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Aspects of Teaching and Learning Science: What students' diaries reveal about inquiry and traditional modes

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Aspects of Teaching and Learning Science: What students' diaries reveal about inquiry and traditional modes

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We present an analysis of students' reflective writing (diaries) of two cohorts of Grade 8 students, one undergoing inquiry and the other traditional science teaching. Students' writing included a summary of what students had learned in class on that day and their opinions and feelings about the class. The entries were analysed qualitatively and quantitatively. This analysis of students' first-person accounts of their learning experience and their notes taken during class was useful in two ways. First, it brought out a spectrum of differences in outcomes of these two teaching modes—conceptual, affective and epistemic. Second, this analysis brought out the significance and meaning of the learning experience for students in their own words, thus adding another dimension to researchers' characterisation of the two teaching methods.

Keywords: *inquiry; characterisation; outcomes; reflective writing; middle school*

Introduction

Active learning of science involves hands-on experience and, equally important, making sense of that experience. Students' reflective writing about their learning in the classroom has the potential to make explicit this attempt at sense making. Analysing what and how students write in diaries as their first impressions of their classroom experience can not only give a glimpse of students' emerging understanding, making clear what students have learned and their beliefs and feelings about it (Aschbacher & Alonzo, 2004; Audet, Hickman, & Dobrynina, 1996; Balgopal & Montplaisir, 2011), but it can also reflect what students do and teachers focus on in their classrooms (Baxter, Bass, & Glaser, 2001; Minogue, Madden, Bedward, Wiebe, & Carter,

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2010; Wiebe, Madden, Bedward, Minogue, & Carter, 2009). In this paper, we analyse students' reflective writing in the form of daily diary entries to examine the outcomes of inquiry and traditional teaching modes as well as a characterisation of these modes from students' perspectives.

Teaching through inquiry is often associated with first-hand exploration by students. What really distinguishes it from traditional teaching, however, is that the teacher does not *explain* concepts to students, but guides and supports students' thinking to help them *arrive at explanations* based on evidence and argumentation (Abell, Anderson, & Chezem, 2000; Cobern et al., 2010; NRC, 1996).

Reforms proposed in science education across the world have a common emphasis on teaching science as inquiry. Yet it is not commonly implemented in actual classrooms possibly because it is challenging to prepare teachers to adopt such practices, and it is unclear whether the outcomes justify the effort. Educational and political debates continue over its effectiveness (Anderson, 2002; Cobern et al., 2010). Researchers in science education have been trying to address this problem in two ways. First, studies have aimed to probe the efficacy of inquiry-oriented teaching (see meta-analyses such as the one by Shymansky, Hedges, & Woodworth (1990) and review studies such as those by Colburn (2008) and Hmelo-Silver, Duncan, & Chinn (2007)). Second, acknowledging the difficulty of visualising inquiry in actual practice, recent studies (e.g. Kawalkar & Vijapurkar, 2013; Martinez, Borko, & Stecher, 2012; Roth, 1996) have attempted to characterise the complex process of inquiry in the classroom and provide real-life descriptions which would facilitate reform.

In general, evidence from studies on outcomes of inquiry teaching suggest that support for it is well grounded, although this evidence is not unequivocal. Many of these studies focus on content acquisition (generally gauged through pre- and post-intervention testing). A need for investigating other aspects has been felt, such as analyses of a wider range of outcomes of inquiry teaching (Minner, Levy, & Century, 2010) and for research involving quasi-experiments in real-world classrooms to assess and compare the impact of learner-centred teaching with more traditional ones on students' perceptions of learning, actual content learned and depth of thinking about (and understanding of) the conceptual underpinnings of science (Wohlfarth et al., 2008).

Further, studies looking at the practice and conceptions of inquiry usually involve either classroom observation by researchers or self-report from teachers. Through analysis of students' own descriptions of their science learning experience we provide another perspective, that of the students. Studies investigating how students conceptualise the constructivist perspective are rare though constructivism represents an influential view of learning (Loyens, Rikers, & Schmidt, 2006). Knowing what students think they know and how their learning is changing is important and in line with constructivist thinking at the core of inquiry teaching.

There have been many studies on the usefulness of students' writing in science notebooks. It is acknowledged that writing in science notebooks promotes learning and serves as a tool for formative assessment (e.g. Baxter et al., 2001; Bernacki, Nokes-Malach, Richey, & Belenky, 2014; Keys, Prain, Hand, & Collins, 1999). A few studies (Klentschy & Molina-De La Torre, 2004; Minogue et al., 2010 and Ruiz-Primo, Li, & Shavelson, 2002) exploring how such writing can provide evidences of practices in the classroom have been reported. In these studies the focus has been on structured, systematic accounts of laboratory investigations by students, not open-ended reflective writing about the overall learning experience. Wiebe et al. (2009) used open-ended writings of second graders in their science notebooks as a tool to examine inquiry practices in the classroom. More recently, Madden and Wiebe (2013) used notebook entries to examine how teachers' instructional practice was interpreted by students.

Engaging in reflective writing, as in diaries, journals or learning logs, can take students to deeper levels of reflection and help identify the significance and meaning of a given learning experience for them (Fink, 2003). By recreating the processes that go on inside the writers' minds, and conveying it to the reader, such writing opens up fields that are not normally accessible to researchers. In science education research, while there have been some studies on reflective writing by teachers (e.g. Harwood, Hansen, & Lotter, 2006), there have been few studies on students' reflections on their learning experience, especially at the school level. Studies at the college and graduate school levels on students' perceptions of their experience using interviews, weekly reports and course evaluation questionnaires have been reported by Hsu and Roth (2010), May and Etkina (2002) and Wohlfarth et al. (2008). In his review of three studies, Lyons (2006) found that high school students in three different countries perceived traditional school science as passive, unengaging and difficult. He notes the need for more studies on students' reflections on their experience especially in contexts which could engender more positive attitudes towards science.

An interesting study at the school level by Hadzigeorgiou (2011) illustrates the usefulness of optional journal entries in investigating students' involvement as well as content learning. He used such entries, of Grade 9 students, to provide evidence that compared to teaching in a traditional way, invoking a sense of wonder while teaching science makes a positive contribution to learning of content as well as involvement with it.

Our study differs from the ones described above in one or more of the following features (a) maintaining a diary was not integral to either teaching or assessment and was not a stringent requirement (b) it was not a formal, structured record during student investigations (c) entries were open ended and reflective in nature and (d) they were used as a tool to explore and compare students' learning in inquiry and traditional classes. The specific questions that guided our analysis were:

(1) What may students' entries in the diaries reveal about their characterisation, if any, of the teaching methods they have experienced? What differences, if any, are there among students' diary entries with regard to what they found interesting and significant in the teaching method?
(2) What is the difference, if any, in the outcomes with respect to students' learning?
(3) What are students' feelings/reactions towards the teaching they experienced?

Theoretical Background

This study is aligned with the social constructivist perspective of Vygotsky (1978), which focuses on how personally meaningful knowledge is socially constructed through shared understandings. It posits that learning occurs first at the social (inter-psychological) level and then at the personal (intra-psychological) level. According to this perspective, social interaction, especially with more experienced members (teachers in the case of classrooms) provides children with ways of interpreting the world around them and thus students become 'enculturated into ways of thinking that are common practice in that specific community' (Palmer, 2005, p. 3). Whether they are aware or not, teachers design the learning environment by setting norms for the kinds of questions worth pursuing, the forms of arguments that are persuasive and the criteria for an acceptable explanation (Lehrer, Schauble, Carpenter, & Penner, 2000). There are constant, mostly implicit inputs and guidance from the teacher about 'what counts' that are conveyed to students who, as they try to make sense of their experiences during the individual process of learning, construct knowledge and understanding through the appropriation or accommodation of these important ideas, ways of communication and habits of mind (Lidar, Lundquist, & Ostman, 2006; Sampson & Walker, 2012). The learner diaries in our study contain indications of students' efforts in making sense of events, and serve as a window into their conceptual and emotional engagement with the teaching they underwent.

