी मार्गदर्शन असताना देखील विद्यार्थ्यांनी त्यांच्या उत्स्फूर्त चर्चेदरम्यान अनेक तपासण्यायोग्य वैज्ञानिक प्रश्न विचारले. अनेकदा शिक्षक जे नकली प्रश्न वर्गात विचारतात -- ज्यांची उत्तरे त्यांना माहीतच असतात, त्याहून निराळे असे प्रश्न विद्यार्थ्यांनी विचारले; विद्यार्थ्यांनी प्रश्न विचारले कारण उत्तर जाणण्याची त्यांची जिज्ञासा खरी होती. त्यांचे प्रश्न मुख्यतः अस्सल होते आणि ते स्पष्ट तसेच अव्यक्तही होते. विद्यार्थ्यांचे प्रश्न हे डायलेक्टिकल प्रक्रियेचा भाग होते ज्यात परस्पर विद्यार्थ्यांमध्ये आणि विद्यार्थी व झाडामध्ये आलेल्या तपासण्याची चर्चा आम्ही इथे केली आहे. जरी या विद्यार्थ्यांनी शाळेत कधीही वैज्ञानिक कृती केल्या नव्हत्या तरी या संदर्भात त्यांनी स्वतःच्या प्रश्नांची उत्तरे शोधण्यासाठी उत्स्फूर्तपणे काही प्रयोग केले. यातील काही प्रयोगांची

गरज नाही हे समजून देखील विद्यार्थ्यांनी ते प्रयोग केले असा पुरावाही आम्ही इथे दिला आहे. मुलांनी कश्या पद्धतीने प्रश्न विचारले व ते प्रश्न का विचारले तसेच त्या प्रश्नांची उत्तरे कश्या पद्धतीने शोधली याची ही चर्चा आम्ही केली आहे. औपचारिक रित्या जरी शक्य नसले तरी पर्यायी कृतीद्वारे विद्यार्थ्यांचे प्रश्न तेजीने कसे वाढवता येतील याची चर्चादेखील या लेखात आम्ही केली आहे.

Student questioning: conflicts

We were initially motivated to do the research described in this report by our observations that students in Indian school classrooms very rarely have discussions in which they ask questions. On the other hand, it seems that pre-school-going children ask large numbers of questions. As children grow older do they ask fewer questions? Or do they ask each other questions but not ask authorities? Or is it just certain kinds of questioning which diminishes? And if questioning does diminish, is it because they start going to school?

We will begin by discussing research related to these underlying questions and the situation we see in Indian classrooms, showing how it clarifies some points but leaves others unanswered. This will lead to the definition of our research objective, which was to investigate students' questioning in a workshop setting which was less structured than their regular classroom. After discussing our framework and methodology, we will analyse the interactions which we observed between the students.

Classrooms without students questioning

We sometimes hear that even outside of class, children do not ask questions, and are quiet, docile, and obedient. Some say that this is part of an alleged 'Indian Culture' which teaches them to respect their elders and adhere to certain caste, gender, and class biases. For example, Hamid Ansari, former Vice-President of India, has said:

In our family life, we do not approve of questioning. Most parents do not like children asking questions. In schools, from nursery to high school, teachers frown upon children raising questions. In colleges and universities, asking questions is often considered 'cheeky' and an attempt by the student to cast doubt on the knowledge of the teacher.

The same holds good for social life. It is considered 'disrespectful' to question an elder, a superior or a leader. (Ansari 2016)

It is not clear whether this is actually true, and given the diversity within the country, it may be difficult to believe. We have not found any recent research reports from India on children's questioning or conversation in their daily lives outside of school. There are a few reports that mention students' written questioning, although most of them are not very recent. For example, some researchers report that students do ask a variety of questions when they are asked to ask questions in written form through postcards and letters (Pal and Mishra 2008) or through question-boxes (Kulkarni and Agarkar 1985).

However, we are more concerned with students' questioning as part of their discussions with each other as well as with their teachers, and there are very few reports of this. The teacher educators Kewal Kandpal (2015) and Mohammad Zafar (2015) have recently reported that when they visited classrooms and encouraged middle school students to ask

them questions, they did do so. But their impressions were in agreement with those of KP Madhu (2015) that students very rarely ask questions as part of the main discourse in Indian school classrooms. We have not found any reports that challenge this perception. Educationists, such as Padma Sarangapani (2003) and Krishna Kumar (1989) have given supporting evidence for this from case studies and classroom observations, for example:

When students do ask a question, it is mainly in order to seek clarification. A student-question which points towards new dimensions of the topic at hand is an extremely rare event. A question challenging the authorised version of knowledge is unheard of. Who has the right to ask questions and whose role it is to answer them, and what kinds of questions are supposed to be asked by whom, are related to the total cultural context of a society and to the conceptualisation of curriculum prevailing in its education system. Family norms in India do not encourage children to ask questions. Studies of adult-child interaction in Indian family settings indicate that questioning, criticism, and independent decision-making are not among approved and encouraged behaviours among children and youth (Narain 1964). Questioning someone older than oneself, such as a teacher, is certainly not an approved behaviour; it is perceived as an expression of one's disrespect for the adult's nurturant authority. (Kumar 1989)

In other countries also, most of the reports on the prevalence of student questioning are not recent [as reviewed by Christine Chin and Jonathan Osborne (2008)]. James Dillon (1988), and Douglas Barnes, James Britton, and Harold Rosen (1971) were among the earlier researchers to report that recordings and observations of classrooms show that students very rarely ask questions, or engage in discussions in which they address each other. More recently, Patrícia Almeida and Francislé Neri de Souza (2010) have reported from Portugal that even when teachers used methods that aimed to be more student-centred, students hardly asked questions. Teacher questioning clearly dominated and guided the classroom discourse. In a study of question asking among college undergraduates, Pearson and West (1991) reported that all students together asked at an average merely 3.3 questions per hour. This comes to be about 0.10–0.20 questions by each student in each 1-h class. Similar observations have been made by Arthur Graesser and Natalie Person (1994), and they reported an average of 0.17 questions per student in an undergraduate class.

Some research has indicated that students, especially as they grow older, do not ask questions because teachers do not allow or encourage questioning, and/or because students do not want to call attention to themselves (Chin and Osborne 2008). In many classrooms student talk is restricted by rules such as not being allowed to speak without permission (Dillon 2004). There are reports from India that students do not even engage in classroom discussions: “When children speak, they are usually only answering the teacher's questions or repeating the teacher's words” (National Council of Educational Research and Training [NCERT], 2005, 13). Jayashree Ramadas and V. G. Kulkarni (1982) reported that students very rarely initiate sequences of classroom conversation.

There are some reports that very young children ask fewer questions in school than at home (Harris 2012). Beverly Falk and Linda Margolin (2005), as well as Dan Rothstein and Luz Santana (2011), have suggested that as children grow older they ask fewer questions, but this is contradicted by Thomas Good et al. (1987). It is not clear whether their questioning stops when children start going to school, or becomes restricted to outside of the observed classroom discourse.

Predominant pedagogy in India

Educationists generally advise that students should be encouraged to ask questions in science classrooms. Indian national curricular framework documents suggest that teachers should encourage student questioning, for example:

The curriculum must enable children to find their voices, nurture their curiosity—to do things, to ask questions and to pursue investigations, sharing and integrating their experiences with school knowledge rather than their ability to reproduce textual knowledge. (National Council of Educational Research and Training [NCERT] 2005, p. 13)

Only if children in, say Class VIII, can connect the chapter on photosynthesis with the real plants around would they think of asking questions such as, ‘How do crotons, which have coloured leaves but no green leaves, manage to manufacture their food?’ (ibid, p. 31)

However, despite such advice, there is a lack of questioning or dialogue in the classrooms, as we have discussed above. Although we doubt whether India has a uniform culture of not questioning, some aspects of the science education system in the country are quite uniform. We will summarise the main features of this uniformity, and readers who are not familiar with it can also refer to Sarangapani (2003), Kumar (1989), and Meenakshi Thapan (2014). The curriculum is defined by State (or less often, National or International) School Boards and prescribed textbooks (Thapan 2015). Science teaching pedagogies are mainly transmissive. It is very rare to see students working in small groups or doing activities. Despite its advocacy in Indian policy statements and textbooks, a constructivist approach is rare. There are two dominant science teaching methods, which can be broadly categorised as (1) teacher-lecturing, and (2) a pseudo-inquiry method. Combinations and variations of these methods are very common throughout a variety of types of schools. In the pseudo-inquiry method, teachers rather than students do most if not all of the inquiring. Teachers ask questions, and the students answer. Most of the discourse involving individual students is between the teacher and one student at a time. It is very unusual for one student to address another student, except in low voices or whispering, which the teacher may tolerate or try to prevent. This method is dominated by the IRE triad: teacher Initiation (often a question), student Response, teacher Evaluation or Elaboration, and its variants (Mehan 1979). Even in the rare cases in which students work in small groups and engage in discussions without teachers, they work mostly on teacher-defined questions.

Inauthentic teacher questioning

As we have noticed in India, and as researchers such as Hugh Mehan (1979) and Barnes, Britton, and Rosen (1971) have noticed in other countries, teachers mostly ask ‘known-information questions’ which are aimed at checking students’ ‘knowledge’ rather than engaging them in meaningful thinking or investigation. Martin Nystrand, Lawrence Wu, Adam Gamoran, Susie Zeiser, and Daniel Long (2003) define such teacher questions as inauthentic. Note that throughout this paper we are using this very specific definition of the term ‘authentic question’, to mean only that the asker is ignorant of the answer and has a genuine curiosity to find it (others have used the terms true, real, or genuine in the same way).

Teachers ask inauthentic questions as part of what we call the ‘school-school game’ they are playing in which they assess or try to get students to state answers and ‘facts’ and develop ideas which comprise the pre-defined science content. We use the word ‘game’ in the sense that it was used by Lev Vygotsky (1966), to signify that the situation is in a way imaginary (or superficial). This is because both teachers and students engage in a rule-bound process that is concerned more with inculcating discipline and acceptance than with the goals of a more creative and transformative education. Their efforts to conform to the rules are mainly explicit, and teachers realise that their questions are not authentic.

Although there are some advantages, there are many reasons why teachers’ inauthentic questioning is problematic. This form of discourse, in which the questions are usually closed, ensures that the teacher maintains almost total control over the proceedings, and may too tightly circumscribe students’ thinking (Hanrahan 2006; Lemke 1990).

Lack of hands-on work

Even ‘practicals’ (laboratory sessions), which in most Indian schools begin only after Class VIII, are considered separate from, and less worthwhile than ‘theory’ or science concepts. Students may merely watch the teacher perform demonstrations rather than work with their own hands. In a survey of Class IX school students by Gurinder Singh and Rajesh Khaparde (2013), indicated that even when students did do some hands-on laboratory work, there were no open-ended experiments. Instead, there was a stress on getting the ‘right’ results, and students had no opportunities to frame questions or design experiments. A cook-book approach was followed whereby students were told the ‘recipe’ of what to do, step-by-step, even including the expected observations and results. Such laboratory work does not encourage students to develop questioning skills.

Is the dearth of hands-on work in Indian schools related to historical caste divisions? As Kancha Ilaiah (2010) puts it, a culture has developed over past centuries in which Dalitbahujans have ‘more of an investigative psychology than an imaginative ability like the Brahmans have.’ Brahmans have been engaged with the world of ideas, spirits, ‘inner consciousness’, reading and writing, and white collar corporate jobs, while Dalitbahujans, have been forced to work with soil, minerals, plants, animals, and filth, and are therefore constantly confronted by curiosities and problems of physical reality which demand investigation (and physical solutions) rather than just introspection. But their questioning and investigating has remained unwritten and unheard by the intellectuals who hold power. Their work has not been recognised as being ‘science’, even though it has led to many technological advances in agriculture, metallurgy, leather making, etc. The caste system and its segregation of mind and body is thought to be one of the major factors that has inhibited the development of science and technology in India. Therefore, our research is concerned with studying these interconnections—and opposing caste division and the over-emphasis of reading and writing at the expense of students’ oral discussions, questions, and hands-on investigations.

Functions of student questioning

There are many advantages of students talking and carrying on discussions in which they ask each other authentic questions, as discussed by Fred Biddulph, David Symington, and Roger Osborne (1986) as well as in the review by Chin and Osborne (2008). Most of the research on student questioning has focussed on its potential in helping students remember

and understand text, or in a few cases, construct conceptual knowledge (Chin, Brown, and Bruce 2002). Many of these researchers have also claimed that students' questions give them a sense of ownership, thereby engaging them emotionally in science education. However, we are interested in understanding the role of student questioning in the process of scientific investigation of physical reality: framing questions for investigation, postulating and testing hypotheses, searching for, analysing, and evaluating evidence, etc. More research is needed especially to better understand the dynamic interrelationships between questioning, observing, and handling material, when they are done collectively. Rather than studying questioning in order to understand questioning, we are more interested in studying it in order to understand how students' develop scientific temper and do science in their everyday lives.

Mattias Lundin (2007) in Sweden, used a cultural framework based on Wittgenstein's concept of language games in order to study the use of questions in transitions between science and everyday language games. However, we agree with Wolff-Michael Roth (2007a) in the forum response to this paper, that it is not clear whether these two language games can or should be distinguished from each other. As we will discuss below, according to our framework and our definition of science, we do not see a clear or large distinction between everyday and science talk. Mattias Lundin's identification seems to be based mainly on the topics, content, and word choice (jargon) of the talk. We are more interested in the functions of questioning in the social process of doing science which includes investigating physical stuff. His reported examples were from classroom discussions which occurred separately from physical acts such as manipulating and observing actual stuff. One of his examples shows talk between students without a teacher, on the topic of food digestion in the human body—a discussion which is based on their textbooks and previous classes. Lundin concluded that the transition from an everyday language game to a science language game required teacher support. As Roth points out in the forum, the teacher 'support' may have actually discouraged student questioning. In any case, the students had little scope for making observations or doing hands-on investigations in order to help them find 'science language' answers to their 'everyday language' questions about how liquids and solids are separated during digestion.

Sharada Gade and Lotta Blomqvist (2016), conducted a CHAT-based study of students' exploratory talk in which they engaged in a process of dialogic inquiry that challenged the social norms of the concept of measurement. The students kept transitioning between 'spontaneous' and 'scientific' concepts, with reference to their past personal experience. Here also, the authors claim that the students' discussions were made possible only under the teacher's guidance, in this case because the teacher was asking questions related to improbable scenarios. However, we wonder whether the students themselves could be the ones to ask confusing questions which could guide such discussions. If students are observing and manipulating stuff, might they engage each other in discussions in which they ask science questions about the stuff without teacher support? Whether they would also try to answer their questions by doing investigations without teacher support is another question. Do these things sometimes happen in science classrooms or in students' everyday lives, and if so, under what conditions? These are the questions which led us to conduct the present study.

Questioning in open-beginninged contexts

Chin and Osborne (2008) write that the most important function of students' questions is that they 'indicate that the students have been thinking about the ideas presented and have

been trying to link them with other things they know.’ This is important, but we would like to explore the creative potential of student questioning in forming new ideas, changing beliefs, and investigating new areas. In order to do so, it may be necessary to use an approach which is not only open-ended, but also ‘open-beginninged’. The term open-beginning has been used to define the openness of a problem/task in terms of its beginning state (Wiliam 1998). Accordingly, a problem is more open-beginninged if it is open for more than one interpretation by students or if students have greater autonomy/freedom in interpreting it. Here we are using this term to define the autonomy given to the students to formulate their own questions and problems within a given context. We find a paucity of research on this topic.

There are not many studies of student investigations where the students have defined their own questions for investigation. Notable examples are by Carolyn Keys (1998) and Wolff-Michael Roth and Anita Roychoudhury (1993) in science, and Sharada Gade and Lotta Blomqvist (2015) in mathematics. In most cases, the teachers’ roles were important, at least in initial stages. Chin and Kavalvizhi (2002) have suggested that students’ freedom to define their own problems for investigation should be limited by confining their questions to prescribed topics (content areas), ‘to ensure that student learning is basically in line with content objectives’.

Perhaps the function of questioning is not just to resolve conflicts, but also to create and to recognise inherent (dialectical) conflicts. Asking questions involves learning what one knows and what one does not know, and trying to figure out what questions are more or less important or relevant. The dialectical essence of the process has often been overlooked.

Culture and questioning

These days in India, conflicts regarding questioning have become prominent in social/political life as well as in education. Whether stated or unstated, one of the main aims of formal education appears to be the enculturation of children so that they unquestioningly conform to fixed social ‘norms’ (Freire and Faundez 1989). Despite having a very diverse and dynamic society, there are some claims that India has one social ‘norm’: an essential Hindutva ‘culture’ (Noorani 2017). Some say that questioning the existence or imposition of this culture is ‘anti-national’. Kalim Siddiqui (2017) discusses how it is becoming increasingly dangerous to question this ‘culture’ or to express dissident opinions, and several intellectuals who have done so have been murdered or imprisoned within the last few years.

Is respect for authority—or an unquestioning acceptance of authority—part of Indian culture? If it is part of the culture, is it one aspect that is relatively static and cannot or should not be changed? We worry that the assertion of a fixed ‘culture’ might be used to rationalise or defend the lack of student questioning and/or discussion in classrooms: teachers may not even try to encourage student questioning. However, Hamid Ansari agrees with Krishna Kumar and many other educationists that students do need to be encouraged to ask questions.

But should questioning be confined to certain areas? Educationists need to worry about socio-political reasons why questioning is or is not important: which questions are to be encouraged, who should ask questions, and from whose point of view. Derek Hodson (1993) has claimed that science process skills are not transferable across domains.

Although he and many other educationists have advocated science teaching as inquiry, transformative education, and the inclusion of socio-scientific issues in the curriculum, they have not focussed on questioning as a science process skill (Hodson 2014). If questioning is a transferable science process skill, then it may be difficult to confine it to certain areas. Even the more controversial social aspects may not be 'safeguarded' from questioning. But is there a worry that if students start asking too many questions on one topic, they may inculcate a habit of questioning which will be detrimental? This problem arose in our minds after a senior teacher observed one of us (Karen) teach a middle-school class, and said 'Well this is all very nice, Karen, but you know, if students are taught like this, by the time they come up to the senior school, they may start questioning everything!'

Returning to the quote we began with, is Hamid Ansari's impression really correct, or do children actually ask questions under certain conditions? Do students become talkative and ask questions if teachers are less authoritative, if the atmosphere is more relaxed, or if the pedagogy is more open-beginninged? Or even if they don't ask authorities, do students ask each other questions outside of class? We were initially motivated to do the research discussed in this paper in order to distinguish between these possibilities. But rather than just making generalisations, finding evidence to confirm or reject stereotypes, or looking for reductionist causes and effects, we decided to investigate the dialectical process (practice) of student questioning in a context which differs from that of the usual classroom, focussing on the following research questions.

Research questions

(A) Will a group of middle school students ask each other questions in a setting which is less structured than their classroom, given a particular context (a variegated bhendi tree), or do they need some amount of teacher guidance? To find out, we tried a series of progressively more direct means to encourage the students to ask questions about the tree:

- Stage 1 *Indirect* The teachers (researchers) call students to the place near the tree, saying only 'Come here', otherwise not talking to the students
- Stage 2 *Less indirect* The teachers start looking at the tree so that the students get interested in the tree
- Stage 3 *Somewhat direct* The teachers start asking the students to look at the tree, with ambiguous exclamations such as, 'Oh! look!'
- Stage 4 *Most direct* The teachers ask the students to ask questions about the tree

(B) What is the nature of the questioning, if any, that the students may engage in at each Stage, and how and why will their questions evolve? As our work progressed, this gave rise to the questions: Did the students ask investigatable questions? Did they search for answers? And, were the students doing science?

Beforehand, we thought that the students may not ask any questions until we explicitly ask them to do so at Stage 4, in which case they may not be asking each other, but asking in response to our request. However, our research questions were actually authentic questions in that we were really not sure of the answers, and we needed to know the answers in order

to figure out how to facilitate teaching/learning situations in which students ask each other questions.

Historical dialectical materialist framework

What is historical dialectical materialism?

Our work is based upon a framework in which science is considered to be a historical dialectical materialist (HDM) *process* and the nature of physical reality itself is also essentially HDM. We realise that nowadays, especially in the west, this framework may not be very fashionable, so we will define and discuss it in some detail. We find it to be particularly appropriate because, as we will discuss, it is concerned with trying to understand the effects of dialectical contradictions. We think such contradictions may give rise to the process of questioning, which is the topic of our study.

By ‘materialist’ we do not mean that only matter exists or that ideas do not exist. We mean that: events occur that humans do not perceive; physical reality (i.e. ‘nature’) existed prior to the existence of human beings and human consciousness; and human consciousness does not exist separately from human bodies, as explained by JBS Haldane (1940). However, for us at present, ‘nature’ means nature/society: the inseparable unity of the human (social) and the non-human living and non-living environment, in their complex interactions, interdependencies, and movement. This is in accordance with Marx’s (1844, p. 143) description of the dialectical relationship between society and nature. Thus, according to an HDM framework, reality is the inseparable object/subject: we human beings are acting upon, studying, and doing science on a material world which is also acting upon us. This social mediation is discussed by John Bellamy Foster, Brett Clark, and Richard York (2010, pp. 215–247), and in a review of their work (Haydock 2017).

What do we mean when we say that nature is dialectical?

As Friedrich Engels wrote:

... the world is not to be comprehended as a complex of readymade **things**, but as a complex of **processes**, in which the things apparently stable no less than their mind images in our heads, the concepts, go through an uninterrupted change of coming into being and passing away, in which, in spite of all seeming accidentally and of all temporary retrogression, a progressive development asserts itself in the end. (Engels 1886)

As explained by Maurice Cornforth (1975) as well as Foster, Clark, and York (2010), this means that in physical reality, everything changes, and therefore things do not exist as things, but as things in the process of becoming something else. Thus we see the difficulties in thinking that a thing is identical with itself: because everything keeps changing and what is ‘self’ at one time no longer exists at another time. This is referred to as ‘self non-identity’ (Roth 2007a). This forces us to modify our everyday system of logic in which $A = A$ to use an HDM logic in which $A \neq A$. In other words, all ‘things’ are actually **processes**, and things may not actually be what they appear to be. We use the term ‘historical’ to mean that physical reality changes in time. Furthermore, the character of change is such that gradual quantitative change eventually leads to radical qualitative change. Thus,

one process is replaced by another process which is qualitatively different. Actually, nothing lasts forever in its same form. Another aspect of nature which makes it HDM is that there are inherent conflicts and inner contradictions in all things/processes which keep the whole in motion. Also, all things/processes are interconnected and interdependent. Following the interpretation by the marxist biologists Richard Levins and Richard Lewontin (1985), dialectical relations are opposing aspects that do not occur separately in time as causes and effects. They exist as a unity of inherent opposing forces (see Dialectics box). However, these dialectical relations give rise to change in physical reality in time, which is why our framework is called ‘historical dialectical materialism’ rather than just ‘dialectical materialism’.

Dialectics

We are using a definition that is similar to the way Engels (1876) defined the laws of dialectics as the transformation of quality into quantity, the interpenetration of opposites, and the law of the negation of the negation. However, following Levins and Lewontin, we will avoid calling them ‘laws’, in order to avoid the misconception that there is some externally imposed ‘law’ which causes things to behave dialectically. Rather, we want to emphasize that nature is inherently dialectical—and non-teleological in the case of non-human nature

Although processes in nature are dialectical, not all descriptions of these processes are dialectical. For example, a description of a variegated bhendi tree growing slower when it gets inadequate water, is simply a matter of cause and effect. It is not a dialectical description. But there are inherent dialectical relations in the same process. For example, there is an inherent conflict because sunlight and water are needed for photosynthesis, but sunlight also heats the leaves, increases evaporation, dries out the leaves, and thus inhibits photosynthesis. White leaves reflect more sunlight, but are not as productive as green leaves because they have less chlorophyll. This is not a matter of ‘balance’: if everything was balanced, there would be no movement, growth, life, death, or evolution. The white leaves exist due to complex interdependencies between social/historical material chance and necessity. They arose by chance due to mutation and then the variegated variety of the tree was purposely bred in order to become a commodity. Thus the value of white leaves is dialectical (as is the value of any commodity as a use value/exchange value, embodying concrete and abstract labour). These dialectical relations are not simply causes and effects. Neither do they occur sequentially. Photosynthesis does not directly cause evaporation. Neither does evaporation cause photosynthesis. Neither does one occur before the other. The entire complex interrelated set of inherent dialectical relations and opposing forces are all part of the process in which the tree keeps growing, or perhaps due to inadequate watering, gets gradually drier and drier until it dies (which is an example of gradual quantitative changes leading to an abrupt qualitative change)

If we use an HDM method to investigate the effect of inadequate water on the bhendi tree, we might investigate these sorts of dialectical relations. If we use a less HDM method, we might investigate just one aspect separately, say the amount of water needed to cause a certain number of leaves to fall, without adequately considering opposing forces, nonlinear dynamics, or interconnections to other factors

Thus, we are using a definition of ‘dialectical’ which is what we interpret that both Marx and Engels meant by it. In addition to writing about **nature/society being dialectical**, they also wrote about the use of a **dialectical method** to understand nature/society. Realising that physical reality is HDM, we need to use an HDM method of science to investigate (and change) physical reality. The HDM world view as well as the method is what we call marxism.

What do we mean by a ‘dialectical method’?

We are not referring to the form of reasoning in which a thesis is first countered by an antithesis and then resolved by some sort of synthesis (Rodrigues, Camillo, and Mattos 2014). We are referring to a scientific method, although science is not always done in a

very HDM way (see **Dialectics** box). We use the term ‘dialectical’ to refer to the type of analysis that Marx (1867) uses throughout *Capital*: ‘to use material evidence and find dialectical relations in it—relationships which reveal contradictions that explain how motion occurs and why processes proceed the way they do.’ (Haydock 2017).

Since nature itself is dialectical, even if we do not consciously try to find dialectical relations—we may find them when we do science. Therefore, and also since we recognise that our preconceptions and our ideological framework effect us as we do science, and that doing science is a social process, it is useful to use an HDM framework (see Levins and Lewontin 1985).

What is the HDM method of doing science and how does it differ from other scientific methods?

Because our study is based on questions related to whether and how students do science, we need to define what we mean by science according to our framework. By ‘method’ we do not mean a standardised procedure. In agreement with many other educationists and scientists, we see the scientific method as consisting of a network of various interdependent combinations, orders and numbers of aspects or elements of a ‘science toolbox’ (Wivagg and Allchin 2002). Within this framework, questioning and observing are two fundamental aspects, and this is another reason why this framework is particularly appropriate for studying student questioning. Our definition of an HDM method is not very different from scientists’ common perceptions of a scientific method, such as the depiction in the Berkeley University website (*The Real Process of Science* 2017). We merely include a few additional aspects that help us to see the dialectics of nature. It is “fundamentally materialist, though not mechanical, and concerned with interconnections and emergent order in nature, though not functionalist” (Foster, Clark, and York 2010, p. 249). As discussed by Levins and Lewontin (1985, p. 267), this method is not positivist—it is necessarily tentative and subjective, influenced by emotions, and interdependent with social, political, and economic systems. These interdependencies are complex, conflicting, and require attention from science educationists. However, this does not mean that we deny the existence of an objective reality or the existence of misconceptions, truth, lies, or right and wrong. The point, rather, is that, as Eleanor Duckworth (2012) says, “In science, the stuff is the authority”. Furthermore, we cannot understand physical reality as isolated ‘things’ independently of past things/processes: we need to study the historical relations between them.

When we do (natural/social) science, understandings are probabilistic and can be challenged, questioned, investigated, requestioned, and reinvestigated. They keep changing as contradictory or new evidence is identified. New evidence keeps being found, partly because physical reality itself keeps changing. In doing science dialectically, we need to investigate how conflicts—inherent physical opposing forces—drive processes, rather than thinking that processes follow basic, abstract ‘laws’. Due to interdependencies in physical reality, it is problematic to do science in an overly reductionist manner, looking individually at separate aspects of things or processes without subsequently reconsidering interactions with the larger context (Foster, Clark, and York 2010).

When we do the education research that we are describing in this study, we consider ourselves to be doing science, and furthermore, doing it using an HDM method.

According to an HDM framework, what is science education?

Using an HDM framework, we see science not as a set of ‘things’ or a bounded or independent ‘body of knowledge’, but as a process of doing HDM science, and we see science education as being concerned with teaching students to use this process and develop their ‘scientific temper’.

The quote by Hamid Ansari at the beginning of this paper was from a speech he made on ‘scientific temper’, which is mentioned as a Fundamental Duty in the Constitution of India. Scientific temper, as defined by Jawaharlal Nehru (1946, pp. 509–515), is similar to but more broad than most definitions of ‘scientific literacy’, in that rather than just relying on authority or faith, it includes the practice of using a scientific method throughout our daily lives to ask and search for answers to all sorts of questions. It must go beyond the domain in which science is professionally done, including the consideration of ultimate purposes, beauty, goodness, truth, and socio-political aspects. Inline with the method of HDM, it is concerned with exploring interdependencies, and it rejects a separation between social and non-human natural science. The kind of scientific temper (or scientific literacy) which we think is important, according to an HDM framework, is not concerned with individuals remembering concepts or performing science process skills such as remembering how to use scientific instruments. These are things that people can learn as and when the need arises—if they have sufficient motivation and scientific temper. Their learning can be through the use of a scientific method which includes both experimentation and communication (e.g. discussion and reference to literature). Scientific temper is a collective, interdependent property of people in particular environments with particular needs. Similar to Roth’s (2007b) definition of scientific literacy, we agree that it is thus an emergent process.

Following Paulo Freire (1968), we see the value of (both natural and social) science education in its possible role to encourage students to work together in order to question the status quo and become more active participants in trying to create a better, more just and equitable world. Countering this, there is a conservative effort to relegate the process of science to professional natural scientists, and to aim science education more at sifting and selecting students and teaching them to remember ‘the (sic) science content’, using cognitivist theories that prescribe some universal laws of development based on the cognitive structure of the mind [e.g. see Paul Kirschner, John Sweller, and Richard Clark (2006)]. However, according to an HDM framework, and in agreement with Anna Stetsenko and Igor Arievitch (2002), we do not find any convincing evidence for universal laws of development, and anyway we are more concerned with those who are being sifted out. We see less need for people becoming walking encyclopaedias and more need for people to question, critically analyse, and find physical evidence for or against what the encyclopaedia says. Researchers have objected to a science education whose main objective is selection: sifting most children away from becoming professional scientists (Roth and Lee 2002). But the situation is even more appalling if science education is also teaching children to stop doing whatever science they may be doing in their everyday lives.

Relation to similar frameworks, such as activity theory

Paulo Lima Junior, Fernanda Ostermann, and Flavia Rezende (2014) have analysed how Vygotsky used a dialectical materialist method and whether or how a number of researchers in science education have used similar methods. However, we agree with André Rodrigues, Juliano Camillo, and Cristiano Mattos (2014) in the forum response to this paper, that

Junior, Ostermann, and Rezende's categorisation of dialectical materialism is problematic and is not corresponding very well to that of either Marx or Vygotsky. Most importantly, they have misinterpreted Marxist dialectics as being just a rhetorical device involving 'thesis, antithesis, synthesis'. The authors of the forum response also point out that Vygotsky was less concerned with exploration of social historical interconnections than Marx was. However, Junior, Ostermann, and Rezende argued that Vygotsky's approach was to concentrate upon the analysis of activities and to look beneath appearances to search for actual explanatory, dynamic relations—which is characteristic of a dialectic materialist method.

Vygotsky tried to understand child psychology, development, and learning as purposive, goal-directed and mediated by material and symbolic cultural artefacts (tools and signs). For example, learning about a physical process observed in the environment could be seen as a goal-directed activity which is mediated by tools such as measurement devices which are material cultural artefacts, and languages which are symbolic cultural artefacts. This was extended and reinterpreted by Piotr Gal'perin and A. N. Leont'ev, who stressed the social, interactive nature of development and learning, and the creation of cultural rules that guide the mediation. This was further used to develop Cultural Historical Activity Theory (CHAT), for example by Yrjö Engeström (1999), which includes the dialectical relations between rules, community, and the division of labour, in addition to the subject/object mediation by artefacts in order to give rise to an outcome in an activity system. This highlights the dialectical relation between individual agency and social structures.

Our HDM framework differs from a CHAT framework in that we are not investigating goal-directed activity systems. Also, we do not define 'cultural' as being separate from non-human nature. As we discussed above, we see nature as being one inseparable unity of the human and the non-human. Similar to Activity Theory, we believe that historical (temporal) changes in physical reality are the root causes of changes in thought, that inherent, interdependent contradictions are driving forces of change, and that there is a dialectical unity of subject and object. However, we are not investigating goal-directed activities in which subjects (students or teachers) purposely transform or produce an object. The students (and ourselves, the teachers/researchers) are merely interacting with each other and with an object (a tree). Our effort was not to teach but to investigate student questioning in an open-beginninged and open-ended context. Thus our focus is on identifying and understanding dialectical relations inherent in the stuff (the tree, etc.) and the students and in their interdependencies with each other and the rest of nature/society.

How do our research questions relate to our theoretical framework?

- Our research questions demanded our investigation into the processes, interdependencies, and inner conflicts in the workshop session we were analysing. We asked these questions in order to understand the dialectics of what the students were doing in relation to each other, their environment, the teachers/researchers, and the larger nature/society context. This also required us to explore how our observations provide evidence to understand the nature of science and non-science.
- Since according to our framework, science is based on physical reality, we have chosen to study students in their direct interactions with physical stuff (the tree).
- Because we think science and questioning are driven by contradictions, we have chosen a particularly confusing tree, in which its inherent contradictions seem to be quite obvi-

ous: its variously coloured leaves, root-thorns, leaf buds which look like flowers, no fruits, an unknown name, etc.