This theoretical framework underscores the importance of research on the ways in which teachers guide the discourse, activities and ways of thinking in the science classroom and how students appropriate them in their learning. Kelly (2007) points out that teachers' choices in pedagogy send messages about the nature of science and in recent years some studies (e.g. Berland & Hammer, 2012; Hammer & Elby, 2003 and May & Etkina, 2002) have examined the epistemological assumptions of classroom discourse. Scott, Asoko, and Leach (2007) note that though we have a much better grasp of the role of the teacher in making scientific knowledge available on the social plane of the classroom, the step of individual sense making, or internalisation has received far less attention. Our study is an effort to explore such individual sense making using students' writing, and relate it to the teaching approach they experienced (which we analyse using independent data sources).

Methods

Setting and Participants

This study is part of a larger project comparing inquiry and traditional science teaching and its outcomes. In this paper, we report part of the data from one phase of the project during which we held summer classes with Grade 8 students (average age 13.25 years). Students from three schools in the vicinity of the researchers' institute were invited to attend these classes at the institute. Students who volunteered to participate were randomly divided into two cohorts of 25 students each. One cohort was taught science through inquiry and the other in the traditional expository mode. The students' schools, with English as the medium of instruction, followed the national curriculum in India, and belonged to the same school system in a residential colony where all students' families lived. Both cohorts were thus exposed to the same curriculum and had access to the same infrastructure outside of the school too. They came from similar socio-economic backgrounds and a variety of linguistic backgrounds. The in-school and out of school experiences of the two cohorts were thus similar on an average. Records of students' academic performance at school indicated that there was no significant difference in marks between the two groups either for all subjects (Figure 1) or for science (inquiry group: 79.24 ± 13.80, comparison group: 80.34 ± 15.18). Interaction with each cohort was for two hours a day, five days a week for a month, in the same setting (at different times of the day). The actual class time was less than two hours, as this period included a short break of approximately 15 minutes.

Two teachers from the research group (one of whom is an author of this report) taught one cohort of students through inquiry. Both had at least a Masters' degree in science but were not formally trained teachers. One of them had over 10 years of experience in research and teaching in inquiry settings. The other was a relative novice in inquiry but had taught at the college level for two years; for teaching through inquiry in this project, she was trained and got support for lesson planning by the expert teacher. Two other teachers, each with a formal degree in teaching and a Masters' in science taught the comparison group. One of them had over four years of experience in teaching at school; the other was a relative novice. Although they taught in the traditional way, they reported that they were able to do fuller justice to their teaching in this programme with no constraints of time or prescribed

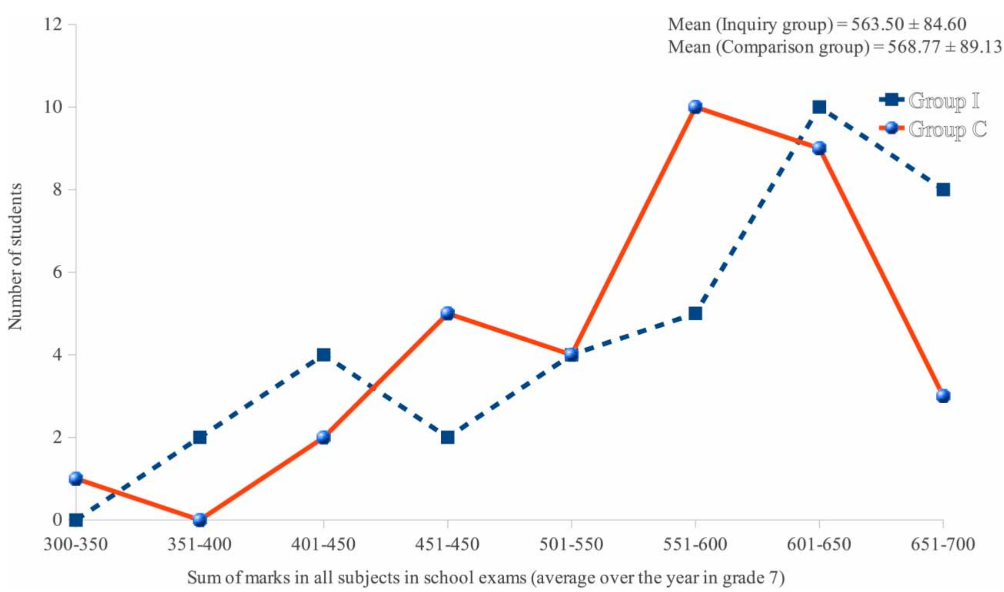

Figure 1. Academic performance of the two cohorts

content of textbooks as in schools. They also had more time for preparation and made considerable effort to make these classes more interactive than their usual ones, using questions and activities.

Data Sources and Analysis

Students' diaries. At the beginning of the intervention, students were given a notebook each, and instructed to note down what they had learned, how they felt about the class and anything interesting that they came across in addition to class notes and homework. We refer to students' reflective writing in their notebooks about their learning experience as diaries; they were the primary source of data for this study. Writing a diary is not a common practice in schools in India, and was adopted specifically for this study. The instructions for writing given to the two groups by their teachers were essentially identical. Both groups were explicitly told that they would not be evaluated individually and that they could be frank in their writing. The diary writing was optional, although it was encouraged. One of the teachers who taught the comparison group gave time at the end of class on four occasions to record entries in the diaries. This was never done with the inquiry group. The teachers never read out or discussed any of the diary entries in class. They accessed the notebooks only rarely because they were planned for research purposes and not for formative assessment. These measures were taken to obtain spontaneous, voluntary and candid writing from students. Students' entries thus served several purposes: (a) the amount (and kind) of voluntary diary writing could be used as an indicator of their engagement level with their learning experience (Hadzigeorgiou, 2011); (b) candid feedback could be obtained from the students; and (c) students' emerging understanding of the content after teaching in each class could be captured. To summarise, we used the diaries to evaluate the intervention—its effect and how students perceived it—and not to evaluate individual students.

At the end of the intervention, notebooks from each cohort were obtained and photocopied before returning them to the students; 19 students from inquiry and 18 from the comparison group turned in their notebooks. Reflective text written on each day was counted as one diary entry. The date of the entry (from dates that had been recorded by students) and the tone of the diary writing helped locate and demarcate diary entries from class notes and homework in the notebooks. A quantitative analysis of the entries—the total number of diary entries per group, the average number of words that a student wrote in an entry and the distribution of entries over the course of the intervention—served to discern the engagement levels in the two groups. A non-parametric statistical test, the Mann–Whitney U test, was used to check for any significant difference in the distribution of average number of words per student for the two groups. As descriptive statistics for the rest of the quantitative data showed large differences, further tests for significance of differences were not necessary.

Qualitative analysis involved inductively and recursively examining each entry to see what aspects of the class interactions were recorded and how. The coding was done by one of the authors who observed classes for both cohorts. An emergent or bottom-up approach to analysis of the content was adopted, that is, the categories were derived from the data instead of using pre-established codes based on theory (Thomas, 2006). The initial three main, persistent categories that emerged in the entries were 'describing what was done', extensive 'summarising what was learned' and 'expressing what was felt'. We found these coding categories that emerged from our data to be very similar to those used by Audet et al. (1996) ('storytelling', 'knowledge claims' and 'affective categories') to analyse undergraduate students' computerised group learning logs. These authors in turn had found that their preliminary coding categories resembled the method of discourse analysis by Newman, Morrison, and Torz (1993) which they then adapted and extended to include affective features of learning logs. May and Etkina (2002) also analysed college students' weekly reports in terms of what they learned ('formula', 'vocabulary', 'concept' and 'skills') and how they said they learned it ('observed', 'constructed from observation', 'reasoned', 'learned by doing' and 'from authority'). It is interesting that different researchers, working with different sets of data, independently arrived at similar categories, indicating that this is a reliable way of characterising students' reflective writing.

Iterative reading and further coding of these categories led to the coding scheme that is summarised along with representative examples in Table 1. We note that this coding scheme has a high degree of objectivity; it is not very interpretative and therefore unlikely to be susceptible to biases.

Students' summaries of what happened in class were coded according to the form—as either declarative sentences or as questions. The instances of 'what was learned' were coded for their conceptual understanding, manner of describing ('personalised' in their own words or repetition of facts, definitions and principles given by the teacher) and source of the knowledge claims (from what was told or explained by the teacher or students' own reasoning). The latter two categories brought out the differences in students' conceptions of learning science. A research associate who had earlier been a teacher but with no prior participation in this study coded 15% of the data independently for these two categories; there was 86% agreement between the two researchers. This agreement is fairly high considering that she was not present during the teaching nor had seen the videos of classes; she explained that what informed her coding decisions was whether formal definitions or principles seemed reproduced in students' writing or seemed reasoned out in students' own words. Students' knowledge claims were also examined for explicit statement of a sense of shared epistemic authority with the teacher, and instances providing tentative solutions to the question at hand.