- We focus on questioning because according to our framework, questioning is central to the process of doing science and science education. Because of the importance of observation and manipulation of physical stuff, we have chosen a context in which observation and manipulation will be possible and likely.
- We use an open-beginning approach because according to our framework, we need to encourage students to develop their own scientific temper. This includes questioning throughout their lives, which they are more apt to do if they have more freedom to define their own problems and areas for investigation than if they just follow the direction of the teacher.

Method of investigating student interactions

The context

Since we wanted to investigate student questioning, and we were not finding it in regular classrooms, we decided to focus on interactions between students in a context which we thought might lead to student questioning. We decided to conduct a workshop which would focus on an ornamental tree, variegated bhendi (*Talipariti tiliaceum*—formerly *Hibiscus tiliaceus*) in the garden of our institute, which has leaves of various colours: completely green, completely white, white with asymmetrical patches of various shades of green, red, red with white and/or green, various shades of yellow and brown, white with yellow patches, etc. (Fig. 1). Knowing that leaves need chlorophyll in order to do photosynthesis to make food, and that the presence of chlorophyll is indicated by the green colour, we wondered how the white leaves could survive. Therefore, because we found it to be odd, we thought this tree might be an interesting context that would encourage students to ask questions. None of the researchers were very familiar with this type of tree. A number of times during the analysis we had to go back outside to examine the tree and its environment in order to interpret the students' discussions and activities. We also had to do some internet research and investigations on the tree regarding its classification, flowering, thorn production, and other properties. Thus, we were continuously learning about the tree and its environment as we were learning about the students (and ourselves).

Fig. 1 The bhendi tree (variegated *Talipariti tiliaceum*)



Participants

The children in the workshop were Class VIII students (12–13 years old) from a neighbouring urban, government-aided school, which we chose because of its proximity and because most of its students were from lower-middle-class families of lower castes. For many years, researchers from our institute had been having contact with the school: teaching, conducting workshops, and interacting both formally and informally with students and teachers. The students' science teacher had already covered the topic of photosynthesis and chlorophyll in Class VII. None of the students had their own phone or home computer, and only a few had occasional access to internet. After an open invitation, six girls (Devki, Mansi, Mohini, Roshani, Srushti, and Vaishnavi) and five boys (Ashish, Kaushtubh, Ketan, Omkar, and Tejas) obtained parental permission and came to the workshop.

Five researchers acted as teachers during parts of the workshop and as observers throughout: Kranti (Project Fellow), raised in a Maharashtrian village 3 h from Mumbai, with degrees in agricultural sciences, Gurinder (a Ph.D. student), having 8 years experience as a science teacher, mainly in Punjab, Rafikh (a Ph.D. student), raised in a small village in eastern Maharashtra, Karen (a faculty member), from USA, with a Ph.D. in Biophysics and 30 years experience in science education in India, including about 10 years as a teacher of school students and/or teachers, and K.K. Mishra (a faculty member) from northern India, with a Ph.D. in Chemistry. The cultural diversity of this group is notable, as indicated by the various places of origin, gender, caste, class, language, and religious backgrounds, and it is significant that only one of the researchers come from upper caste backgrounds, and at least three of us are from lower-middle class backgrounds.

Throughout the workshop, the students spoke mainly in Marathi, which was the mother tongue of all of them. They were also able to understand, and to some extent speak in Hindi, but they were not able to converse in English. All researchers were fluent in Hindi and English, but only Kranti and Rafikh were fluent in Marathi (their mother tongue). Due to neo-colonialism and the structure of the present political economy, Hindi, officially the national language, is considered to be inferior to English (Kumar 1996). Marathi (a predominant language in Maharashtra) is considered to be equal to or at a lower level of hierarchy than Hindi. Since we wanted to observe students interacting and conversing with each other, we realised that we would have to allow and encourage them to speak to each other in Marathi. Therefore, we did not try to speak to them in English, and at first we did not say much in Hindi either. The students spoke to us in Hindi if they found that we did not understand Marathi. Our use of Marathi probably helped to somewhat lessen the power relations that created considerable divisions between us. In hindsight, we think the researchers should probably have refrained from speaking in English to each other in front of the students since this emphasized our position of dominance and interfered with the students' conversations.

Through classroom observations in the students' school, and discussions with their teachers, we found that the teachers do most of the talking, sometimes reading or asking students to read individually or in chorus from the textbook. There were typically 50–80 students in each classroom. Both teachers and students speak in Marathi most of the time, although the written work and answers on tests are in English. Teachers usually progress through each chapter in order, translating and explaining the English science textbooks in Marathi, and writing questions and answers on the board for the students to copy. Some teachers also ask questions orally and the students answer individually (with or without being called upon) or in chorus (for short answers and sentence completion), following

an IRE format. The answers have usually already been given by the teachers or the textbook. In the classes we observed we never heard more than 2 or 3 student questions per 40-min class. Not more than half a dozen different students ever gave individual answers to the teacher's questions. Before Class IX, demonstrations, laboratory sessions, group work, and activities done by students are very rare or non-existent. When we asked the students in our workshop, they said they had never done science experiments or activities in their classrooms.

Workshop plan

In order to encourage the students to freely converse with each other, we conducted a 30-min warm-up activity at the beginning of the workshop. After everyone introduced themselves, we all played a game together in an effort to become relaxed and talkative and get accustomed to the cameras. In the game each person (students and researchers) took turns to go off behind some bushes and change something in their appearance (e.g. move a watch from the right to the left hand), and then the others would observe and discover the difference. The game was played in a fairly non-competitive manner, without mentioning winners or losers. There was a lot of laughter and the students did become talkative and playful. During the game and afterwards, the students did not seem to pay much attention to the cameras, except at a few points which we will discuss. This may be because taking photographs and videos was not very uncommon in public places in the area in which the students lived. Also, we had obtained videotaping permission from the students and their parents beforehand.

We had originally planned the workshop in order to investigate a larger set of research questions than those which we are presenting here. Therefore the workshop was divided into the following sessions (spread over 3 days): Session (1) to collect the students' questions about the tree by writing them on A3 sheets as we heard the students ask them (in the garden of our institute); Session (2) to post the questions in the classroom of our institute and ask the students how they might find answers to their questions (we also wanted to find out whether they would mention aspects of the science process without us telling them); Session (3) to ask the students to categorise their questions according to how difficult or how long it might take to find answers; Session (4) to ask small groups of students to choose one of the posted questions and write plans for how they will investigate it; Session (5) to let the students go back outside and conduct their investigations, and record their data; Session (6) to ask the students to come back inside and write reports of what they did; Session (7) to present their investigations to each other and discuss the findings. Immediately afterwards we also conducted interviews with some of the students individually or in pairs. We informally kept in touch with some of the students after the workshop, occasionally meeting them on the street or in our library. Two years after this workshop, after most of our analysis had been done and an early draft of our paper was being written, we invited the same set of students back for another workshop to view the videos and discuss the analysis and paper (and to revisit the tree). In this paper we will focus on the first session, which occurred on 1 May 2014, near the variegated bhendi tree and lasted for 48 min.

Method of analysis

We are using the HDM method of doing science which we outlined above to do the research which we will discuss in this paper. Thus, we are analysing material evidence

(interactions between students, ourselves, and the environment) and finding dialectical conflicts which may be leading the students to ask questions and to do science.

During the workshop, we observed, took notes, photographed, and recorded using two simultaneous video cameras and two audio recorders. We used the recordings for an extensive transcription, translation from Marathi into Hindi and/or English, and analysis. Interviews with students were also video-recorded and analysed. We analysed the data using a Conversation Analysis method (Roth 2005) in which we tried to analyse how social meaning was constructed through the conversation, activity, gesture, and interactions between people as well as between people and the environment (particularly the variegated bhendi tree). We included ourselves as well as the students as subject/object of study, analysing the effects of power relations and differences between the students' and researchers' perceptions and understandings. We tried to understand and interpret students' meaning, reasoning, intentions, emotions, and signs of doing science or exhibiting scientific temper, concentrating on the progression of the group conversation rather than analysing the utterances of individuals in isolation. Of special concern were the evolution of conflicts and questioning and their interrelations and interdependencies. In line with our HDM framework, our identification and categorisation of questioning evolved as we analysed the data.

Analysis was done collectively by the authors and the other researchers and participants listed above as well as project staff Kalpana Sangale, Ankita Sawant, and Swapnaja Patil, all of whose help we gratefully acknowledge. The analysis required continuous referral back to the original audio and video recordings, rather than a dependence on the transcriptions and translations, which continued to evolve with repeated observation and analysis. Thus, the transcription, translation, interpretation, categorisation, and analysis were all interdependent and evolving throughout the research, requiring continual referral back to the data for verification of our interpretations (Lincoln and Guba, 1985). Doubts and disagreements were discussed and in some cases remained categorised as questionable, with alternative interpretations preserved. Photographs, and snapshots from videotapes were also used to analyse and understand students' meanings, expressions, and gestures. We also made maps of student movements during the session in order to interpret their discussions and activities. At various stages we shared and discussed tapes, transcriptions and our analysis with other researchers at our and other institutes.

Transcription notation

We use a transcription notation system which facilitates readability as a narrative. Therefore, we mention times of the beginning of each utterance rather than using other notations to indicate overlaps and pauses. The time is indicated in minutes and seconds from the time the students started walking to the garden. Since they had rushed out ahead of us, they were out of range of our audio recorders until 1:26, although they first came close to the tree at 1:18. When the identities of speakers are in doubt (due to the poor quality of the recording) we have put question marks after their names [e.g. Mohini (?)]. For the utterances, we use commas (,) to indicate short pauses, full stops (.) to indicate longer pauses (roughly one full stop for each second), question marks (?) for explicit questions, and exclamation marks (!) for emphasis. A dash (–) indicates that the speaker seemed to cut off their utterance before completion. We give all utterances in the language in which they were originally spoken, followed by translations into English in parentheses (). Translations are fairly literal, with explanations if necessary. In square brackets [] we describe actions, expressions,

and gestures. Students' questions are in bold. We will refer to the researchers as teachers throughout, and show all their utterances in italics.

Analysing what happened in the workshop

We observed and videotaped the students the first time they were brought to the area around the variegated bhendi tree, to see whether they observed it, what they said to each other, and whether they would ask each other any questions about the tree. The researchers/teachers kept quiet as much as possible, since we were interested in interactions between students without adult input. In case a student spoke to us directly, we tried to just vaguely acknowledge them. From the beginning, Kranti wrote each question she heard the students ask on an A3 size sheet of paper. These sheets would be needed for the subsequent sessions (discussed in a separate paper), when the students would work in small groups to select a question to investigate with some teacher guidance.

We will first discuss whether and how students asked questions at each Stage, giving a few episodes as examples. Then we will discuss the types of questions they asked, and the chronology of questioning. This will lead us to a discussion of whether the students did science, their agency, and the power dynamics.

Stage 1: Did the students ask questions spontaneously?

During the entire 48-min session there was literally no gap of more than 3 s when a student was not talking. From the beginning, the students spontaneously formed pairs and small, fluid groups of 3–5 (usually segregated according to gender) although they all remained within hearing distance of each other.

Under the conditions of Stage 1, in which the teachers were most indirect, Gurinder asked the students to come close to the bhendi tree, but without mentioning the tree, in order to be relatively open-beginninged. The boys, including Tejas and Kaustubh, walked past the bhendi tree to a Casuarina tree about 4 metres away. Apparently they were attracted by the label attached to its trunk (the label was not part of our plan and the bhendi tree did not have a label). The label contained the common name of the tree in Marathi, 'सुरु' (which is the same as its Hindi name) and in English, 'Mast tree', followed by the scientific name '*Casuarina equisetifolia*' and 'Family: Casuarinaceae'.

Our open-beginninged effort resulted in a situation in which the students did not 'perform' according to our expectations: they did not at first focus upon the topic we had planned. In the students' first conversation, they did ask some questions, but contrary to our plan, they were about the Casuarina tree rather than the unusual variegated bhendi tree:

EPISODE 1

1:26	Tejas: सुरु. मास्त tree. (Suru. Maast tree.) [reading from the label in Marathi and English]
1:27	Kaustubh or Ketan (?): काय आहे हे ? (What is it?)
1:28	Tejas: मास्त. (Maast.)
1:28	Kaustubh: [looking at the label] Mast tree. [pronounced मस्त, like the english word 'must']

1:29	Tejas: [after looking up to the top of the tree] मस्त tree! (Intoxicated tree!) [as he touches the tree trunk, loudly, jokingly, and smiling turns to the camera]
1:30	Kaustubh: मस्त tree! (Intoxicated tree!) [He smiles, then Ketan looks up to the top of the tree]
1:33	Tejas: [Tejas again looks up] तिथे कुठे ? (Where is it?)
1:35	Gurinder: [some distance away] इधर आ जाओ. (Come over here.)
1:38	a boy (Tejas?): मस्त! (Intoxicated!)
1:39	a boy (Kaustubh?): मस्त! (Intoxicated) [Tejas, Kaustubh and Ketan all look up]
1:40	Kranti: मस्त tree! (Intoxicated tree!) [gesturing to the Casuarina, then Tejas again looks up]
1:46	a boy: ये हिंदी का हे ? (Is it Hindi?)
1:46	a student: चढायला येत का ? (Can you climb?)

Thus, the boys collectively observed both the label and the tree top, and explicitly asked four authentic questions, without any teacher direction. The first explicit question, ‘काय आहे हे ?’ (What is it?) arose when the asker observed the label and/or heard Tejas read it, but realised that he did not understand what it was. Then they smiled naughtily, clearly because in their process of interactively decoding the text, they were confronting an amusing conflict between the English name and the similar sounding word in Hindi that means overjoyed, carefree, or intoxicated. This conflict between beliefs as to whether the word was Marathi, Hindi, or English was expressed as the question ‘ये हिंदी का हे ?’ (Is it Hindi?) at 1:46. It is interesting that the first thing that attracted them was this label—an artefact, rather than nature. From the interviews at the end of the workshop, we found out that there were no gardens anywhere around some of the students’ homes. Thus it may not be surprising that the bhendi tree was not initially particularly curious to them—the entire garden was new and interesting.

When Tejas asked, ‘तिथे कुठे ?’ (Where is it?) he was probably trying to see the top of the Casuarina tree, which was quite high. We think there was a conflict between his belief that the treetop was there and his observation that the treetop was not easy to distinguish amongst the other treetops. He probably looked up because he wanted to find out what the tree was, through direct observation, and its leaves were all at the top.

We take this episode to be an indication of the practice of considerable scientific temper, because the students engaged in an emergent, interdependent process of questioning, observing, communicating, and even touching the tree. Their analysis of the text was interdependent with observing the tree, which led them to the consideration—or challenge—of climbing it, which could be seen as their very physical ‘embodiment’ of the tree. Our analysis of this recorded episode led us (much later) to further investigate the tree names, and we found out that the English common name, ‘Mast tree’ was a mistake—Mast tree is actually *Polyalthia longifolia* (False Ashoka), which was cultivated because it has one main, tall, straight trunk which (nostalgically, for Europeans) resembled Mediterranean Cypress, and/or because it was used to make ship masts (although wikipedia now claims that it’s ‘purpose’ is to alleviate noise pollution). Thus it’s interesting that we initially thought we understood more about the tree name than the students did, but we later found out that even we were making a mistake. As we shall see, this was not the only time

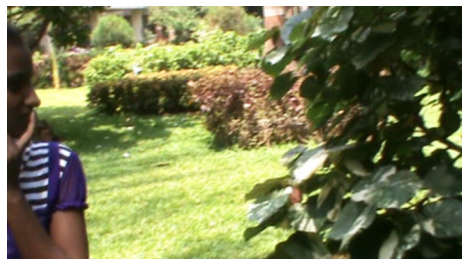
during our analysis that we felt humbled before the students, even though of course we are in positions of privilege over them. In this case, it was not that the students ‘knew’ more than us, but that they were practicing better science. They were observing and questioning the name which we had not even noticed, and even showing a curiosity and humour which was beyond us.

The girls had by this time gathered nearby, and they had the following conversation:

EPISODE 2

1:53	Mansi: काय ओळखायचं आहे ? (What should we identify/look for?)
1:56	Devki: ओळखायचं ? (Identify?)
1:56	Roshani: मग ते काय ते तर वृक्ष आहे. (Well there is that tree there (to identify/look at.) [pointing to the Casuarina tree, smiling]
1:57	Karen: [to Gurinder] Bring that paper.
2:00	Devki: हे जास्वंद आहे. (This is a hibiscus.) [pointing at the hibiscus next to the bhendi tree, then laughing]
2:02	Mohini (or Mansi (?)): चल! (Come on!)
2:02	A girl: हां जास्वंद. (Yes, It's a hibiscus)
2:04	Mohini (?): इथे काय exam चालू आहे ? (What's going on here—an exam?)
2:07	A girl: अरे हया इथे बघ. (Oh—look here) [probably referring to the hibiscus]
2:07	Roshani: [indistinct] पाने पाने ..कळत नाही का पाने. (The leaves—don't you know—the leaves) [at the same time Karen turns the camera to focus on the bhendi]
2:08	Devki: हे काय आहे ? (What is it?) [referring to the bhendi tree]
2:10	[Srushti turns and looks at the bhendi, with a finger on her teeth—Fig. 2]
2:11	Rafikh: तुला काय वाटतय ? (What do you think?)
2:12	Devaki: हे ना show च आहे. (This is an ornamental one—using the english word ‘show’ for ‘ornamental’)
2:14	Rafikh: Show?
2:15	a girl: Show.
2:15	a girl: This, is, tree. [slowly, word-by-word, in English]
2:19	Srushti: White पानांचं झाड. (White leaf tree.)

Fig. 2 Srushti looking at the tree: at 2:11 Srushti was filmed looking at the tree with one finger on her teeth. We think this gesture may imply that she was asking herself an unvoiced, implicit question, even though she did not voice any question or statement even afterwards



Our interpretation is that due to the prevailing power relations, it is expected that the students would try to figure out what the teachers wanted them to do. But they confronted a conflict when they saw that the teachers were not acting as they believed teachers should act. This led the girls to explicitly ask the question at 1:53. They began trying to identify the plants because they had heard the boys talking about the Casuarina tree and they believed that plant identification would be an educational or science kind of thing that should be done in this context. They were trying to play their part in the ‘school-school game’. However, since no researcher was initially taking on the full role of a teacher (e.g. giving directions and asking questions), the students themselves could and did talk to each other and ask each other questions. They also tried to answer their questions. This seems to be inline with what was claimed by Van Zee and Minstrell (1997): ‘Once students begin asking questions, a vigorous student–student dialogue may ensue if the teacher refrains from either asking or answering questions.’ But when the girls started trying to name the plants, they did not immediately try to name the bhendi tree, perhaps because it was unfamiliar to them and they were concentrating on playing a ‘school-school’ game in which they would succeed—if they knew the answers. This game may have temporarily prevented them from being more curious about more unusual things. However, as we shall see, the students gradually deviated more and more from the usual game.

Stage 2: What happened when the teachers started looking at the tree?

In Episode 2, at 2:07 (see above) Karen purposely looked at and turned the video camera she was operating towards the bhendi tree, and the girls did turn their attention to it. In hindsight, we think we were too quick in moving to this Stage of teacher involvement, and the students might have turned their attention to it even if we had not done so. Devki then asked the other girls the first question about the tree: ‘हे काय आहे?’ (What is it?). Note that for the other plants they were identifying, no one explicitly asked this question. Apparently in this case it was asked because the answer was not known by the asker. Devki was asking because she was confronting a conflict between the tree she was observing and trees that she had previously seen. In subsequent session she said that she had never seen any tree of this type before. We observed throughout the workshop that Devki tended to be one of the most dominant students. The girls’ smiles and laughter may indicate that they were amused or anxious or that they knew this game of identification was somewhat silly.

Although we had decided not to ask the students any questions or converse with them, Rafikh asked two questions in this episode and the students answered, assuming their usual role as students—with one student even formulating a sentence in English, as might be required in school (perhaps this was also to impress others, a common reason to use English, although she has perhaps instead succeeded in ridiculing English hegemony). The researchers had a hard time conforming to our own new rule of remaining quiet, since we were used to playing the talkative ‘teacher’ role, in which we maintain control over the proceedings by asking questions. However, for the most part we did manage, and almost all of the discussion in the initial session was between students. Our silence was made easier and more authentic by our preoccupation with filming and recording, as well as because some of us could not understand the students’ Marathi.

When at 2:19 Srushti named the bhendi tree ‘white leaf tree’, this was the first mention any of the students had made of the colours of the leaves. It indicates that, just as we did, she also saw the whiteness of the leaves as being remarkable—and contradictory. After this, (at 2:21) Mansi asked, ‘हे कोनते झाड आहे?’ (What tree is it?) [laughing] and another

girl repeated the question. It is interesting that although none of them knew its name, they invented various names: white-leaf tree, mixed-colour tree, and ‘show tree’. This required their agency as well as their realisation of lack of knowledge—a dialectical relation. We see this as dialectical because a realisation of agency is empowering while a realisation of incompetency (not knowing the name) is disempowering, so the two realisations are opposing each other. However, the act of inventing names requires both these realisations at the same time. Also, they may have realised that names have meanings and usually refer to some characteristics of the thing being named. This realisation may be facilitated by the cultural use of words with commonly known meanings even for people’s names (e.g. Roshani means light, Tejas means energetic, Devki means god-like, Kranti means revolution). The students’ passivity is imposed by their cultural standing as being lower class, lower caste, and non-english speaking (and female, for some), so we did not expect that they would realise that they had the agency to try to name the tree. Perhaps they would not have done so if they were talking individually, directly to a teacher/researcher.

It is also interesting that the students recognised the tree as a ‘show’ or ornamental tree, i.e. a tree which is bred, produced and commodified not for any use value except for decoration in gardens. This implies that they saw the tree as obviously having certain qualities—perhaps beauty, curiosity, or uniqueness—which are socially defined to have exchange value. It was clear that the tree was someone else’s property, and they initially assumed they were not supposed to touch it or disturb it.

At 2:44, after Roshani said it was a show tree, Mansi objected: ‘**हो ना मग show चे झाड आहे, हां मग त्याला नावं काहीतरी असेल, ना?**’ (Okay it’s a show tree, but it should have some name, no?). This could indicate a conflict between a belief that a general name is adequate and a belief that a more specific name is needed. And/or it could indicate a conflict between the belief that a girl can assign a name and the belief that she cannot. None of the students knew the common or scientific name of the bhendi tree, but (breaking the usual school-school rules) they did not directly ask any of the teachers, and they stopped talking about its name until (at 32:11) Roshani told Kranti to note down the question: ‘**हे झाड कोणते आहे ?**’ (Which tree is this?). Thereafter there was no talk about the name until (at 41:19) Srushti noticed another tree nearby, and asked Kranti, ‘**नाव तेच असेल, ना?**’ (It will have the same name, no?). This tree was a *Thespesia populnea*, known as bhendi in Marathi. The variegated bhendi is in the same family, Malvaceae, although it is a different genus. Kranti answered, ‘Don’t you know the name, bhendi tree?’ One or two of the other girls did know that the unvariegated tree was called bhendi, and they had used its leaves to make whistles. It was interesting that Srushti could tell that the two trees were from the same family, because the *Thespesia* is much taller and different in appearance. Both of them have cordate leaves with reticulate venation, but then so do a number of other common local trees, such as the peepal tree, as Tejas pointed out at 44:48.

At 3:39, the girls started talking about their plans, whether they would come for the workshop or go to their village for this summer vacation, etc. This was the only time we heard the students having a conversation that was centred on social issues rather than on what was in their environment. This conversation was also full of questions, although they were what might at first appear to be ‘non-science’ questions. We question this categorisation, since we think that asking why we should do science, and how learning is related to everyday activities, are actually integral parts of learning science. For example, at 4:08, in reply to Devki asking her whether she would come to the workshop the next day, Mohini said, ‘बघेन, तसा मला कंटाळा येतो.’ (‘[I] will see, anyway it [the workshop] is so boring.’) But at 4:17 Devki asked the other girls to continue coming to the workshop, saying, ‘मजा येते’ (It is fun.) To this, Mansi replied, ‘काय गं? मजा? इथे शिकायला येतो कि मजा करायला?’

(What? Fun? We are coming here to learn or have fun?), a rhetorical question indicating that she thought, perhaps based on her school experience, that learning is not or cannot be fun. This, as well as Mohini's rhetorical question as to whether an exam was going on, at 2:04, were both asked as a result of the girls' conflicting beliefs and observations as to whether the workshop and learning are or are not fun. This conversation ended at 4:54 when the girls noticed that Kranti was writing 'What is this?' and after discussing whether it referred to some tree, they again turned their attention to the tree.

An illicit experiment

At 2:26, Tejas was the first boy to ask a question about the bhendi tree (as he looked at and touched a leaf which was mostly white with a little green): **'रंग तर गेला नाही ना?'** (**Hasn't the colour gone?**). Another boy, Ashish, immediately said, **'हात नाही लावायचा रे, कळत नाही काय ?'** (**Don't you know that you should not be touching it?**) and Tejas moved back. We did not hear Tejas's question at the time, and in fact we did not hear many of the students' questions until we started analysing the videos. When we heard Tejas's question on the tape, we were puzzled as to the wording and what he meant. After spending many more hours of analysing the videos, we found the following two fragments, which led us to an understanding of his question:

EPISODE 3

- 6:26 [Tejas stands with his arm around Kaustubh, within 2 metres of the bhendi tree, both looking intently at its leaves (Fig. 3a)]
- 6:28 [With one hand holding the video camera which is focussed on the boys, one of the teachers (Karen) looks closely at the bhendi leaves, without touching them, and puts her finger to her cheek with an admittedly overacted, puzzled look (in order to encourage the students to look at the bhendi tree—but without actually asking them to look)]
- 6:29 [Tejas knocks Kaustubh's head to turn it away from the tree, towards Karen (Fig. 3b)]
- 6:30 [Tejas points towards Karen (Fig. 3c)]
- 6:41 [Tejas mimics Karen's gestures in a humorous way (Fig. 3d) (but without paying much attention to the bhendi tree), and they both laugh]
- ...
- 7:35 Tejas keeps looking at the bhendi leaves (Fig. 3e)
- 7:42 Tejas: अरे पुढे बघ. (Look in front) [to Kaustubh, as Tejas reaches out and scratches the green part of a bhendi leaf which has both green and white areas (Fig. 3f)]
- 7:44 Kaustubh: थांब ! (Stop!) [softly, as he leans out from behind Tejas, looking directly at the camera Karen is holding]
- 7:45 [Tejas quickly withdraws his hands from the leaf (Fig. 3g) and then turns to the camera]
- 7:46 [Tejas raises his head and stares at the camera, while Kaustubh turns his head down and away (Fig. 3h)]
- 7:47 Kaustubh: क्या है ? (What is it?)
- 7:48 Tejas: सफेद, हरा (white, green) [as he again touches a leaf, and then Kaustubh nods his head in agreement]
- 7:51 Kaustubh: Three colours. [looking at and touching the leaves]
- 7:53 Tejas: Three नाही. Four colours. (Not three. Four colours) [after this, the boys on one side and girls on the other side continue talking about the colours of the leaves]
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Fig. 3 An Illicit Episode: Tejas and Kaustubh doing an investigation to find out whether the green colour can be easily scratched off the leaves



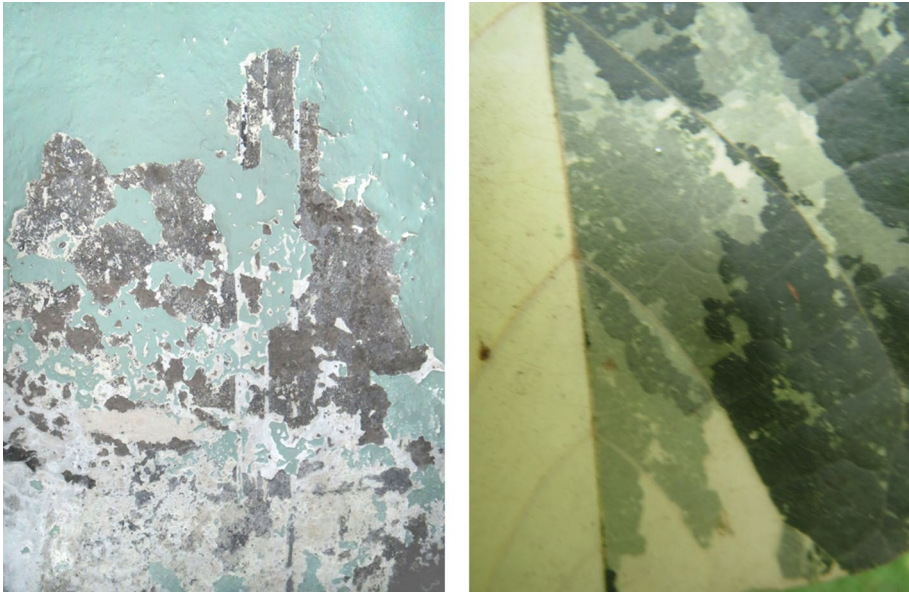


Fig. 4 Colour change? Paint chipping off a wall, compared to a variegated bhendi leaf

Our interpretation is that at 2:26 Tejas was asking an authentic question as to whether the leaves used to be green but had now lost some of their colour. He was confronting a conflict between the strange leaves he was observing and previous leaves that he had observed. The variegated leaves may have reminded him of the way a wall looks when its paint starts chipping off (Fig. 4), and by analogy he hypothesized that the green colour was chipping off the leaves. He wanted to test this hypothesis by performing an investigation: scratching the leaf to see if the green colour comes off easily. However, he had been warned by Ashish, and he was afraid that he might get in trouble if he touched or disfigured them. He did not think that his question or investigation was valid or was considered to be science in the eyes of teachers.

Demonstrating scientific temper, Tejas did not give up on his original question. At 7:42, more than 5 min after he first posed it, when Ashish was some distance away, he joined his friend, Kaustubh, and asked him to watch the teacher (Karen) and tell him if she looks at him while he scratches a leaf. Maybe Kaustubh knew what he wanted to do and was a partner in the investigation. In any case, he did help Tejas, and when he saw Karen looking he told him to stop. Then they each pretended in their own way that they were not doing anything wrong: Kaustubh looked down and away, and Tejas defiantly looked straight at Karen, with an expression of contrived innocence (Fig. 3h). After all this, Tejas and Kaustubh tried to behave themselves by returning to what they thought (or what they thought the teacher would think) was a more innocent activity—of just naming and counting the colours of the leaves—which is actually a less adventurous science investigation of the implicit question, ‘What are all the colours of the leaves?’ Interestingly, they also switched from Marathi to Hindi and English, as they conformed to the supposed requirements of ‘school-school’. This reminds us of an episode Shirley Brice Heath (1982) reported of a young boy internalizing his teacher’s inauthentic questions by asking, e.g. ‘What colour dat truck? What colour dat car?’ on the way home from his first days at nursery school, rather

than the authentic questions such as, ‘How da firemen know where dey going?’ which he asked during his pre-school-going days.

Colours of leaves

The students also had the following interactions regarding the colours of the leaves on the variegated bhendi tree. They were walking around close to the tree, observing it, and pointing at it as they spoke. By this time they were also touching and manipulating branches and leaves, although not plucking or disfiguring. They had become more relaxed and less worried about our expectations after seeing that we did not admonish them.