The conceptual correctness of the entries related to content learning was analysed and discussed among the authors themselves first. Then the statements showing incorrect understanding from both the groups were collated together, along with some correct statements, divided into three parts and evaluated by three other researchers, each of whom checked statements in the area of his/her content expertise. There were only a few differences between the authors and the other researchers; these differences were easily sorted out through discussion. Statements that were judged to be even partially correct were taken as correct.

Table 1. Coding scheme for analysing content of the diaries

Coding categories	Instances from students' diaries
1. Summaries of what was done	
Descriptions of the events in class (what was done and how)	Today we went to the lab [sic] and did an experiment there. Both the thermocol and wood blocks floated on water. We had to find out how much (what fraction) did float in water.
Descriptions of the lesson or activity framed as a question	Today we studied about heart. How does it pump? How it works? [sic] How does the blood flow?
Descriptions of class events as debates/arguments/discussion	What decides amount of water displaced (1) Mass (2) Size This question started a hot debate. We also had an argument on whether sea horse is a fish or not [sic]. We discussed about the experiments and the doubts[sic].
Descriptions of the teacher's action as 'told'/'taught'/'explained' with details	She told us the different names of fish. She taught us how SI units are derived. She explained how oxygen goes from alveoli to haemoglobin of blood.
Descriptions of the teacher's action as 'told'/'taught'/'explained' without any detail	She told us about density. She taught us about fish. She explained about buoyancy and density.
2. Summaries of what was learned[a]	
• Understanding of the content	
Instances with conceptual errors	… But I think volume of displaced water depends upon weight, size and mass of the object. *(Instance 1)* Today we learnt that the object which has more mass and volume has less density and the object that has less mass and volume has more density. *(Instance 2)*
Instances showing conceptual understanding	The sinking or floating of an object doesn't depend upon the weight of the object but actually how the particles in that object are arranged. *(Instance 3)*
• Way of describing	
Limited to recall of definitions of scientific terms and principles + interesting facts told by the teacher	The teacher also taught us Archimedes' principle. The Archimedes' principle states that any object which is wholly or partially immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object. *(Instance 4)* Today we learned that the object which has more mass and volume has less density and the object that has less mass and volume has more density. *(Instance 2)*

(*Continued*)

Table 1. Continued

Coding categories	Instances from students' diaries
Personalised descriptions of what was learned in their own words	… But I think volume of displaced water depends upon weight, size and mass of the object. *(Instance 1)*
• Source of what was learned	
What was told/explained by the teacher	Today we learned that the object which has more mass and volume has less density and the object that has less mass and volume has more density. *(Instance 2)* The sinking or floating of an object doesn't depend upon the weight of the object but actually how the particles in that object are arranged. *(Instance 3)*
Students' reasoning as answer to a question or as inference from an experiment and/or class discussion	So from this (experiment) we can understand that the thing which has more volume will float and less volume [sic] will sink in water.
3. Expression of what was felt	
Positive	It was great to get a chance to present our views in the debate. Overall I enjoyed this day very much.
Negative	Today I did not enjoy as much as yesterday.
Reflective notes on teaching—learning	Teacher showed us a picture and we were guessing which animal it was … but we all felt it was difficult. First I thought it was a dolphin then I changed my mind as its tail was moving right to left but mammals' (tails) move up and down. The most shocking thing was it was (a) reptile.
4. Expression of own involvement	
Statements explicitly showing a sense of shared epistemic authority	We had a lot of discussion on it, at last we concluded that the material which has more height will displace more water. We convinced the teacher about our answer. Then [we] raised doubts which the teacher and we answered.
Statements showing modification of conclusion/ tentative solutions	First I thought it was an ancestor of dolphin then I changed my mind. I had to change my mind again. I think we should look at gills, snout and fins to look anything as a fish. If any creature has two of its factors, it is fish. First I thought it was the container having more volume but I was wrong the bottle had more volume and it was because even if the height of the beaker was more but the base was less while the bottles base was more and less height. So the bottle volume was more.

[a]Each instance of what was learned was examined for conceptual correctness, ways of describing and source. Using multiple examples, we have attempted here to illustrate how each of them was assigned to these sub-categories. Note that the larger context in which these statements were written helped the researchers in assigning the codes.

Students' descriptions of the teaching as well as of what they had learned from it were compared across the two groups to arrive at a characterisation of teaching in the inquiry and traditional modes. Their affective responses to the teaching were analysed to find which aspects of teaching–learning were liked or disliked by them. We also found indications of other affective outcomes, namely a feeling of self-efficacy and students' engagement with learning. Other components of students' notebooks such as spontaneous notes and questions written during class were examined for evidence of students' engagement levels.

Video records and field notes. Video records of classes and field notes by observers formed additional data sources. The classes were video recorded with two cameras, using a wide-angle lens on one to capture the whole class continuously. Detailed field notes in class were taken by observers (including an author of this paper) who were not teachers. These video and written records were used to examine the content and structure of the lessons and details of classroom interactions, as well as details such as the exact instructions for diary writing and contexts of particular entries. Also, patterns of instructional practice in the two modes were identified using these video data and field notes, and compared. Further, results from the analysis of diary entries were used as cues to examine video records and check if they corroborated aspects of classroom interactions that were recorded in students' diaries.

Content and Structure of the Lessons

Two units, one on the concept of density and the other related to fish were taught in both the classes. In both groups, each teacher taught the units which fell in her area of training—physical science or biology. The unit on density basically consisted of teaching (a) pre-requisite concepts of volume and mass and the relationship between density and these two properties (b) density as the property of a substance and relative densities of different substances (c) floating and sinking of objects and (d) the Archimedes' principle. The unit on fish consisted of (a) fish as a unique group of animals different from others, that is, 'What makes a fish a fish?' (b) similarities and differences between different taxonomic groups of fish (c) internal structure of fishes with special attention to gills and the swim-bladder and (d) respiratory and circulatory systems of fish in comparison to corresponding human systems.

Students had very little or no prior exposure to these topics in the school curriculum they had undergone before participation in our programme: The topic on fish is not covered at all in their school curriculum; the concept of volume is cursorily treated in the mathematics curriculum as Volume = length × breadth × height. We note that both topics offered rich opportunities for exploration (whether hands-on or otherwise), experiments and demonstrations, and for helping students arrive at conclusions through analysis and reasoning based on their observations.

Teachers of both cohorts had access to the same resource material (including audio-visual material) and shared ideas for conducting activities. They had the same support in preparing for, and conducting, hands-on activities in class. However, transaction of the material was entirely left to them. The differences between the teachers were thus, essentially, in their teaching practice. In inquiry teaching, discussions and activities were used to elicit students' prior conceptions, to probe and address conceptual difficulties students have, and in guiding and supporting students to arrive at explanations rather than giving away answers. In the traditional classes, the teacher set the stage (to generate interest or explore pre-requisites), gave explanations with the help of activities and then revised what was taught. The essential difference between the two teaching modes was how students acquired a concept—whether the teacher explained it, or they grappled with it and developed it through exploration, with scaffolding by the teacher.

We illustrate how these different modes of teaching were transacted in our study with sketches of the teaching–learning sequence for the unit 'What makes a fish a fish?' (Figures 2 and 3). These were derived from video records of classes. We have given a flow chart of the lesson that was built on the main theme, leaving out details of any digression which, however, have been depicted in boxes with dotted boundaries. These sequences depict how in traditional teaching, students were engaged in activities and questioning before receiving explanations while in the inquiry mode there was a constant dialogue and the teacher tried to stretch students' thinking through questions and counter-examples. Examples of students' diary entries given throughout the paper are from both units; they provide glimpses of these units and the contrast between these two modes of teaching.

We note that there were many demonstrations by the teacher in the inquiry as well as traditional classes. McCrory (2013) makes persuasive arguments for the effectiveness of demonstrations in the science classroom—they capture and hold interest and exploit the power of curiosity, among other attributes. What differed in the two groups was how they were located within the discourse—whether they were directly addressing a student concern and used to build the lesson or were done as verificatory experiments.

The time taken for teaching the units was different in the two modes (Table 2). The teachers in the comparison groups took less time for common units, and used the extra time they had to teach additional units (cells, electricity and magnetism). The difference was pronounced in the unit on density which is a difficult concept for middle school students to grasp. Its in-depth exploration requires a considerable investment of time and planning on part of the teacher, and involves many pre-requisite concepts and students' mathematical as well as hands-on skills. Notably, in the discussions prior to the intervention period, teachers of both groups had gone over, in detail, the difficulties students may have with this concept.

Results and Discussion

Comparison of the Two Modes of Teaching from Video Records and Field Notes

The characteristics of the two modes of teaching are described throughout the following sections in the context of what emerged from students' diaries. Here we summarise

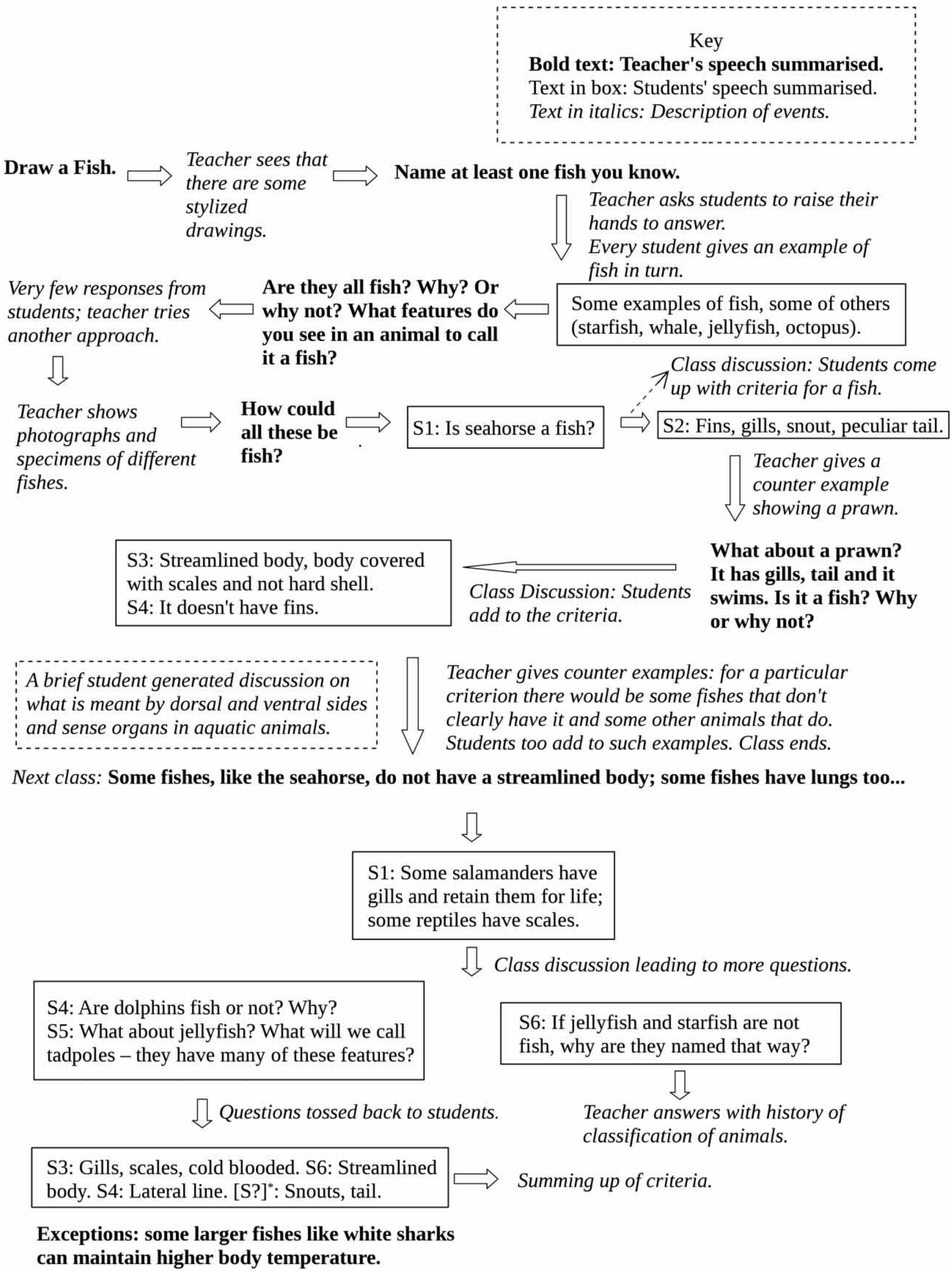

Figure 2. A flowchart of the teaching sequence for 'what makes a fish a fish?' in inquiry mode: guiding students to arrive at explanations using activities and discussion. Note: 'Sn' indicates Student 'n'; [S?]* indicates multiple overlapping responses by students who could not be identified from videos due to the camera angle in use.

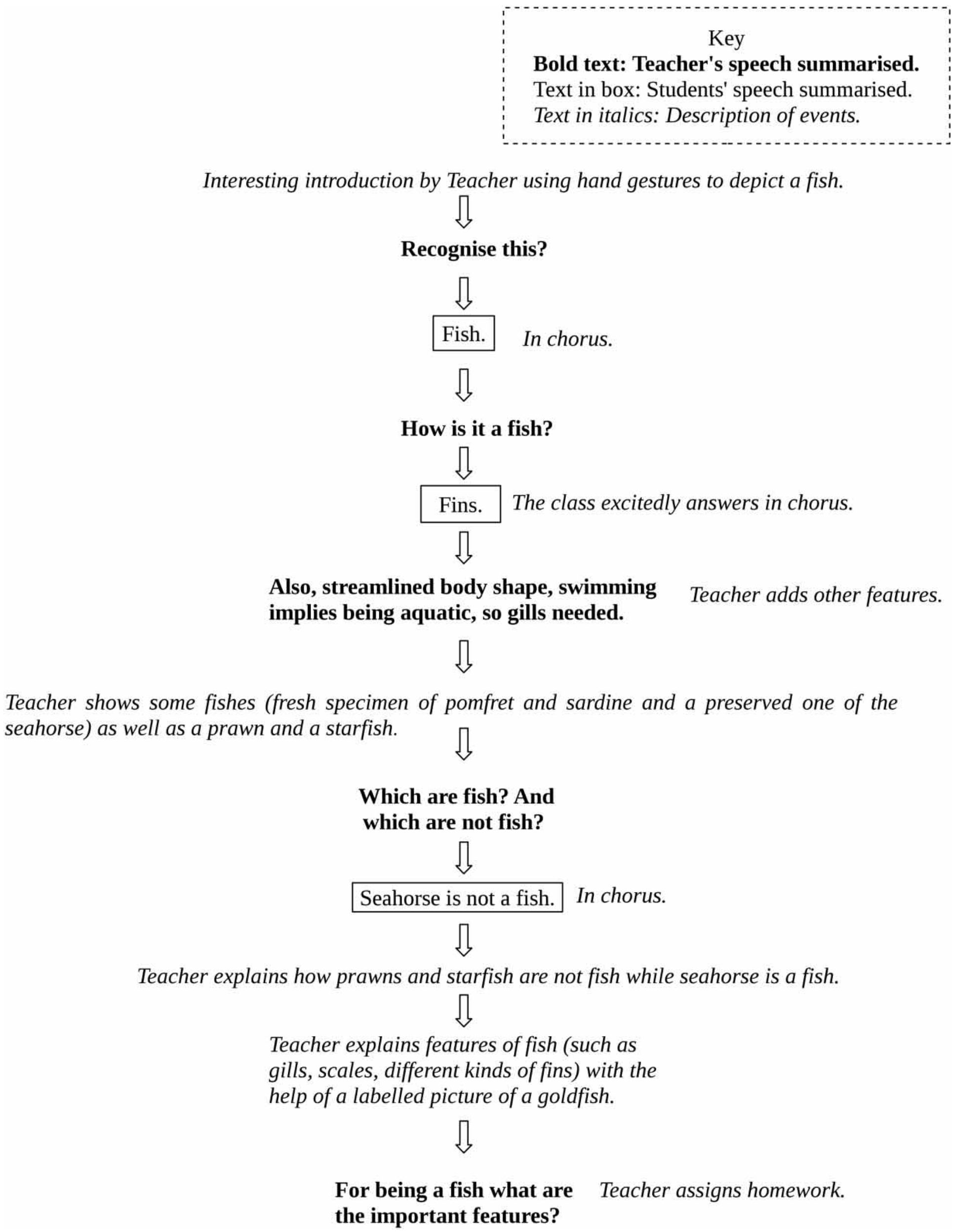

Figure 3. A flowchart of the teaching sequence for 'what makes a fish a fish?' in traditional mode: explaining the concept with the help of activities

aspects of the two modes from video data and field notes. Teachers in the comparison group often started the class with questions, solicited them during class, and appreciated students' questions (if any). Indeed, they had explicitly told students at the beginning of the intervention not to hesitate to speak or ask questions. However, unlike in