EPISODE 4

- 9:05 Vaishnavi: या झाडा वरचे सगळे colours बघायचे आहेत. Green, brown colour, white... (We should see all the colours on this tree. Green, brown colour, white...) [softly, to Srushti (probably no one else could hear), while looking at and pointing to leaves]
- 9:10 Srushti:... [inaudible—leans towards Vaishnavi, glancing towards camera]
- 9:13 someone [probably a boy]: Green! [as Devki goes away to pick up a *Champa* flower to make a ring for her finger, as Vaishnavi had done]
- 9:26 a girl: Pink पान आहे. (There’s a pink leaf.)
- 9:27 a girl: Pink. [as Vaishnavi moves leaves aside]
- 9:29 Roshani: Pink नाही. Light pink. (Not pink. Light pink.)
- 9:30 a girl: दुसरा colour देखो. (See another colour.)
- 9:32 a girl: Light pink.
- 9:34 Devki: Chocolaty.
- 9:35 a girl (Vaishnavi (?)): Yellow पान आहे. (There is a yellow leaf.) [waving at some leaves]
- 9:36 Vaishnavi [pointing at a leaf]: Brown.
- 9:38 a girl: Yellow. Brown.
- 9:39 a girl: Green.
- 9:40 a girl: White.
- 9:43 a girl: Pink पान आहे. (There is a pink leaf.)
- 9:44 Devki: Chocolaty colour पान आहे. Chocolaty. (There is brown colour. Brown.) [as she goes forward, bends down, and touches some leaves]
- 9:46 Mohini: Light pink. [leaning towards Devki and looking where Devki is looking]
- 9:46 a girl [Vaishnavi?]: Skin colour. [also leaning towards Devki]
- 9:47 Vaishnavi: Skin colour आहे बघ. (Look, there is skin colour.)
- 9:48 a girl: Brown. [Srushti has her hand on Vaishnavi’s shoulder]
- 9:50 a girl: Light pink.
- 9:52 a girl: Brown. Brown colour. [Vaishnavi puts her hand on Mohini’s shoulder]
- 9:54 Devki: मेहंदी colour. (Henna colour.)
- 9:55 a girl: मेहंदी colour नाही... (Not henna colour...)
- 9:59 Vaishnavi: Light green पान आहे. आणि dark green. (There is a light green leaf. And dark green.)
- 10:04 Roshani: Light green. Orange.
- 10:05 Devki: पान white नाही आहे मुळात म्हणजे. (The leaf is not [proper] white colour.)
-

- 10:07 Vaishnavi: माहित आहे थोडा वेगळा आहे हा. (I know, its quite different.)
- 10:08 Devki: घरांना असतो ना colour तसा. (The colour of the house—maybe referring to the building nearby)
- 10:09 Mohini: Brown. Light brown.
- 10:11 Srushti: xkq! [clicks tongue to say no!]
- 10:13 [Srushti takes Mohini by hand, goes to another part of the tree, and shows her a leaf]
- 10:18 Ashish (?): Golden.
- 10:20 Vaishnavi (?): आ घोड्याचा बघ ना ? घोड्याचा chocolaty colour ना तसा... (It looks like a horse, no? A chocolaty horse colour... [difficult to hear])
- 10:22 Mohini: मग तोच असेल. (Then that's it.)
- 10:23 Gurinder: क्या हुआ? (What is it?)
- 10:24 Srushti: वो पत्ते का colour कौन सा है वहां पे ? (What are the colours of the leaves there?)
- 10:26 Mohini: Dark colour.
- 10:28 girl: कौनसा ? (Which one?)
- 10:29 Mohini: तो brown सरखा आहे तो ना. Purple आहे तो. (Its not like brown, its like purple.)
- 10:34 Roshani: ये purple है. (It's purple.)
- ...
- 11:08 Devki: Golden नाही ते जरा सुद्धा. (It's most certainly not golden.)
- 11:10 Mansi: Golden.
- 11:10 Srushti (or Vaishnavi (?)): **Golden असा असतो ? (Golden looks like this?)**
- ...
- 12:29 Ashish: Golden colour आहे... (There is golden...)
- 12:32 Devki (?): नाहे golden! (There is no golden!)
- 12:34 Ashish: हा बघ golden. (It looks golden!)
- 12:35 Other girls: हा काये golden आहे !? (This is called golden!?)
- 12:37 Ashish: थांबा, तुम्हाला चस्मा आणून देतो. (Stop, I'll go get your spectacles!)
- 12:38 girl: दे. हा जा ! (Go get them!)
- 12:39 Girl: काये बोलला तू (What did he say?) [Ashish leaves and joins the other boys.]
- 12:42 Kranti: अरे भांडू नका. [laughing] (Hey don't fight.)
- 12:47 Tejas: हे काय आहे ? (What is this?)
- 12:49 Ashish: अळू. (*Alu*. (*Colocasia*)) [referring to the plants growing below]
- 12:52 Tejas: अळू नाही आहे. (It's not *alu*.)
- 12:55 Kaustubh: Nine च्या सूर्य प्रकाशत सगळे golden! दिसतात. (In 9 o'clock sunlight everything looks golden!)
- 12:56 boy: मी पाहिले वरती golden आहे. (The top part is golden.)
- 12:57 Ashish: मग तेच ना! त्यांना सांगून पटत नाय. (We told them, but even so they don't understand.)
- 13:00 Kaustubh: वर golden आहे ना. पिकलेली पान पण आहेत. (The upper part is golden. There are ripened leaves.)
- 13:25 someone from boys talking about ripened leaf [barely audible]

13:34	Roshani:... कौनसा है? (Which colour is...?)
13:34	Overlapping voices: Golden, yellow, brown...
13:36	Devki: [looks at the tree from a distance, then walks over to it, keeping her eyes on it, then reaches out to the leaves] Brown आहे. (It's brown.) [spoken while touching a leaf. Then she immediately turns and walks back]

This episode was actually a continuation of the conversation about the name of the tree and leaf colours which had started at the end of Episode 2. The students' effort to create a name for the tree had evolved into an effort to observe the tree more closely, which led the students to start naming the different leaf colours they saw (from 2:19 to 2:37). When they first started naming colours there may not have been any underlying question. They may not have doubted that they knew what colours of leaves there were. It seemed that one glance had revealed the colours. Only after they spent some time observing and stating one colour after another did they realise that they may not be observing all the colours or knowing all the colours' names or how many different colours there were. Their listing colours makes it clear that they were searching for colours, and were asking the implicit question, 'What colours are there?' At 9:05, Vaishnavi made this question explicit, but she was whispering privately to Srushti. After the students continued observing and naming various colours, Gurinder asked Srushti, 'What is it?' when he did not clearly hear what she was saying. Srushti replied, loud enough that all could hear (at 10:24), 'वो पत्ते का कलर कौन सा है वहा पे' (What is the colour of that leaf there). This made the explicit question accessible to the entire group, and they continued to investigate colours. Thus, we see this as an example of a discussion of an implicit question which got stated explicitly later on.

This type of process of observation may not be uncommon: at first glance thinking that we know what something looks like until we look more deeply and find out that things look differently and that we do not know or we disagree with each other about what we are seeing.

Thus the students' questioning emerged through what we claim is an HDM process. That is, it was based on several internal conflicts regarding the material that they were observing and interacting with: (a) a conflict between knowing what colours of leaves there were and not knowing what colours of leaves there were; (b) a conflict between observing a colour and not knowing what name to use for that colour; (c) a conflict between knowing that leaves are normally green and observing leaves of unusual colours; and (d) conflicts between different students regarding the colours of the leaves. In this process, implicit questions emerged and became more explicit.

Here again we see that the students were not just questioning and discussing but also investigating the tree in order to answer their questions. In this case, they were observing, identifying, classifying, communicating, and naming the colours of the leaves. At the time, we were surprised that they were so involved in investigating and arguing about the colours. We claim that their arguments were not just a matter of not knowing or not agreeing as to which colours there were—they were also not knowing what names to use for the colours. The words they chose to use to describe colours are very interesting. Many of the Marathi words for colours are derived from plants and nature, but instead of using these, they tended to use English words—using more English here than at any other time. This is not surprising, since the hegemonic English names of colours are probably one of the first things that they were taught in school, and using English conveys social status. They later told us that 'chocolaty' is Marathi, and was the only word they knew for

brown—apparently the original Marathi words have decreased in usage. However, as with tree names, they also took the agency to invent their own names for colours, based on other things with similar colours, such as a house and a horse.

It was also interesting that although the most common leaf colours were various shades of green, white and reddish (in that order), the students were concentrating particularly on browns and golden. We doubt that it is just coincidental that these two types of colours also have important social/economic significance. ‘Golden’ signifies a colour as well as the characteristic of being made of gold, which is of course extremely important to the students (and all of us) as a mysterious dialectical commodity which is a use value/exchange value. Gold is not what it appears to be: ‘*Thus much of this will make black white, foul fair, Wrong right, base noble, old young, coward valiant...*’ The browns have connotations which (often erroneously) signify skin colours, races, and castes, and the students explicitly referenced this in using the terms, ‘skin colour’ and ‘mehandi’ (henna, the dye that is applied to decorate hands and dye hair). There may be a contradiction between what one perceives one’s own skin colour to be and what one perceives a leaf’s colour to be. It may be considered demeaning to perceive that the colour of a person’s skin is actually darker than ‘skin colour’. The apparent tint depends on the social (cultural) context as well as the surrounding colours and other aspects of the physical context. As Kaustubh pointed out at 12:55, the colour of an object depends on the light which it reflects. For these reasons, it is not easy to identify these colours.

Some other examples of student questioning

The students also asked and investigated the questions, ‘Does the tree have thorns?’ and ‘Does the tree have flowers?’ Although they might at first appear to be trivial, these questions were rather difficult to answer because the tree had unusual ‘root thorns’ and peculiar stipule buds which resembled flowers. Having flowers is a process which occurs over time, not a thing that exists at one particular time. Since flowering may be at various stages of development, it may be difficult to find evidence for it. The students investigated these questions by handling, observing, reasoning (including analogic and inductive reasoning), and communicating with each other.

A 10 second example of this is shown in Fig. 5, in which Mansi demonstrated genuine critical thinking by doubting what she heard her friends say because it was contradictory to her own observations. This led her to investigate by looking more thoroughly for thorns, finding them, and then changing her belief. If the circumstances had been less conducive to the expression of scientific temper, she might have just believed what her best friends

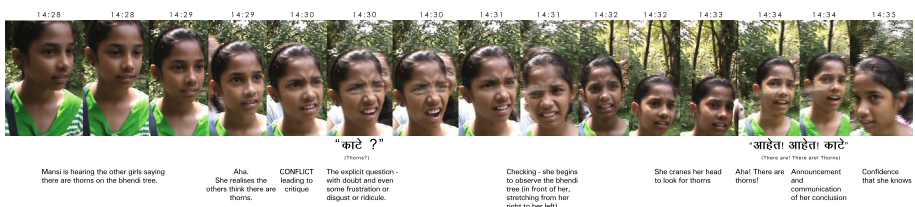


Fig. 5 Mansi doing a 10 second science investigation: a time sequence of photo grabs from a video recorder which was being held amongst the branches of the bhendi tree, facing Mansi. The time in minutes and seconds is shown above and Mansi’s utterances are shown below, along with our interpretation of what she was doing and thinking

were saying without looking. In this and other examples, the students demonstrated good observation skills and authentic discovery. In fact, they were more observant than we were. Perhaps our previous ‘background knowledge’ had constrained us to be concerned mainly with the leaves, and therefore we never noticed that the tree had thorns.

This dialectical process of questioning arose partly because the material stuff the students were observing was itself dialectical: the leaves were in the process of changing colour as they developed and every leaf was different from every other leaf. The leaves were not inherently members of separate, individual categories. The same colour appears to be a different colour, depending on the social context and the light and shade and the other colours surrounding it.

Did the students discuss and ask questions about the bhendi tree because they noticed us looking directly at the tree? It is hard to tell, because we looked at the tree a number of times, and we noticed a variety of reactions: e.g. they began to discuss the tree (at 2:07); they changed their focus from the tree to us (at 6:28); or they walked away from the tree (at 7:10, although in this case we are not sure if they had just seen us looking at the tree). In any case, they did look at, discuss and ask each other questions about the tree before Stage 3, when we asked them to observe.

Stage 3: What happened when students were asked to observe?

The first time we directly asked the students to look at the bhendi tree was long after they had already started looking at it and talking about it, at 17:56 when Karen said, ‘अच्छा इधर आओ, ये देखो, ध्यान से देखो.’ (Come here. Look at this. Look carefully.) [referring to the tree in general]. Devki responded by coming close, looking carefully, and saying, ‘कहा क्या है ? ये wow तिथे कित्ती छान आहे! ते बघ ते एकदम असं गुलाबी गुलाबी white आहे ते. खाली अस खूप छोटी छोटी. खूप छान दिसतंय.’ (Where? Oh wow! How nice it is there! Look there—that pink-pink white is so nice!)

Devki continued to make a big effort to observe and state her observations to Karen, who was focussing the camera on her. At one point she congratulated herself: ‘ये देखो यहां hole है... काय निरक्षण करतोय आपण! वाह वाह! शाबाश! शाबाश लडकी, शाबाश!’ (Look, there’s a hole here... [then walking away] What an observation I’ve made! Hurrah! Very good! Very good girl, very good!) (at 22:35). She seemed to have fallen into the teacher’s game, telling her observations in order to please the teacher. Although we might think that what she said actually mocks our intentions, it is doubtful that she was purposely mocking us, considering her interactions with us throughout the workshop. Also, she was talking about observations of things that were quite remarkable and that conflicted with what one might expect to observe.

We see some interesting changes in what the girls did and said before and after they were explicitly told to observe the tree. While they were actually looking carefully at the tree even beforehand, afterwards they continued looking and began stating one observation after another without asking as many questions. This was an unexpected result. We thought that if we asked them to observe they would observe more closely and if they observed more closely they would also ask more questions.

Devki had asked 10 explicit questions before 17:56, although only two of them were related to the bhendi tree. But after she was asked to observe, she did not ask any explicit question until after 29:52. More significantly, she started stating observations about different topics without pausing to answer or further investigate any one of them. Our interpretation is that making an observation became an end in itself, because it satisfied the

teachers' assignment. After being asked to observe, her main implicit question seems to have become, 'What else can I observe?' Her observations before she was asked to observe seemed to be less contrived, more spontaneous, and maybe even more relevant, important, or basic (although perhaps also simpler).

Stage 4: What happened when students were asked to ask?

The first time we asked any of the students to ask questions was at 29:52 when Karen said to the girls (in Hindi), 'Any more questions about these things?' Interestingly, they did not react by just trying to think of questions, they turned to the tree and observed it. Mohini started looking at and prying apart some leaves, but when Karen directly asked her, 'Hmmm?' she investigated a little more, but then stopped and said 'No.' and walked away. But as the following dialogue shows, Devki reacted differently when she was asked to ask. She generally appeared to be more confident of herself and talkative, even as she tried to speak in Hindi, which she was not able to do very well:

EPISODE 5

31:22	Devki: [clicks her finger as if she got an idea] 'Ant उस पान eat को करती है.' (The ant is eating this leaf.) [to Karen]
31:26	Karen: 'हाँ.' (Yes.)
31:29	Devki: 'ये देखो छोटी छोटी मुंग्या आहेत.' (Look here—there are little tiny ants.)
31:32	Karen: 'तो प्रश्न है इसके बारे में?' (So do you have any questions about this?)
31:36	Devki: 'Leaves को—ant eat करती है क्या?' (Do ants eat these leaves?)

She may have clicked her finger because she suddenly put two observations together—her previous observation of small holes in the leaves and this observation of ants. Although she has stated it explicitly upon request, we don't know whether the question of whether ants eat leaves is an authentic question in her mind. This is an example of how just because a question is explicit, it does not necessarily mean that it is more of a question than if it were just implicit. In this case we did not explicitly discuss with the students whether or not this is an authentic question, but we did have such discussions on some implicit and explicit questions related to the leaves. We found that it is not easy for students to identify which of their own utterances are really questions or questions with answers they do not know. They often seemed hesitant to say that they were not knowing the answers.

This episode is an example of one of a number of episodes which made researchers feel embarrassed while analysing the videos. Although we did not speak as much as we usually do when we are teaching, in hindsight it seems that we were speaking too much, interrupting, and also making it difficult to hear what the students were saying at a number of places in the recording because we were talking to each other. In this case Karen was asking Devki to ask a question at a point where it was actually unnecessary, since Devki had already been asking questions. Furthermore, Karen's question was both didactic and leading. Exercising her power over a student, she seemed to be making Devki turn her former statement into the form of a question. On the other hand, one could argue that a useful role

for a science teacher is to try to make students' implicit questions more explicit, as we will discuss in the conclusions.

Devki proceeded to observe and come up with more questions based on her observations. Between 29:52 and 46:00 she asked six explicit questions, all about the bhendi tree or the insects on it. One was the implicit question (around 40:00) which she also investigated: 'Do the leaves hold water?' She made a cup out of a leaf with assistance from some other girls, and tested whether water passed through the leaf, was absorbed, or was retained.

Significantly, we also found that in both Stages 3 and 4, the student–student interactions decreased, interactions between one teacher and one student at a time increased, and the student work became more individual, as is shown in the case of Devki. We suspect that this decrease in collaborative work between students is one of the factors that led to a decrease in investigating.

Towards the end of the session, when the boys were asked if they had any more questions, they began dictating them quickly one after another to the teachers. Some of these questions appeared to be recollections of questions which had previously been asked during the spontaneous discussions. The students were still standing right next to (or inside) the tree, observing and touching it, which must have helped them remember or frame new questions.

Some of these questions did not appear to be related to each other. For example, (at 43:13) Ashish dictated the question: 'या झाडाचे रंग वेगवेगळे कसे काय?' (How is it that the plant is having different colours?). Immediately afterwards, (at 40:20) Tejas glanced at the base of the bhendi tree and dictated: 'या झाडाची मुळे अशी बाहेर का आली आहेत?' (**Why do the roots come out above ground?**). There was no further discussion on this topic; immediately afterwards Kaustubh showed Tejas a leaf bud and Tejas asked a question about it. These questions do appear to be authentic, although some of them appear to have been framed in order to satisfy the teachers' specific assignment rather than as part of a process of investigation.

In other cases, one student's question seemed to have been influenced by other students' questions. For example, questions about whether leaves were one colour or another colour had gradually evolved, and probably later led Ashish (when he was asked to ask questions) to state the question (at 44:25): 'ये झाडावर जास्तीत जस्त किती रंगाची पाने अस्तात ?' (**How many different colours of leaves can grow?**). Perhaps this is what then led Omkar to state the rather different question (at 45:12): 'हे झाड जेव्हा वाढतं तेव्हा रंग का बदलत ?' (**Why does this tree change its colour as it grows?**). The initial questions were quantitatively similar to each other: they differed only with regard to the value and number of colours (Is it golden? Is it brown?). But, although it is related to leaf colour, the question about why these colours change over time is a qualitatively different sort of question. This could be an example of a dialectic change: how the gradual, quantitative evolution of questions leads to a new question which is qualitatively different.

What kinds of questioning?

Questions can be identified and defined in terms of forms and functions, meanings, causes and effects, answers, actions, the intentions of the asker and/or the interpretation of the hearer—which may be very complex and difficult to discern. Based on our HDM framework, and since we are interested in the role of questions in the process of learning, we are more interested in the process of questioning than in identifying particular questions

as forms or entities in themselves. Thus we have to analyse questioning in the context in which it occurs. Our categorisation evolved as we analysed our data, and we found that the questioning could be defined as the following overlapping categories. We will also discuss how the dialectical nature of each type became clear.