Table 2. Number of classes taken by teachers of the two groups for different units

Units		Number of classes	
		Inquiry group	Comparison group
Biology units	Fish	15	14
	(circulatory and respiratory system)[a]	(8)	(4)
	Structure of living cells	–	3
	Total	15	17
Physics units	Density	20	9
	(Volume)[a]	(3)	(1)
	Electricity and magnetism	–	7
	Total	20	16

[a]These were sub-topics that differed considerably in terms of time taken to transact them.

inquiry classes, rarely was a discussion developed or sustained in the class. Table 3, which complements (Figures 2 and 3), shows the episodes of discussions and their durations in both groups for the first three days of the intervention to illustrate this difference. An interaction that was longer than a single Initiation-Response-Feedback cycle was treated as a discussion for the purpose of this table; it thus includes interactions where there were several distinct (non-chorus) responses (R's) by different students to a teacher's question (I), each followed by the teacher's acknowledgement/feedback (F); this was the only kind of discussion seen in the comparison group. By contrast, in the inquiry a discussion consisted of long I-R-F-R-F … chains, building on a topic, as can be seen from Figure 2. Also, there was clearly a much wider participation in discussions in inquiry, as is given in Table 4.

In the inquiry classes, activities and experiments were an integral part of the teaching and were investigative in nature, with students' observations leading to classroom discussions; further development of the lesson depended on what students concluded from the experiment. This can be seen in the contexts given in Table 3. In traditional teaching, they were most often verificatory in nature. Experiments (and discussions centred around them) dominated inquiry classes, whereas direct explanation dominated the traditional ones (Figure 4). In addition to discussions, in inquiry a considerable fraction of class time was also spent in student activities such as drawing, observation and each student reading his/her poem, thus accounting for the difference in time taken to cover the units in these two modes of teaching.

In the following sections we illustrate our findings from the analysis of diaries with quotes from students' writing. A quote given to support a particular claim may imply other aspects too; we have used it to highlight the most prominent aspect. We first describe and discuss, separately for inquiry and traditional classes, the characterisation of the two teaching modes that emerged from students' diaries. In subsequent sections we juxtapose the differences in a range of outcomes of the two modes as evidenced by their diary entries.

Table 3. Comparison of class time spent in discussion and direct explanation

	Discussion time in min:sec (with context)	Direct explanations in min:sec (with topic)
Density Day 1 (I)	09:15 (demos to compare capacities of pairs of bottles); 02:40 (volume of an irregularly shaped object); 03:35 (estimate of capacity of differently shaped bottles); 13:20 (why the measuring scale is non-uniform in a non-cylindrical jar) **28:50/53:20**	
(T)	01:50 (which bottle of a pair is bigger? (repeated twice)); 02:10 (measuring cylinder and cup, which one will hold more water?); 01:10 (Properties of liquids) **05:10/ 46:25**	05:10 (what is volume?); 02:25 (properties of liquids and solids); 08:00 (dimensions and orientation) **15:35/46:25**
Day 2 (I)	03:20 (students' experiment: immerse objects and measure overflow); 08:25 (does the amount of overflow depend on size or weight?); 06:10 (is wood 'lighter' than water?) **17:55/53:20**	
(T)	05:10 (mass and weight); 02:00 (floating and sinking—bittergourd and carrot); 12:30 (floating and sinking—sponge ball and rubber ball); 07:20 summary of what was learned **27:00/01:00 h**	05:30 (volume—units); 05:00 (mass); 05:50 (floating sinking—wooden blocks); 03:20 (arrangement of particles in solids, liquids and gases); 05:50 (air is not responsible for floating); 02:40 (fractions submerged); 04:30 (relation of mass and volume to density) **31:50/01:00h**
Day 3 (I)	07:00 (previous day's experiment—have students changed their answer? If so, why?); 11:00 (why does the volume of overflow equal that of the immersed object); 02:00 (measurement errors in this experiment); 10:00 (demo: relating volume of overflow of a closed bottle to its capacity); 13:00 (calculation of volume by L X B X H and history of measurement units and formulas) **43:00/01:04:31**	
(T)	05:35 (what is density?); 06:10 (calculation of density of a wooden block); 02:00 (liquids denser than water) **13:45/42:00**	02:10 (density of water); 02:00 (Dead Sea); 03:00 (story of two donkeys carrying salt and cotton) **07:10/42:00**
Fish Day1 (I)	05:20 (sea horse: a fish or not?); 05:00 (comparison: pomfret and sea horse); 05:30 (dorsal fin); 03:00 (positions and names of fins); 03:10 (comparing fish specimens) **22:00/33:30**	
(T)	01:30 (characteristics of fish); 01:15 (dolphin as a mammal); 01:00 (streamlined shape of fish) **03:45/29:00**	05:30 (external features); 01:50 (why dolphins and whales are not fish); 02:00 (number of species of fish); 06:30 (features of fish with the help of pictures); 09:10 (body symmetry of fish and positions of organs) **25.00/29:00**

(*Continued*)

Table 3. Continued

	Discussion time in min:sec (with context)	Direct explanations in min:sec (with topic)
Day 2 (I)	08:40 (lateral sides of fish); 04:35 (meaning of anatomy); 12:40 (lateral line); 18:35 (streamlined body—its advantage in swimming, other body shapes aiding swimming) **44:30/51:10**	
(T)	03:00 (what scales are made up of); 02:00 (function of mucous); 06:20 (lateral line function and rounded eyes) **11:20/30:50**	05.00 (why sea horse is classified under fish); 03:20 (lateral line position and secretion of mucous from the gland beneath the scales) **08:20/30:50**
Day 3 (I)	05:00 (difference between the shown specimens and barbels of cat fish); 07:00 (shapes of fins); 05:25 (pectoral fins of shark) **17:25/1:04:50**	03:25 (Groups of fish) **03:25/1:04:50**
(T)	02:40 (does a catfish have scales?); 04:00 (porcupine fish—defense strategy) **06:40/ 44:10**	07:50 (presence of adipose fins and finlets in different kinds of fish); 09:10 (fin structure and unusual fins); 03:20 (interesting fish like butterfly fish and angel fish and their parts); 08:10 (modified scales) **28:30/44:10**

Note: Time in minutes:seconds is followed by the context, given in parentheses. The total time for discussion/direct explanation is given in bold at the end of each entry, as a fraction of the class time.

Characterisation of the Two Modes of Teaching Implicit in Diary Entries

Traditional teaching. Diary entries of students in this group provide evidence that the instruction here was different from the commonplace science teaching in their schools in that there were many activities, the class was kept interactive through teachers' questions, and audio-visual material was used: 'Teacher showed us many experiments and examples. She asked us many questions'. 'This is the reason I like the camp because the same topics of school taught with experiments and practicals seem more interesting'. 'Our teacher showed us parts of fish and about fish on LCD screen. She also showed us real fishes'. 'Then teacher asked everybody to give one example that [sic] how magnets are fun to play'. The teachers were perceived as friendly and many of the students said that they 'explained nicely'.

However, it is also evident through students' descriptions that though interactive and activity-rich, the teaching in the comparison group was in the transmissive mode where concepts were explained directly and there was an emphasis on definitions and formulae: 'We studied about buoyancy and wrote laws of floating', 'Teacher taught us about volume and gave definition',

> The definition of density is the space occupied by the mass in a unit volume is called density [sic]. The unit of density is gram/cm^3 or gram/cc. The density of water is 1 gm /cm^3. The formula to find density is mass/volume.