Explicit and implicit questioning

In the languages we have used in our studies (Marathi, Hindi, Punjabi, and English), explicit questions (also called direct questions) may be identified by the use of WH signifiers (who, what, why, where, how), word order, or by the use of a typical inflection or rise in intonation on a particular word, all indicated by question marks when the questions are transcribed. Some authentic questions are not asked with any of the above indicators.

During the beginning of the workshop we thought the students were tending to make statements rather than ask questions, but we thought maybe there were implicit questions behind their statements. For example, they were saying that the leaves are white, pink, brown, or that one leaf is thinner than another or that fallen green leaves become yellow as they become old. Behind these statements they may have been asking themselves, ‘Which colours of leaves are there?’ ‘Is this leaf thinner?’ and ‘Why are the leaves different colours? Do they change colour?’

However, when we later viewed and analysed the tapes, a different picture emerged. We found that although it was sometimes difficult to determine which utterances were questions, there were certainly many more questions than we had first thought. But it also became clear that we had to include and distinguish between relatively explicit and implicit questioning, as well as relatively authentic and inauthentic questioning.

We have found two main types of implicit questioning:

- (a) Verbally expressed, but not in the form of an explicit question (‘I wonder if this is really a flower’, or ‘This is a flower... No, this is not a flower’ both imply that the speakers have the implicit question, ‘Is it really a flower?’)
- (b) Expressed, but not verbally (a quizzical facial expression, e.g. Srushti, Fig. 2)

Perplexity may be expressed in many nonverbal ways. For example, a quizzical look may be indicated by furrowing brow (Fig. 5), raising eyebrows (perhaps just one eyebrow), opening eyes wider, glancing to the side, or by smiling or opening the mouth, as in surprise. There are various gestures that may indicate perplexity, such as shrugging, raising and turning a hand inwards, pointing, scratching one’s head, putting a finger or a pen on one’s teeth or lips (Srushti 2:11), or various kinds of fidgeting. It is only in the context of the process of social interaction that such signs can be analysed and understood. We saw examples of all of these in our workshop, and they helped us to identify and understand the process of questioning.

Implicit questions might be either conscious or subconscious, but we will not try to distinguish between the two. Also, we are not here concerned about questions which are consciously formed, but not expressed in any form (e.g. thinking in one’s inner voice, ‘Is it really a flower?’, but remaining silent and inexpressive), which are also called covert nonverbal questions (Greg Kearsley 1976).

Implicit questions can be included in what Vygotsky (1966) called unvoiced, internal speech, which he distinguished from two types of audible speech: private and external, depending on whether it is directed primarily to oneself or to others. Vygotsky also



Fig. 6 Srushti’s internal (implicit) question as to whether there are flowers becomes externalised in a question: **a** at 15:55 she looks frustrated; **b** at 16:07, fidgeting and **c** at 16:12, explicitly asking herself whether there are flowers

identified a process by which learners hear external speech (perhaps of a teacher) and then personalise it by talking aloud to themselves, and finally internalise it fully by ‘self-verbalising’, talking silently to themselves. This is a dialectical process, in which the personalisation includes implicitly or explicitly confronting conflicts between the learners’ and teachers’ beliefs.

We propose that in the process of student questioning, this sequence may sometimes be reversed. One example we found of this was when Srushti seemed to have a conflict—an internal question about flowers. The conflict arose between what she observed and her prior conception of the definition of a flower. (Even her prior conception of what a flower is may have been unclear or conflictual.) The things that appeared to be flowers were somewhat different from other flowers in her past experience. But they were also similar. She could not fit them into her pre-conceived categories. We interpret this as an example of a self non-identity type of HDM logic. They were flowers and simultaneously they were not flowers. She expressed the conflict as an implicit question of type (b), expressed nonverbally through fidgeting and an expression of frustration (Fig. 6a, b). A few seconds later (Fig. 6c) she asked herself out loud, looking at the tree, the private question, ‘अरे आहेत कि नाही फुले?’ (Hey, are there flowers or not?) [looking directly at the buds (Fig. 7)]. Then

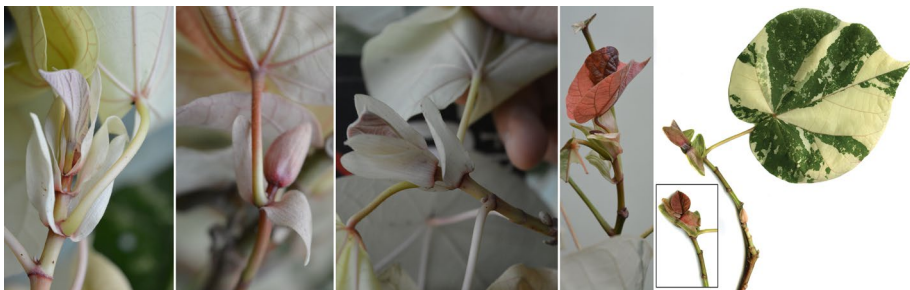


Fig. 7 Possible flowers: it may be difficult to immediately tell whether these plant parts are flowers, leaves, flower buds or leaf buds. Some of them are actually leaf stipules. Immature stipules can be pried apart to reveal tiny, folded leaves inside. We have never observed actual flowers or fruits on this tree, although we have seen them on other specimens of variegated bhendi

she took Mohini by the hand, pulled her to the tree, showed her some buds and at 16:23 asked her out loud the external (explicit) question, ‘हि फुले आहेत का?’ (**Are these flowers?**)

As Piaget (1923, pp. 1–29) also pointed out, people, and especially young children, have a tendency to sometimes use an audible ‘internal’ speech, in which they ‘talk to themselves’ rather than to communicate with others, even though an audience may be required. We noticed many examples, in addition to this private (internal) question Srushti asked, in which students appeared to be asking their questions to themselves. We think this is an important part of the process of making implicit questions explicit. Perhaps forcing students to be silent inhibits this process. In typical classrooms, students’ implicit questions may not evolve into personal or explicit questions because students are not allowed to talk to themselves or to each other. Attempting to individualise, internalise, and cerebralise the inherently social and environmentally interdependent process of learning may be self-defeating. Does such individualisation necessarily increase as teachers take on more explicit teaching roles in the classroom—or is there some way that teachers can try to circumvent it?

It may be difficult to say that an implicit question occurs at a particular moment, since it may be formed in the inner-mind before it is expressed in any way, and also it may evolve over a period of time. For example, as we mentioned above, the implicit question ‘What colours of leaves are there?’ gradually evolved during the naming of colours. This is also an example of a question that existed implicitly before it was made explicit.

Both explicit and implicit questions may be ‘group questions’, which are formed by two or more people interacting with each other. In the case of explicit group questions, two or more people may verbalise the same question at the same time, or one person may finish the question another person started. Questions may get clarified or modified as they are stated by more than one person. An example of an explicit group question occurred at 43:14 when Gurinder did not understand the question Ashish dictated to him in Marathi and the question was translated to Hindi simultaneously by Ketan and Tejas and then repeated in a slightly different form in Marathi by Rafikh as he wrote it down. In the case of implicit group questions, several people make utterances, gestures, etc. which imply that they are working together to ask the question (e.g. ‘What colours of leaves are there?’ was an implicit group question). This is an example of ‘unconscious collective consciousness [which emerges] from the embodiment of experiences in an inherently social and material world’ (Roth, 2007b)—i.e. it emerged from the group physically interacting with the same tree. Translations between languages played an important role.

Authentic and inauthentic questioning

Like explicit questioning, implicit questioning may be authentic or inauthentic. We define questioning as being authentic if the askers realise that they are not very sure of the answers. For example, at 2:08 Devki asked her friends the explicit authentic question, ‘What is it [the tree]?’ and we later confirmed that she did not know its name. Also, all the questions in Episode 1 we classified as authentic. Of course, this classification is not a binary—there is a range of authenticity.

Rhetorical questions are one type of inauthentic question, if the askers think they know the answer. For example, at 33:49 Tejas said: ‘**Blue कैसे दूढ रहे हो? Blue कधी असतात का झाड?**’ (**Why you are looking for blue [leaves]? When are plants blue?**). This comment is also interesting in that it indicates that Tejas has judged that this is not a question worthy of investigation, presumably based on his past observations. Evaluating the importance and

relevance of questions is important in doing science, and therefore this is a sign of scientific temper. Rhetorical questions are also explicit, as shown here by the WH signifier and the inflection. They are usually asked in order for the asker to build an argument, and therefore Dillon (1983) has called these types of questions ‘expressive/argumentative’, or when the asker also answers, ‘self-answered’. In agreement with Dillon we find that these types of questions are very common—in some discussions they are even the most common type of question. Sometimes they may be addressed mainly to oneself, as if one is thinking aloud and considering conflicting ideas, which points to their dialectical and emergent nature: being statements and questions all at once.

Confirmation questioning is another example of rather inauthentic questioning. A confirmation question is often a statement with a ‘, no?’ appended to it, which makes it an explicit question. An example was Mansi’s question at 02:44: **‘हो ना मग show चं झाड आहे, हा मग त्याला नाव काहीतरी असेल, ना?’** (Okay it’s a ‘show’ tree, but it should have got some name, no?). Perhaps the last word is added in order to soften the statement or make the hearers more likely to agree—forming a leading question (e.g. at 3:50 Devki said to Mansi, **‘मग ये इकडे, ना?’** (Then come alone, no?). Or, it could be an emergent question: the asker began to make a statement, but then decided to change it into a question as it was being voiced. At what point was it a statement and at what point was it a question—or was it always a statement in the process of becoming a question, or both, or neither a statement nor a question?

Both rhetorical and confirmation questions may have some implicit authenticity. Rhetorical questions may be requests, inviting the hearer to agree or react (Francisca Snoeck Henkemans 2009, p. 16). Confirmation questions may be asked because the asker has some lingering doubt, or wants to check whether the hearer agrees. There seems to be a dialectical logic to such processes of questioning, and we cannot say categorically whether they are authentic or inauthentic. Therefore, we have categorised some rhetorical and confirmation questions as both authentic and inauthentic.

Investigatable and non-investigatable questions

Investigatable questions were defined by Christine Chin (2002) as those that ‘allow students to generate and collect some original data, analyse and interpret their findings based on these data, and finally make a conclusion that addresses the investigative question posed, on the basis of available first-hand evidence.’ We agree to this definition—except for the word, ‘finally’ and the implication of steps in one particular order, rather than a network of mixed-up aspects (which cannot even be separately distinguished in time). Our identification of questions as being investigatable was often verified by evidence that the students actually did investigate: they collected data in an effort to find answers. For example, they searched for and identified various colours in order to answer the question, ‘What colours of leaves are there?’ and they tested the thickness of leaves by feeling them in order to find out whether some leaves were thinner than others.

Basic questions of reality are one kind of question that is relatively non-investigatable. These are similar Piaget’s (1923) definition of ‘questions of reality’. For example, at 38:23 Roshani asked, **‘कोणाला मिळाले हे?’** (Who found this [the eggs]?) We thought in this context this question was too simple, specific, and inconsequential to be investigatable. Our classification also depended on how the question was answered, and in this case the answer was clear and uncontested.

Questions of language may also appear to be relatively non-investigatable, and we have tentatively classified them as such. Some examples are, ‘ये हिंदी का है?’ (Is it Hindi?) asked by a boy at 1:46, and ‘काट्यांना काय बोलतात ग?’ (How do you say thorn [in Hindi]?) (Mansi, 14:27). Of course even these sorts of questions are actually investigatable from a linguistics, historical, and cultural perspective. Here again, our classification depended on whether the questions were investigated by collecting evidence that went beyond simply asking an authority.

Rhetorical, procedural, confirmation, and clarification questions are also non-investigatable. Procedural questions were about what the students were doing, or were supposed to

Table 1 The distribution of questions students asked on each topic

Topic	Explicit questions	Implicit questions	Total questions
Bhendi leaves	37	15	52
Bhendi flowers and fruit	12	0	12
Bhendi thorns	5	3	8
Other aspects of bhendi tree (identity, branches, roots)	19	3	22
Other plants (causaria or colocasia)	11	0	11
Insects (ants or eggs)	24	2	26
Social talk (e.g. where do you live?)	12	1	13
Figuring out what to do (e.g. What should we identify?)	15	1	16
Not sure what topic (e.g. what?)	2	0	2
Total questions asked by students	137	25	162

These are non-overlapping categories

Table 2 The distribution of different types of questions

Students' questions (total)	162
Authentic questions	140
Investigatable	73
Procedural	23
Clarification	22
Basic questions about reality	16
Questions of language	7
Inauthentic questions	33
Rhetorical	25
Confirmation	10
Teachers' (researchers') questions to students	44
Clarification (authentic)	20
Asking to ask questions (authentic)	8
Probing (mostly authentic)	9
Rhetorical (inauthentic)	7

Some students' questions belong to more than one category. Also, in case we could not decide how to categorise a question, we have assigned the question to more than one category (e.g. there are 11 questions for which we were not sure whether they were authentic or inauthentic so they are included in both categories). The terms are as defined in the text

be doing. Clarification questions were similar to confirmation questions, but were more probing and authentic, with the askers being more unsure of the answers.

Chronology and distribution of questions

Upon analysing the 48-min session by the tree, we heard the students make 522 utterances, of which about 162 were questions. We define an utterance as any talk made by one person which is more-or-less not interrupted by another nearby person’s talk. Each utterance was at least one word, more often a short sentence or two, or rarely, more than 25 words long. In Tables 1 and 2 we show the distributions of the different types of questions. Rather than claiming that these numbers are precise or significant in themselves, our objective is to give a general idea of the variety, bearing in mind that the classifications are very approximate (in cases of doubt, we may have assigned a question to more than one category.) Nevertheless, we think it is significant that we heard the 11 students ask more than 3 questions per minute, which compares to the total of 3 questions that we heard their entire class of 61 students ask in a 40-min classroom period that we later observed with their usual teacher conducting a science class. Also, there was no student who did not ask any investigatable questions, showing how collective the session was, even though no one made any effort to involve all students.

We see that the students asked a large number of authentic questions, more than half of which were investigatable (73 of 140). This occurred even though we never talked to the students about investigations or mentioned that we would like them to ask questions for which they could somehow find answers. Their investigatable questions were on a variety of topics (Table 1), but more were on the bhendi leaves than any other topic, in agreement with our hypothesis that they would find the leaves questionable.

How many questions at each stage?

Figure 8 shows diagrammatically how the questions and topics of discussion were distributed over the 48-min session. We counted 287 student utterances before we directly asked the students to observe (at 17:56, when Stage 3 began), of which 72 (about 25%)

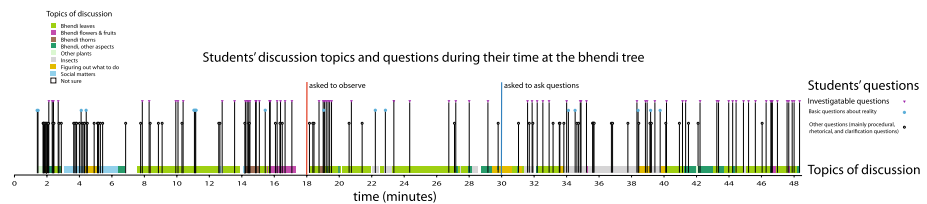


Fig. 8 The distribution of students questions and topics of discussion throughout the 48 min session near the bhendi tree. The colour strip at the bottom indicates the topics of discussion between the students. Just before 19 min, two different groups of students were discussing different topics, and this is indicated by double colours. Each question asked by a student is shown by a black bar at the time it was asked. The longest black bars (labelled with purple triangles) are investigatable questions, and the intermediate length black bars (labelled with blue circles) are basic questions about reality. The teachers first asked the students to observe the tree at 17:56, and we first asked the students to ask questions at 29:52. These signify the transitions between Stages 2–3 and 3–4. The transition between Stages 1 and 2 may have occurred at different times for different students, between 2:07 and 6:28. (Color figure online)

were questions. During Stage 3, the students made 86 utterances, 24 of which were questions (28%). During Stage 4, which began (at 29:52) when they were first asked to ask questions, we heard the students make 151 utterances, of which 66 were questions (44%). We suspect that the students may not have been able to ask so many questions in Stage 4 if they had not already spent more than half an hour observing and discussing the tree.

Significantly, there were a large number of explicit investigatable questions even before Stage 3. It is interesting that between 1:15 and 3:00, we counted 49 student utterances, of which 18 were questions (all explicit), and this included 7 questions about either the leaves or some other aspect of the bhendi tree. There were four questions about the identity of the tree, one about the absence of colour, one rhetorical question about not touching it, and one incredulous repeat of another student's question. Over the 48 min, most questions were authentic (about 80%), and inauthentic questions were fairly evenly distributed.