Table 4. Comparative data on students' participation in class for the first three days

		Instances of students volunteering a question/ comment/response	No. of distinct students	Duration of interaction (min:sec)/ The total class time
Density				
Day 1	(I)	31	13	39:00/53:40 (14:40 students' experiment)
	(T)	5	4	26:40/37:25 (10:45 for calculation)
Day 2	(I)	12	10	18:00/54:40 (36:40 students' experiment)
	(T)	29	9	59:10/59:10
Day 3	(I)	31	13	43:00/43:00
	(T)	5	4	26:10/41:20 (15:10 for calculation)
Fish				
Day 1	(I)	26	13	24:20/33:00 (08:40 students' drawing)
	(T)	14	7	29:00/29:00
Day 2	(I)	74	22	49:20/49:20
	(T)	5	5	27:30/27:30
Day 3	(I)	17	8	25:50/54:20 (16:30 observing specimen + 12:00 video screening)
	(T)	5	4	40:30/42:30 (03:00 video screening)

Note: Participation in polls (for e.g. which of a pair of bottles had greater capacity) have been excluded from the count for both cohorts.

As demonstrated in the last example above (previous paragraph), the class was kept interactive (typically using questions that placed a low cognitive demand on the student) but for interaction per se, not to develop the lesson. The way students wrote about the activities is indicative of these being verificatory and not investigative in nature: 'We learnt about density and **did some activities to clear the concept**' (emphasis added by author).[1] 'We learnt that thicker the wire in size, the lesser the resistance it has and the longer the wire, the more the resistance it has. **We did an experiment to see the difference**' (emphasis added by author).

Inquiry teaching. Students' entries in this group prominently reflect the focus on inquiry. It is interesting to note that many a time (Table 5) students wrote about a lesson or activity describing it as a question to be pursued (e.g. 'Is that the sea-horse is a fish? We were asked to reason why it is fish [sic]', 'Why 1gm of gold is

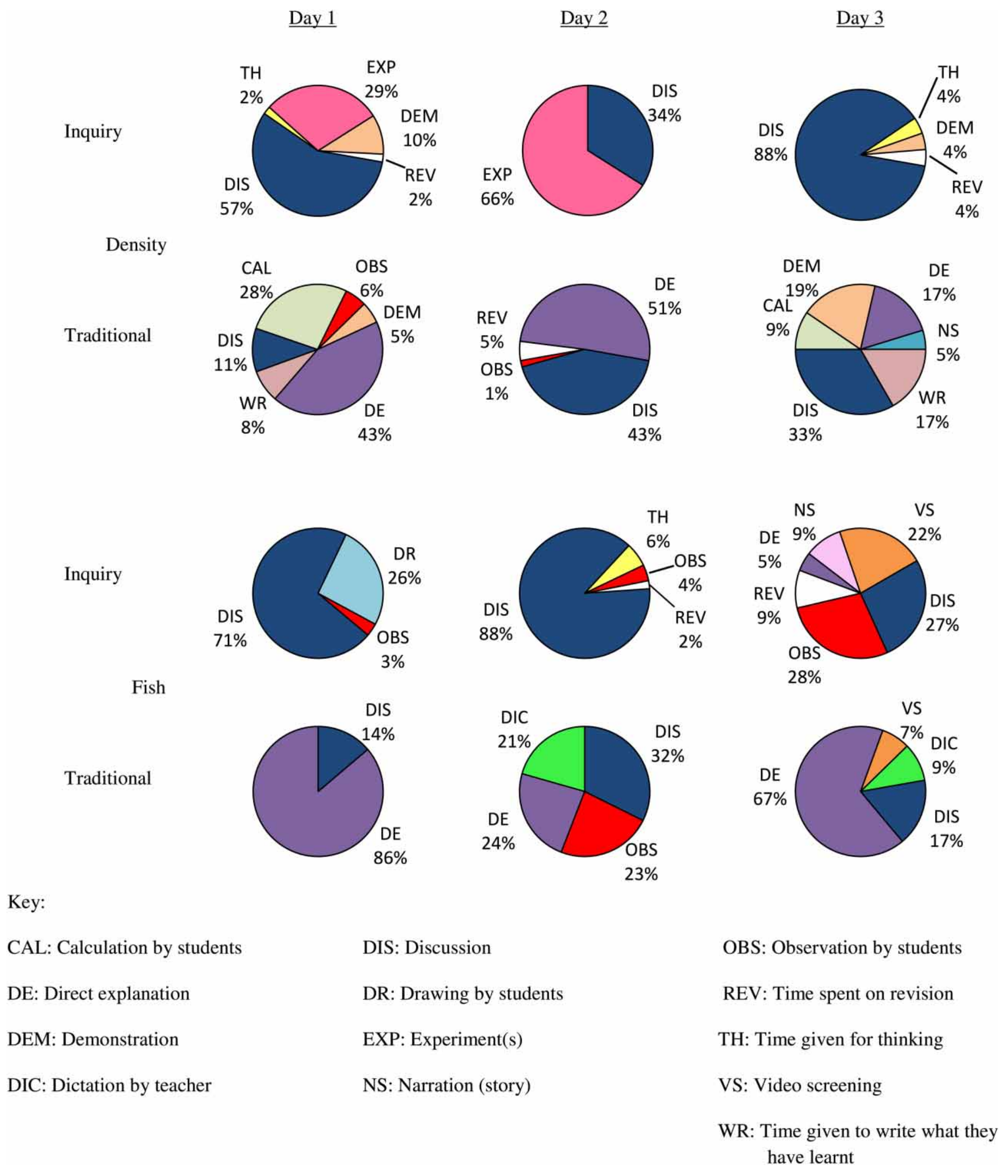

Figure 4. Day-wise comparison of time taken for different classroom activities for the first three days, illustrating how they were conducted in the two modes of teaching

denser than 1gm of silver?', 'How did people in the past consider the circulatory system to be in human beings?'). Learning through inquiry involved higher level cognitive demands as reported by students and was contingent upon observations and discussions in class: 'We did an **experiment to find out if** (emphasis added by author) the water fell out [overflowed] because of the mass or size [of the object]'. 'The crown battle had started … we were thinking how Archimedes had

Table 5. Comparison of the content of diary entries of the two groups

Categories coded to analyse the content of diary entries	No. of instances in inquiry group	No. of instances in comparison group
1. Summaries of what was done		
Descriptions of the events in class (what was done and how)	140	53
Descriptions of the lesson or activity framed as a question	31	6
Descriptions of class events as debates/argument/discussion	52	1 + 6[a]
Total	223	66
Descriptions of the teacher's action as 'told'/'taught'/'explained' with details	96	3
Descriptions of the teacher's action as 'told'/'taught'/'explained' without any detail	15	28
2. Summaries of what was learned[b]		
• Understanding of the content		
Instances with conceptual errors	11	47
Instances showing conceptual understanding	79	64
• Way of describing		
Limited to recall of definitions, scientific terms and principles given by teacher + interesting facts told by the teacher)	4 + 16 [c]	50 + 5[c]
Personalised descriptions of what was learnt in their own words	70	46
• Source of what was learned		
What was told/explained by the teacher	53	86
Students' reasoning as answer to a question or as inference from an experiment and/or class discussion	37	15
Total	90	111
3. Expression of what was felt		
Positive	68	57
Negative	6	4
Reflective notes on teaching–learning	10	2
Total	86	63
4. Expression of own involvement		
Statements explicitly showing a sense of shared epistemic authority	35	–
Statements showing modification of conclusion/tentative solutions	7 + 6[d]	1 + 11[d]

[a]6 of these were contributed by one student.

[b]Each instance coded under this category was further coded according to the three overlapping sub-categories.

[c]Number of interesting facts recalled

[d]Responses to a question framed as 'give your guess' and explicitly asking why it may or may not be correct.

decided which crown is of gold and which is of silver'. 'After we said [sic] our guesses, our teacher **would find the answer** (emphasis added by author) by … '

> Teacher asked us what would happen if there were no alveoli in lungs or all the alveoli were somehow fastened to lung walls, what would happen due to this. I enjoyed the discussion very much. I also gave good answers.

'All gave good answers but some didn't manage to do it'.

The teacher helped them meet these high cognitive demands by being responsive to their ideas and difficulties and providing the necessary scaffolding. There was an explicit, gradual building of the lessons—subsequent activities and discussions were based on the earlier ones. This scaffolding is illustrated in the teaching–learning sequence given in Figure 2, where the teacher elicits the answer from students through a series of questions and counter-examples to students' statements. This aspect is also reflected in students' entries: 'She told us to guess the answers from what we had learned before'.

> I like today's class taken by her. She revised all the experiments and things that she told us about sinking and floating objects. She told us and we also saw that things which have air, it is not necessary that they float.

'It was a superb class—we discussed about [sic] the experiments and our doubts [sic]'. 'Teacher asked some questions which were not easy … By this method [1000cc = 1 litre] it was easier to answer the questions and the concept was clear'. 'She asked a question which in the end almost all could answer'. We note the absence of definitions reproduced verbatim in the diaries of the inquiry group, a reflection of the teaching not being centred on definitions.

Students' Affective Responses to the Teaching Modes

Students' diary entries in the two groups differed in both the number of entries as well as in how detailed they were. Students in the inquiry group wrote almost twice the number of entries on an average compared to the group taught traditionally (Table 6). Also, the journal entries of the inquiry group were longer, with a significantly higher number of words (on average) than those of the comparison group (the means and the range of values are given in Table 6); the distributions in the

Table 6. Comparison of the quantitative aspects of diary entries of the two groups

	Inquiry group	Comparison group
Number of diaries submitted	19	18
Number of days of interaction	18	18
Average number of diary entries per student	15	7
Total number of diary entries for the group	284	126
(Geometric) mean number of words per entry	86 (range 152–48)	55 (range 206–23)

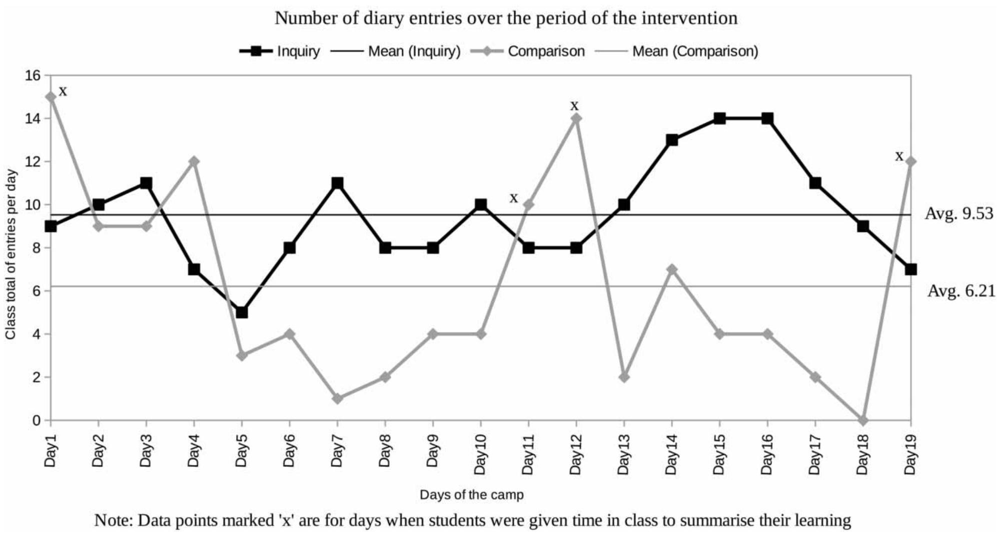

Figure 5. Day-wise plot of diary entries by the two groups

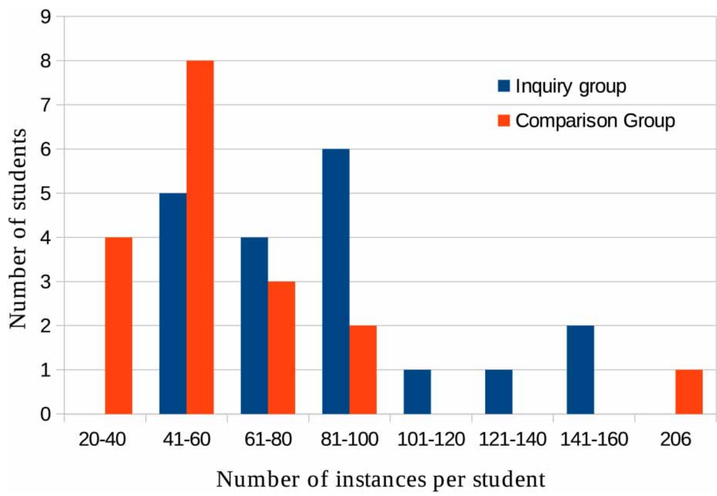

Figure 6. Average number of words in a diary entry

two groups (Figure 5) differed significantly (Mann–Whitney U = 77, p = .0045, two-tailed). Moreover, diary writing was voluntarily sustained over the four-week period of the camp in the inquiry group. Figure 6 shows a plot of the class total of daily dairy entries for the two groups. Note that in spite of being given specific time for making entries in class on four occasions, the average number of entries per day is smaller for the comparison group. The students in the inquiry group clearly had more to say (and made the effort to do so) than the comparison group. The amount of optional diary writing, and how detailed it is, is indicative of the degree of involvement in learning (Hadzigeorgiou, 2011).

Table 7. Comparative data from students' notebooks indicating students' engagement levels

	No. of instances in inquiry group	No. of instances in comparison group
Spontaneous notes made in class (including noting teacher's questions asked during teaching)	29	8
Attempt at an answer or question	15	4
Students' questions noted down spontaneously	23 + 13[a]	3

[a]One of the students asked 13 of the 36 questions.

Additional evidence for the higher level of engagement in the inquiry group comes from the higher amount of spontaneous notes by students during teaching and the large number of self-generated, spontaneous students' questions written in the notebooks (Table 7). These questions were voluntary (once in each of the groups, the teacher asked students to come up with at least one question each; we excluded those questions from our analysis here; only their spontaneous questions are included). Students' spontaneously getting re-engaged in a topic, and for a longer period, is evidence of their greater engagement with it (Engle & Conant, 2002). We note that these students' in-class engagement with the topic was also higher, as can be seen from the nature of their participation in class—Figures 2 and 3, show that the number of students who individually contributed to classroom discussions was greater in the inquiry classes (See also Table 4). More students making substantive contributions to the classroom discussion is an indicator of engagement (Engle & Conant, 2002).

Analysis of these spontaneous questions written in class also revealed several differences in learning between the groups. Out of the 36 questions asked by students in the inquiry group, 22 probed and built on the content taught while the rest were questions out of general curiosity and not related to content from the classes. We coded all the questions according to types described by Chin, Brown, and Bruce (2002). Only 9 of the 36 questions were factual or 'basic information' questions while the rest, (75%) either sought comprehension, indicated anomaly detection or involved thought experimenting. Chin et al. (2002) classify all these categories as 'wonderment' questions. They point out that wonderment questions are reflective of a deep approach to learning and further stimulate productive discussion and higher order thinking. Some examples of questions from the inquiry group, and all the questions from the comparison group are given in Table 8. Note that in Figure 2 students' questions asked in class were also wonderment questions leading to further class discussions. Marbach-Ad and Sokolove (2000) too found that students from 'active learning' groups were better able to pose questions and at a higher level than those taught in a traditional lecture format. Our findings further suggest that in active learning environments students ask more wonderment questions.

The spontaneous notes made in class by students in inquiry consisted of (a) teachers' questions noted down to think over them (b) pre-requisite facts (such as the relative sizes of proton and atom or atomic weight and size of silver and gold)

Table 8. Students' questions: some examples from the inquiry group, and all the questions from the comparison group

Questions from inquiry group	Questions from comparison group
When we took a clay ball which was hollow from inside it sank and when we covered a (plastic) ball with clay it still floated. Why?[a]	What are lanthanide and actinide series?[c]
Can some things float *and* sink?	Does starfish also have parts like other fishes?
If we put ice in very cold water will it melt or not or will it take time to melt?	Why do we categorise sharks as fish and not as mammal though most of the sharks give birth to young ones?[a,b]
How big is an atom and a nucleus?[c]	
If starfish, jellyfish are not fish, why do we call them fish?[a,b]	
Why is it there no nucleus in a RBC?[a]	
Fishes get birth [sic] in water, they die in water but from where does air come inside the air bladder (swim bladder) inside them?[a]	

[a]These questions probed or built on what the teacher had taught.