Most of the procedural questions occurred in the first 9 min (in Stages 1 and 2). Initially the students appeared confused because the teachers were not giving them any instructions, and they asked each other what they should be doing. Even at 8:18 when Roshani asked the other girls, it was clear that none of them knew. But when at 8:47 we asked Srushti and Vaishnavi what they were whispering to each other, Vaishnavi asked, 'colour?' apparently inquiring whether they were supposed to be looking for leaf colours. Although Gurinder responded with a joke rather than affirming their guess, they resumed looking for colours. Soon after this they also realised that we were writing their questions on A3 sheets, and by 14:51 Roshani had taken it upon herself to help Kranti by dictating to her the questions the other girls were asking.

Only 6 of the 72 questions students asked before Stage 3 were directed to teachers, and 7 out of 24 in Stage 3. Most of these questions to teachers were indirectly elicited by the teachers, in that they were asked immediately after a teacher requested clarification (e.g., Srushti's question at 10:24). Apparently students felt more comfortable talking to a teacher after the teacher initiated the talk. In Stage 4 most of the questions (43 out of 66) were directed to teachers since they were in reply to their requests to ask. Thus in all, 56 out of 162 questions were directed to teachers.

As shown in Table 2, most of the teachers' questions which were directed to students were for clarification (e.g. 'What did you say?'). We asked only nine authentic 'probing' questions in order to ask students to think deeper or differently (e.g. 'Whose eggs are these?' 'Have you tried it [using the leaf as a whistle]?') We wondered whether a more dominant student might take on the role of a teacher, using IRE methods. But there were no IRE sequences between students. This contrasts with the report by Carol Rees and Wolff-Michael Roth (2017) that in the absence of teachers, students engaged in IRE triad dialogues.

We analysed the data to find out whether there was a difference between the kinds of questions students asked before and after they were asked to ask questions. One difference was that the questions they asked afterwards were more focussed on the tree or the insects, and less on social matters. They also included a larger number of 'why' questions, and questions which might be considered to be higher-order critical thinking questions according to Bloom's taxonomy. There were also a higher percentage of investigatable questions, and questions which the students later judged would require more time or be more difficult to answer. However, after they were asked to ask, they did not spend as much time investigating the questions to find answers. When they

Table 3 Students' questions related to bhendi leaves, as sorted into three sets by the students

Simple to answer/requiring less time

1. Is this leaf completely white? (Devki 10:05)
2. Is the leaf golden? (Devki 11:08)
3. What is the colour of dried leaves? (several students 13:35–13:50)
4. What is that growing near the petiole of a young leaf—a flower or a leaf? (Srushti: 15:40)
5. Is this leaf thinner than the other leaf? (Ashish 18:45)
6. Does the flower close to the leaf [stipule or bud] have the same colour as the leaf? (Devki: 19:19)
7. Do smaller leaves have more serrated [crenate] margins? (probably Srushti 21:33)
8. Why is the venation in the pink leaf more clearly visible than in the white leaf? (Vaishnavi 24:11)
13. Does the leaf hold water? [Does it absorb or repel water?] (Devki 40:06)

Not so simple to answer/requiring somewhat more time

12. If we pluck the leaf, will a new leaf grow from the same place? (Devki 32:55)
15. How big can the leaves of this tree grow? (a boy 48:00)
17. Why are white leaves smaller than green leaves? (Roshani, in classroom)

Difficult to answer/requiring more time

9. Why some young branches are pink and some are brown? (Srushti 28:00)
10. How does the colour of a leaf change from its emergence to falling? (Ashish and others? ~29:00)
11. Does the leaf dry out after being green? (Ashish 29:23)
14. Why are there dots on dry leaves? (Kaustubh 45:36)
16. When a leaf gets ripe [mature], the white part remains white but the green part turns yellow? Why? (in classroom)
18. Do white leaves make their own food? (in classroom)

The name of the students who asked the question and the time in minutes is shown in parentheses. As indicated, a few of the questions were added later in the classroom discussion sessions. This list includes only the questions we heard during the session. When we listened to the recordings we found that they had asked many more questions

spontaneously asked questions, they were observing, interacting with, and thinking about the tree, seeming to be genuinely motivated to ask questions.

Moving from simple to complex questions

In a subsequent indoor session, we asked the students as a class to sort their questions which were about the bhendi tree (the ones which had been written on A3 sheets) into one of three sets on bulletin boards: (1) those which might be easy to find answers to by doing something within the remaining 2 days of the workshop; (2) those which may not be so easy or may require more time; and (3) those which would surely be too difficult or would require more than 2 days to find answers. The students sorted by rough consensus, as shown in Table 3. As may be expected, the simpler questions were generally asked earlier and the more difficult ones later.

Did the students do science?

Although we did not realise it at the time, after viewing and analysing the videos, we saw that the students did do science, according to our broad definition of science. For each investigation, the students engaged in different orders and combinations of several elements

of the ‘science toolbox’. For example, the investigation of leaf colour included the hypothesis that the colour may come off easily, and was tested by scratching. The investigation of whether the tree had thorns included the hypothesis that thorns could be felt by running one’s hand over a branch, and this was tested. Other investigations, such as the flower investigation, did not include hypothesis-making. The investigation of whether colour comes off when a leaf is scratched was done without much communication or discussion. Even the results were never voiced. On the other hand, the investigation of whether the tree had flowers included discussion and reasoning between five girls. All the questions (except for a few procedural questions and a few which were concerning social relations, such as, **‘Where do you live?’**) were connected to observations of things in the students’ immediate environment, even in the cases where no investigations were done to find answers.

We also noticed that they often had some difficulty deciding whether or not their questions were questions or whether they already knew the answers. We take this as evidence of how seeing, touching, hypothesizing, communicating, and questioning evolve simultaneously in an interconnected manner in a small group. This emphasizes our belief that science is a process, not a static thing. It also leads us to consider another teaching objective: for students to be ready to consider compelling evidence which contradicts even a strongly held belief in order to resolve contradictions. In other words, we hope that students are learning that in doing science, they must keep questioning and referring back to the ‘stuff’ as the authority (Duckworth 2012).

However, we doubt whether the students were thinking that they were doing science during this session. For example, (at 29:39) Devki said ‘C.I.D. वाटतोय आपण. [laughing]’ (We are playing C.I.D.—referring to the popular crime detective series on TV), and (at 38:26) she said, **‘दुसरा game खेळणार, ना?’** (**Can we play a different game?**), indicating that she thought of the activity as a game. In our conversations with the students afterwards, they gave us the impression that they thought science is what scientists do, not what students do. However, this was because they did not use the same definition of science that we are using. When we discussed science and viewed the videos in the follow-up workshop 2 years later, they did seem to agree that they were asking questions, observing, testing, and investigating.

The students’ efforts to answer their own questions were based primarily on observing rather than just reasoning. However, they did use inductive, deductive, and analogic reasoning. For example, Mansi used deductive reasoning when she stated (at 15:44) that all ‘झाडाला’ (trees) have flowers, and so the bhendi tree must also have flowers. Of course, this generalisation must itself be based on her own or others’ previous observations, and observations are also influenced by previous experience and ways of thinking. When the students were trying to figure out how or why insect eggs were stuck to a leaf, Roshani made an analogy to the way ‘magic balls’ stick anywhere. Another student said they should put the leaf back where they found it because the mother who laid the eggs may be looking for them, making an implicit analogy to the way human mothers care for their children. Inductive generalisation was used in connection with many of the observations the students made (e.g. when Srushti and Vaishnavi saw very few thorns on a few branches and concluded that the tree does not have many thorns).

Student agency—was the joke on us?

There were differences between how different students interacted with the bhendi tree, and how their interactions changed over time, wavering between passivity and agency (Roth 2007c). Initially, most students hesitated to touch the tree because they thought they were

not supposed to do so, or just because they were not motivated to do so. Some, like Tejas, took the initiative to start observing and touching, others did so only after seeing other students doing so. Their agency/passivity dialectic could be resolved through collective action, first between Tejas and Kaustubh, and then expanding to include others. By the end of this 48-min session, as a group the students were touching and manipulating the tree, although they did not go so far as to pluck any leaves, buds, or branches until the next day.

Episode 3 seems to indicate that Kaustubh and Tejas are defying the hegemonic power structure and making fun of Karen, who is easily identifiable as an older white foreigner, as well as a teacher. We think they were purposely making the researchers appear to be foolish by imitating our antics. But they actually also ended up making us feel foolish in two ways. One was that their imitation made us realise how ridiculous our research methods were: we were ‘play-acting’ in order to try to make the students observe the tree and ask each other questions about it—but actually they were already observing the tree and asking questions, and our antics just made them stop observing it and pay attention to us.

The other way they are making us feel foolish is by demonstrating that they did science in a way that we did not think would be possible. We thought they would not do science investigations before we told them to do so. We thought that since they had never done science investigations before, they would not know how to do so. We thought they would have to first frame their questions—which perhaps they would not do until we asked them to ask questions—and they would not immediately try to find answers. We thought we would have to help them think about ways to investigate. We thought they would need our help to plan experiments before they could conduct the experiments. We thought they would have to write their plans beforehand, record their results during the experiments, and write their conclusions afterwards. We thought they would need teachers to teach them how to do science. But what happened is that as teachers, even though we were trying to suppress our ‘teaching’, we were actually in a number of ways inhibiting the students from doing science. (In hindsight, perhaps this is not surprising, given the pedagogical ideology and kyriarchy of the system in which we are embedded.) Now we see that our initial thinking about the students was condescending and patronising.

The students not only started asking investigatable questions without our telling them to do so, they even started investigating and finding answers to their questions. The irony was that they thought they were not supposed to be doing all this, and they had no idea that this was actually what we wanted them to do, or that it was science! This interpretation was supported by our later discussions with the students. When we watch the videos, we often cringe. Some of us are quite disappointed to see how we were not listening to the students, we were interrupting them, and misinterpreting and not understanding what was going on at the time. Even now, we must be misunderstanding to some extent, but after spending so much time observing and listening to the students on the videos, it seems that we understand much better than we did initially. When the students watched the videos, they found them to be hilarious (partly because when they viewed them they were 2 years older). However, their initial expressions of embarrassment, if any, were accompanied by signs and statements that showed they were also quite happy with themselves.

Conclusion: students asked questions—and also did investigations

In order to understand students’ questioning outside of their classroom, we investigated student talk in a context which was not just open-ended, but also relatively open-beginninged.

When we brought the students close to an unusual variegated bhendi tree without giving any instructions (Stage 1), they spontaneously engaged in discussions without teachers in which they asked each other authentic questions. It was unclear whether the attention they paid to the tree was dependent on the teachers' looking at the tree (Stage 2). However, when we asked the students to observe the tree (Stage 3), they stopped asking each other as many questions until we explicitly asked them to ask questions about the tree (Stage 4).

Although we purposely tried to ensure that the students would eventually ask questions, they engaged in much more questioning and at earlier Stages than we had initially hypothesized. The same students who do not ask questions in their classrooms with their regular teachers, did ask each other questions in this context, even before they realised that this is what we wanted them to do. Almost a third of their utterances were in the form of questions, and most of their questioning was 'group questioning', which arose collectively through discussion.

We were surprised that the students also spontaneously and collectively investigated several questions they raised by handling the tree, closely observing, discussing, and even carrying on experiments without being asked to do so. They did not initially ask for or get answers or guidance from teachers. In fact, their initial investigations were done illicitly, because they thought they were 'not allowed'. Doing their own investigations and not asking authorities for answers indicates that their curiosity was genuine and that they were exhibiting considerable scientific temper. For example, they asked and investigated the questions: 'Have the leaves lost their colour?', 'What colour leaves are there?', 'Does the tree have thorns?', 'Are some kinds of leaves thinner than others?' and 'Does a leaf hold water?'

We used a historical dialectical materialist (HDM) method to do our analysis, which we found was appropriate because the nature of the bhendi tree was itself HDM. The students themselves also used an HDM process in doing their questioning and investigating.

What kinds of questioning did they do?

Most of the students' questioning was related to the unusual tree and its colours that were contradictory to what one thinks of as being 'normal' leaf colours. However, they did not spontaneously ask the same questions that we had asked ourselves when we first saw the tree, such as how a white leaf can do photosynthesis. Although their regular teachers had previously asked them to memorise 'the facts' about photosynthesis and chlorophyll at a very elementary level, they did not recall these 'facts' or spontaneously relate them to the tree. This supports our claim that the process of doing science, and asking questions, is based on physical reality as well as the history and experience of those who are doing science. The authentic questioning we saw was not based just on reasoning. There were several topics—e.g. the tree's root-thorns and strange stipule buds, and insects on the tree—which the students asked questions about which we had not even observed beforehand. Thus, the usual 'school-school' game and alienating power structure was somewhat disrupted in that the students had explored areas and questions that we teachers had not planned. And the teachers ended up learning from the students.

We have derived a categorisation, definition, and analysis of types of questioning which may be useful for future research. We found that the students engaged in both implicit and explicit questioning in what we identified as a dialectical process of implicitly and explicitly confronting conflicts. Most of their questioning was authentic, in that it was done in order to find answers—for genuine curiosity. We were surprised to hear a large proportion of investigatable questions. Other types of authentic questions we heard were: procedural,

clarification, basic questions about reality, and questions of language. They also engaged in some types of relatively inauthentic questioning: asking confirmation questions as well as rhetorical questions, which may be dialectical in that they are both/neither statements/questions. They may be emergent questions, dialectical in the sense that within the utterance there is an inherent opposition of conflicting questions/answers/observations. The entire act defines the question which is uttered.

As Maria Cifone (2013) pointed out with regard to research on student questioning in science education, ‘...most analysis has concentrated on the questions themselves, rather than the questioning process which generated them.’ Since we see science as a process, and we are interested in helping students to practice this process throughout their lives, we are also interested in questioning as a part of this process, rather than seeing questions as static ideas or ends in themselves. Our analysis revealed the difficulties in identifying questioning and distinguishing it from the process of making statements. We found that it is not possible to define a binary of questioning versus non-questioning, or to identify a particular moment when a person or group definitely ‘has’ a question. Implicit questions may gradually or suddenly become explicit, and may evolve over time, depending on the interactions between the students, and the interactions between the students and the real-world context—the stuff they are handling. Questions may appear and disappear—and even suddenly become replaced by transformed questions. Since the stuff itself is continuously changing (leaves fluttering in the wind and falling, buds opening, roots becoming thorns), this is another reason why questions about the stuff may also keep changing. A question formed at one time by one teacher or student may not be relevant at another time. Thus, in the process of our analysis, it became clear that the process of questioning is an inherently dialectical process.

Why did the students ask questions?

Our investigation shows how several factors which were very different from the usual classroom context for this group of students resulted in very different interactions and activities—including their own questioning. The interdependent factors were: (1) the subverted rules of the ‘school-school’ game and the subverted teacher/student power structure; (2) dialectical conflicts when students interacted with the physical stuff; (3) language factors. We claim that it was the inherent contradictions within each of these factors, and their interactions, that led the students to ask questions, as we will discuss below.

(1) The subverted ‘school-school game’ and teacher/student power structure

According to the stereotypical ‘school-school’ rules, which may extend even to laboratory work, a teacher gives the ‘questions’ and the students try to guess or somehow figure out what the teacher thinks the correct answers are. The implicit question in the students’ minds is, ‘What does the teacher think the answer is?’ In our study we explored what would happen if we tried to turn this game on its head. Thus, in the beginning of our workshop, the teachers (researchers) did not ask the students any questions or give any directions, except ‘Come here’, as they stood near the variegated bhendi tree. The students’ implicit (and at times explicit) question was, ‘What are the teachers asking us to do?’ or ‘What is the question that we are supposed to answer?’ What we were doing is turning the usual implicit question about the answer into an implicit question about the question. We did this in order to find out whether, why, and how students might ask questions as part of

their fairly informal discussion in a more open-beginning context. As teachers, our main role, initially, was to provide the context (the tree) and not speak.

We think that the students' confusion about what they were supposed to be doing proved to be useful in encouraging them to carry on authentic discussions in which questioning occurred. They initially did and said a number of things, some of which were in order to try to find out what we wanted them to do. However, they did not ask us what they should do. Presumably, it was due to their inferior position in the power structure that they felt safer asking each other. Also, they were probably accustomed to waiting for lessons to start because teachers are often preoccupied with other work or bureaucratic matters. At different times they hypothesized that we wanted them to identify plants, observe the tree, or tell what colours of leaves there were. They tested these hypotheses by proceeding to do these things. Seeing our reactions and our lack of objection allowed them to explore—and helped them find out that we wanted them to ask questions about the bhendi tree. However, they also did and said some things of their own accord, which were obviously not efforts to do what we wanted. For example, they discussed their plans for the next few days, whether the workshop was worthwhile, their spectacles, and their finger nails. Their informal expression convinced us that initially they were observing, discussing, and asking questions about the bhendi tree largely of their own genuine interest. This is in line with the hypotheses of Dillon (2004) and others that if teachers stop talking and stop asking questions, students do talk and do ask many questions.

We saw evidence that the students were struggling in the dialectics of agency and passivity (Roth 2007c), particularly with regard to touching the tree. We had purposely tried to subvert the hierarchical power structure in which teachers tell students what to do, but we were not sure how the students would react. However, they did show collective agency. They gradually took control over the situation, as they realised that they could take quite a bit of freedom, and that the teachers were joking around with them and not admonishing them. There was an underlying power struggle between students and teachers, and the students actually took more control than we had intended. We thought that the students would find the tree odd in the same way that we found it odd. But they found their own kinds of oddities. In planning the workshop, we had thought that the students would only frame questions in their session by the tree, but not investigate them until the subsequent sessions. We thought we would need to provide a considerable amount of scaffolding in order for them to carry out scientific investigations. However, we were surprised to find that the students were less reductionist than we were: they did not separate questioning from investigating, and they proceeded to begin to carry out their own investigations beginning in Stage 2 of the first session itself, even though they thought we may not allow them to do so.

Power relations between students and teachers are intrinsic and need to be explicitly examined. There is a delicate student/teacher dialectic which has to function as a creative force in order for meaningful teaching/learning to occur. In this case, we were experimenting with subversions of the usual power structures. But it was not easy for us, as teachers, to give up our power. Although we had planned to avoid talking to the students as much as possible in the beginning, and especially to avoid asking them questions, it was very hard for us to do so. We cringe as we view the tapes and see ourselves slipping up and interfering with the students' own questioning and investigating. This is inline with the report by Patrícia Almeida and Francislê Neri de Souza (2010) that it is difficult for teachers to stop asking questions and thus relinquish their power over a class, even when they try to do so. On the other hand, our relinquishing of power was in a sense a pretence, since we were maintaining our over-all power over students by 'making' them play our new 'student-questioning'

game. Students were trying to figure out what we wanted them to do and then do what we wanted. Our control became explicit after we asked them to ask questions.

The outdoor physical environment itself was a subversion of the students' usual classroom consisting of rows of desks facing the teacher, and it led to interactions between the students (and between the students and teachers). Particular arrangements of desks, chairs and tables are well known to individualise and confine students in particular ways—and signify a foreign, western culture to students who may be more comfortable sitting on the ground in informal groups. Because the students in our outdoor session were free to roam around near the tree, their collective discourse was in some respects relatively free. Although we had not planned it, the students spontaneously formed their own small, fluid groups. Working with each other and being able to wander and switch groups was both a cause and a result of their taking agency. It was an important factor that led the students to ask each other questions. That the students generally segregated themselves according to gender reflects the cultural historical constraints. However, there were tensions between girls and boys, the boundaries were occasionally broken, and they did occasionally interact with each other.

(2) Dialectical conflicts when students interacted with the physical stuff

Our analysis showed that students' questioning arose as a result of a number of different types of conflicts they faced: (a) conflicts between different observations; (b) conflicts between observations and beliefs; (c) conflicts between one's own beliefs; (d) conflicts between different peoples' beliefs; (e) conflicts between [observing or knowing] and [not observing or not knowing]. This last type of conflict is what is usually referred to as 'gaps in knowledge'. However, just realising that there is a conflict, does not necessarily lead people to try to resolve the conflict or engage in questioning. They also need to have the agency to ask questions.

The outdoor environment, and particularly the variegated bhendi tree, was itself dialectical. The tree was inherently contradictory: in addition to green leaves, it had leaves which were white and other colours even though green pigment is required for photosynthesis; it had root/thorns; it was a 'flowering tree' without flowers; etc. Even the colours were not what they appeared to be: they depended on the light and the environment, and even on social factors. We claim that this obvious dialectical nature of the tree led the students to observe more closely, and observation led them to become more aware of the dialectical nature of the tree. The dialectical nature of the tree was the basis which gave rise to the students' dialectical conflicts which in turn gave rise to interactions, discussions, and questioning.

Since they were walking around and forming small fluid groups and pairs, conflicts between students with different perspectives and experiences were apt to arise. Different students made different observations about the same stuff. When they voiced their observations, other students became aware of conflicts, and this gave rise to questioning. Without confusion or without a conflict, an authentic question will not arise. A student exploring more individually may be more apt to think a question is resolved before it is even explicitly stated, as happened when students were interacting individually with a teacher at Stage 3. However, we also found a number of instances when a student's questioning arose from conflicts between their own previously expressed observations or beliefs without much interaction with other students.

The tree was only about 4 metres in height, with low branches almost touching the ground in a bush-like structure. This structure allowed the students to handle and

manipulate the tree, and even climb inside it—without teacher guidance—and we think this intimate interaction facilitated discussion and questioning. We suspect that if we had asked them to ask questions before they had spent half an hour investigating it in this way, they may not have come up with the same quantity or types of questions. Their questioning was integrated with their handling and observing.

Other researchers have also reported on connections between observing and asking questions. Emily van Zee et al. (2001) found close connections between questioning and observation, although they concluded that student questioning required more teacher modelling and guidance than what we found to be necessary. Margaret Eisenhart (2008) has reported that in an after-school program, students orally asked many scientific questions, e.g. when they were shown a video of jellyfish. However, in her case they had little opportunity to do observations or investigations to answer their questions since their context consisted only of a video. Most of their questions seem to have been directed to their teacher, who also tried to answer their questions. A student was so impressed by her authority, that she remarked, ‘See! She [the teacher] does know everything!’ We agree that this was a worthwhile—and fun—science learning experience that included authentic dialogues that deviated from standard IRE sequences, and that students’ ‘questions led to discussions of far-ranging science topics’. However, we see a need for some opportunities in which students do more than just rely on authorities for answers if they are to further develop their scientific temper. This may be more likely to occur if the students have the stuff in their hands as they ask questions about it.

(3) Language factors

One factor that encouraged the students to talk and ask questions was that they were allowed to speak in their own language. They had discussions among themselves addressing each other directly without seeking the agency of the teacher. Not only did they speak in Marathi, they also took the freedom to use non-academic language, and even coin their own words for naming colours and the tree, without asking for recognition of these terminologies from authorities. Ann Rosebery and Cynthia Ballenger (2008) have recommended that teachers should allow students coming from diverse linguistic backgrounds to use such styles of discourse, so that they can understand that their own languages and experiences are valid and important for learning and doing science. There is a dialectical conflict between non-academic and scientific language, and both are necessary.

The quality of the science the students did may not have been very rigorous or ‘professional’, largely due to problems related to communication and language. They were constrained by not knowing scientific jargon and by problems due to lack of fluency of both teachers and students in all the three languages in use. They did not refer directly to any text, website, or source of authority, except for the few times when they directly asked the researchers—and even then the researchers did not always provide any answers. However, later on in the workshop the students did occasionally make references to things they had remembered from their textbooks, what their teachers had previously told them, or what they had seen on TV. Due to problems of class and caste, the students as well as their regular classroom teachers have very limited access to written material which could be useful in doing science investigations. Most science books and journals are not available because they are being sold for very high prices. Internet is expensive and not available everywhere. Also, much of the material required for science is in English, and translations into Marathi and Hindi are very limited. Making material more freely available would obviously allow

people to have more access to science education, and it is significant that this is not being done—except through illegal ‘pirating’. The implication is that, through its commodification, science communication is being criminalised.

The students encountered several conflicts involving language: conflicts between the different languages and names on the Casuarina tree label; conflicts between possible names for the bhendi tree; conflicts involving the names and categorisations of colours; and conflicts between Marathi, Hindi, and English. These conflicts led them to ask each other questions. We have discussed how the dialectic nature of the names of colours and the colours themselves were one of the main areas that led to conflicts, discussions, and questioning.

The dialectics of tree naming was exhibited at a number of instances in the session. The tree names were not what they first appeared to be. This was partly because of mistakes and coincidental meanings in different languages, but also because of the functions of the names. Plants do not fit into well-defined categories. People make categories and names for various purposes. Scientific names are dialectical in that they made in order to accurately communicate across cultures as well as to establish an elite culture of ‘science’ which is not accessible to all. Local plant names may also be dialectical in that they may reflect their use values as well as their exchange values, if they are used to label plants as commodities. While the students did not explicitly discuss these functions of names, their comments and questions revealed that they were implicitly grappling with the dialectics of naming.

In the beginning, the girls seemed to think that maybe we wanted them to identify the plants, so they started asking and telling each other the names. None of them knew the common or scientific name of the variegated bhendi tree, and no authorities told them. However, they were quite creative in suggesting their own descriptive names. Then, for about half an hour, they forgot about naming, and continued exploring the tree. It is remarkable how towards the end of the session one student noticed a nearby tree from the same family and wondered whether the two trees might have the same name.

If the students had initially known or been told the name of the tree they might not have been so curious about it. The act of naming something may actually thwart exploration and learning, since it can be taken to be a conclusive, definitive answer to a school-school game which is concerned primarily with recall—and particularly with the recall of seemingly random, unconnected ‘facts’:

Find the right label for some process, and you know about it. If you know about it, you needn’t think of it any further. ‘What is its name?’ becomes a substitute for ‘How does it work?’ While giving names to things, obviously, is an indispensable human activity, it can be a dangerous one, especially when you are trying to understand a complex and delicate process. (Postman and Weingartner 1969, Ch. 2)

Naming may also make a thing/process appear to be less of an interconnected process with causes and effects and more of a static, individual thing.

In this study we have only reported on students’ oral questioning. We suspect that one reason that they asked so many questions was that they were talking, not writing. Oral questioning is a dynamic process, which is mo–re changeable, responsive, and ‘living’ than a relatively fixed, static piece of writing. Because talking is more spontaneous and immediate than writing, it may be more open to innovation and questioning. Talking within small groups is less individualistic and less alienating than usual forms of writing, and it is more subject to evolution as it passes from person to person and group to group. Of course this last point can also be a disadvantage, in that it may introduce inaccuracies and spurious errors and contradictions between direct observations and reported observations.

Lev Vygotsky (1966) pointed out that, 'The motives for writing are more abstract, more intellectualized, further removed from immediate needs. ... Writing also requires deliberate analytical action on the part of the child' (pp. 181–182). There is no doubt that the written word is very important in doing science, and in making the implicit more explicit. Vygotsky wrote about the dialectical movement between more abstract thinking and talking and more concrete writing, and their importance in learning. Although student discussions hardly occur as part of main classroom discourse, unplanned pauses and interruptions provide some time for authentic student discussions. More research is required to find out whether some meaningful learning is occurring at such times, as well as when students 'whisper' to each other during a lecture, demonstration, or presentation by the teacher.

Implications of the students' investigations

At the same time that the students asked each other questions, they also worked together to do investigations to find answers. They investigated by observing, testing, measuring, feeling, hypothesizing, analysing as well as asking questions. These aspects were not discrete steps—their order, fluidity, and interdependent combination were varied. This experience led us to conclude that it does not make sense to try to artificially separate asking from answering. According to our definition of science as a cooperative, collective process of using a scientific method which includes questioning and observing (among other aspects), we think that they did science. However, at the time, the students themselves did not think of their activities as being science. This reflects how the term 'science' has been exclusively appropriated by professional scientists.

We did not expect that the students would ask so many investigatable questions even though we never asked them to or discussed what investigatable questions are or how a scientific method might be used to answer questions. Christine Chin (2002) reported that most of the questions students asked in her study in Singapore were not amenable to their own hands-on practical investigation. Similar to our study, she studied 'novice' middle-school students who had not been previously requested to pose questions for investigation in school. Unlike in our study, she reported that when individual students were asked to pose questions, some of her 39 students were not able to formulate any investigatable questions—or sometimes any questions at all—until the teacher gave examples of such questions and let the students work in groups. The above three factors that led our students to engage in questioning were minimal or absent in Chin's study, especially before the students worked in small groups.

In the study by Carolyn Keys (1998), students defined their own investigatable questions when they were asked to do so and worked in small groups. Unlike our study, her students first read and summarised background information, watched the teacher perform demonstrations, and did exploratory activities. Roth and Roychoudhury (1993) reported that when students were asked to define their own research questions in particular contexts, they did do so, and were highly motivated. Without being explicitly taught, they also learned to use higher order science process skills to plan and carry out open-ended inquiries to answer their questions. Over a period of 14 months, their research questions became less broad, involving specific variables. However, Roth (1995, p. 127) has also written that asking students to frame their own questions was met with opposition from parents who expected the usual lecture mode of teaching.

Based on our results, we wonder how much teacher-led scaffolding is really necessary or desirable. Is there a risk that it may lead to 'recipe-following' or IRE sequences based on inauthentic teacher's questions, rather than encouraging students to do more rigorous

thinking and acting for themselves? There is no need to completely avoid such teaching, but it should not be used to an extent that excludes student questioning.

One question a number of researchers have raised is whether young students can ‘create knowledge’ and enable further knowledge creation (Bereiter and Scardamalia 2010). Rather than thinking about some product or ‘knowledge’, we think it is more useful to think in terms of the tentative and probabilistic *process* of ‘creating knowledge’—i.e. doing science. One reason why students are not encouraged to ask questions in class may be that science is often treated more as an unquestionable ‘body of knowledge’ than as a process. The objective of activities may remain focussed on learning science concepts rather than learning and practicing science processes such as questioning. In addition, individual learning is stressed and assessed, rather than group learning.

Our results also suggest that perhaps students need not wait until they have acquired a certain amount of ‘knowledge’ before they begin to ask their own investigatable questions and try to figure out how to do their own research to find answers. This underlines the point that there actually is no single prescribed set or order of the aspects of the scientific method: questioning, investigating, observing, communicating, and other aspects are intertwined. Students can sometimes be free to ask questions and carry out investigations spontaneously, without making careful plans and writing things out.

Perhaps the most important lacuna in our students’ spontaneous investigations was that they did not always make their implicit questions more explicit, and they did not always verbalise or explain their observations or the reasons for their statements. They needed more experience in finding and discussing evidence. This was obvious, for example, in their investigation of whether or not the bhendi tree had flowers. This investigation was based on observations, but the students did not discuss their observations in sufficient detail. A teacher could have tried to guide them to state reasons. In this case, even we were not initially sure whether the observed buds were flower buds or leaf buds, so perhaps we would have asked relatively authentic questions if we had participated in the students’ discussion. Another role for teachers in the sorts of interactions we observed, could be to encourage students to make implicit questions explicit—both orally and, sometimes, in writing. More research is needed to explore these possibilities.

Doing science as a subversive activity

One of our most important findings was that initially students did not think that their questioning and investigating were legitimate, were science, or were considered to be science in the eyes of the teachers/researchers. They were afraid to touch the bhendi tree. They were afraid to scratch or pluck the leaves. They initially discussed the tree in whispers and refused to tell the teachers what they were saying. They asked each other questions but they did not ask the teachers. They seemed to be making observations which made them confused, but were hesitant to make their implicit questions explicit. But, interestingly, the students’ misconception that we did not want them to do all these things did not entirely prevent them from doing them. And, according to the HDM framework upon which our work is based, we believe they were doing science. In other words, the students did ‘science as a subversive activity’! It is subversive because schools seem to be teaching students to stop asking questions and stop doing investigations.

There are several obvious systemic constraints that make it difficult for students to engage in discussions, investigations, and questioning in Indian classrooms. Most obvious are the severe shortage of teachers, the pressure of external examinations, lack of teacher

autonomy, inadequate infrastructure, and insufficient budgetary allocation (Jain and Saxena 2010; Tewari 2015). In each classroom one teacher usually has more than 35 students—typically 50–80, and sometimes more than 120. Educationists, teachers, parents, and children do protest these conditions, but so far the government has not responded, except to try to privatise education, which worsens these problems (Nambissan and Ball 2010).

Although we cannot generalise from our results, we have provided one example of a context in a more relaxed out-of-school setting in which students do engage in questioning and investigating, even though they do not do so in their regular classrooms. Does this mean that the students did not have a culture of being shy and submissive and not asking questions? Not necessarily. But it does imply that they acted despite whatever constraints or compulsions their culture or the education system may or may not have imposed upon them to do otherwise.

The main outcome of our study is the evidence it supplies to indicate that students may not need to be ‘taught’ to ask relevant investigatable questions. Our findings also lead us to suggest that perhaps the students we studied might also engage in questioning and investigating in their school, even without being encouraged to do so by the teachers or school authorities. Students may have to act subversively, carrying on discussions by whispering, or even doing some form of investigating illicitly in their classrooms. Can students speak up in class, and interrupt—maybe without even raising their hands or being called upon?

Student questioning may increase if the ‘school-school’ rules are broken and teachers keep quiet. Of course, this requires addressing the hegemony of power, which is normally carefully guarded. Power will not be relinquished without a demand.

However, teachers who are so inclined might also engage in subversive acts to encourage questioning, even under the systemic constraints they face. They might do this by occasionally allowing students to have some freedom to engage in activities which are outside of their plans and expectations. Teachers might sometimes deliberately ignore students’ whispering and illicit investigation—or they might validate it. They need not always expect all students to explicitly ask questions out loud as part of the main classroom discourse. They might bring confusing stuff to class or demonstrate conflicting processes which may be likely to confuse the students so that they face contradictions and engage in questioning. Science teachers might try to allow students to broaden their questioning so that it more explicitly addresses socio-political conflicts. Students can sometimes just be *allowed* to ask questions, while they observe and manipulate some sort of historical dialectical material.

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