[b]These questions were asked after the topic had been taught.

[c]These questions are examples of basic information questions while the rest are instances of wonderment questions.

which they needed to solve a problem and (c) wonderment facts, for example, 'The hotter the atom, the faster it moves. It never stops' (although strictly speaking it is the material that is hot not the atom) and the number of red blood cells (RBCs) in a drop of blood.

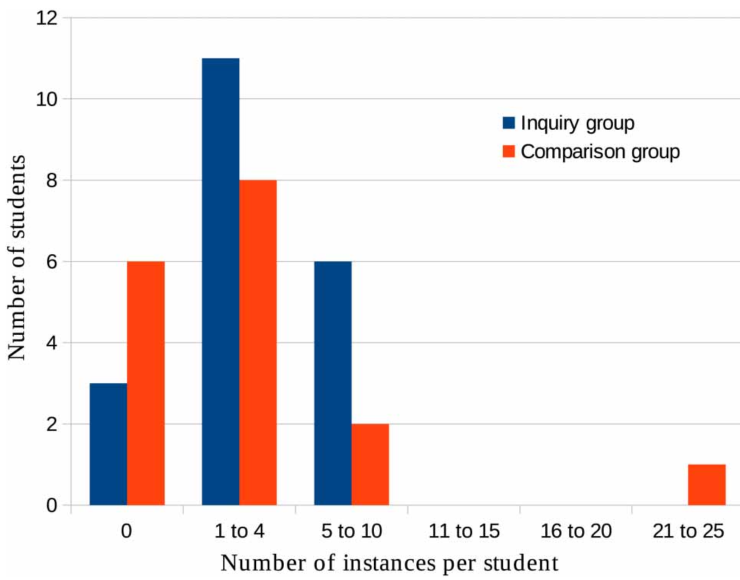

Figure 7. Instances of expression of positive feelings

Table 9. Comparison of the categories of positive responses from students

Aspects that students liked	No. of instances in inquiry group	No. of instances in comparison group
The class in general	15	28
Teacher or teaching	7	9
Experiments and demonstrations	24	14
Cognitive engagement/high cognitive demand	12	1
Whole-class discussion	4	0
Videos and slide shows	6	5

While students in the inquiry group gave a lot more detail about what happened in their class, instances of expressing feelings about the teaching–learning and those summarising what was learned were not too different between the two groups (Table 5). Although the number of entries expressing positive feelings was also almost the same in both groups, their frequency distribution was different (Figure 7). Note that 22 out of the 57 entries in the comparison group were written by a single student; a maximum of 10 entries were written by one student in inquiry. Both cohorts equally reported liking their teachers, the way of teaching in their class, hands-on activities and the audio–visual material (Table 9). In addition, students in inquiry reported that they enjoyed the classroom discussions: 'It was great to get a chance to present our views in the debate'. 'This question started a hot debate. We said [sic] and **convinced the teacher of our answer**' (emphasis added by author). 'This whole day [one class period] went in asking questions and giving/finding answers. I was a little bored and also happy listening to everybody's questions and answers'. 'We asked our yesterday's [sic] unanswered questions and doubts [sic]'.

These students also noted that they appreciated the component of history of science built into the teaching: 'We were back in the past with some great people of that time—Aristotle, Galen and William Harvey … She told us about the experiments done by Harvey to find out about circulation', 'Teacher told us about this brilliant scientist, Archimedes. I liked today's class taken by her'.

While teachers in inquiry have noted that students enjoyed intellectual challenges (Kawalkar & Vijapurkar, 2013), it is interesting to find that students have themselves reported their higher cognitive engagement in problem-solving: 'It was a good and tricky sum [problem] **but we tried our best**' (emphasis added by author). 'Today we learned how to prove that an organism is a fish. It made us very excited'.

> Today we had to find the volume of a thermocol [Styrofoam] piece. We dipped thermocol in water but it floated … we kept putting washers on it till it completely sank, but it was difficult because the block with washers would always topple. So we stuck tape … whole day's time it took [sic] [a two-hour class period]. But it was enjoyful [sic].
>
> Teacher showed us a picture and we were guessing which animal it was … but we all felt it was difficult. First I thought it was a dolphin then I changed my mind but I was sure that it was a mammal. I again had to change my mind as its tail was moving right to left but mammals' [tails] move up and down. The most shocking thing was it was a reptile.

Instances from students' diaries in inquiry show that these students reflected on their self-understanding, reporting not only what they found difficult but also what intrigued them. Some instances from their diaries in which they were attentive to what fascinated them in class and articulated it in detail: 'I **noticed** (emphasis added by author) the gills and the tail fins of the fishes. They were all different-shaped and interesting'. 'We were shown different pictures of unique and beautiful fish'. 'We washed the gills and touched them. It was soft and had many filaments. There were many eggs in the egg pouch'. There was also an indication of students gaining a sense of self-efficacy in learning science: 'Today we learned how to prove that an organism is a fish. It made us very excited. **I answered many questions**' (emphasis added by author). 'Today we did experiments and brought the poems we wrote on fish. **I wrote a good poem**' (emphasis added by author). 'We **~~answered,~~**[2] **tried to answer** (emphasis added by author) which ones were fish and which were not. **Almost all my answers were correct**' (emphasis added by author).

The negative responses of students in both cohorts were about some of the classes being 'not so exciting' or even 'boring'. Of the two instances in inquiry, one student complained that the same topic continued for three consecutive days and another said, 'Today I did not enjoy as much as yesterday. We enjoyed the first session but after that I was not understanding[sic]'. Evidence of such conscious awareness of their learning was absent in the diaries of the comparison group. Although many students in the comparison group said that the teacher explained well, there were conceptual errors in their learning while in inquiry, students said it was difficult but they tried, or were 'not able to understand'.

Comparison of Students' Content Learning

A large number of instances of what was learned, written by the comparison group (47 as compared to 11 in inquiry), indicated a lack of conceptual clarity, and several instances of misunderstanding of the concepts. This was particularly stark in situations when there were inverse relations or more than two variables involved in understanding a concept such as in density (21 of these 47 incorrect instances were related to density). Some examples: 'Objects which are not heavy will float, heavy objects will sink'. 'If the volume of an object is **greater than the mass** (emphasis added by author) then the density is less as the molecules are loosely packed'. 'We learned that the object which has **more mass and volume** (emphasis added by author) has less density and the object which has less mass and volume has more density. So density is related to mass and volume'.

> Density is the property of matter … [within the same entry] When there is a comparison between two objects of same material but of different sizes then, object with bigger size will have more density as it will have more weight because it is having [sic] more quantity of matter … Thus objects of **same material but of different volume show different density** (emphasis added by author).

Notably, these common conceptual difficulties among students (such as the assumption that weight alone determines if something sinks or floats or the difficulty in understanding inverse relationships) were discussed at length with the traditional teacher during the preparation for teaching the density unit. However, these difficulties were not explicitly addressed in class and they persisted after teaching. In inquiry teaching they were tackled head-on during investigations, for example, basing the density unit on a question—whether the amount of displaced water depends on the weight or volume of the immersed object. Sometimes, incorrect statements in the entries of the comparison group immediately preceded or were followed by related correct statements indicating incoherence, as in the last quote above. When conclusions of an experiment were recorded by students of the comparison group, they were often incorrect: 'Carrot sinks [while bitter gourd didn't] because it has more water molecules'. 'I never knew that salt has such high voltage' (in an experiment to compare conduction of electricity through plain and salt water). 'Saline water has less density. This was proved by an experiment that egg or potato sinks in normal water but in salty water they float'.

Also, a few entries reflected incorrect content told by the traditional teacher (e.g. 'Due to their big sized body, sharks need to swim always to keep their body afloat.') This is perhaps indicative of the classroom culture in the traditional teaching mode, which is by and large uncritical and where facts and concepts are not used to build a coherent picture.

In the inquiry group too, students arrived at incorrect conclusions although as noted above there were only a few such instances. Some examples: 'Today, teacher showed us three cubes with different number of nails pierced in them. First one floated on top, second one sink [sic] and third one sank to the bottom. **This shows the density of water**' (emphasis added by author). 'Then teacher asked us a question—volume [of displaced water] depends upon what? I think it depends upon its weight, size and mass'.

We note that these errors of observation, arguments and confusion such as between height and volume were made in the initial stages of the sub-topic, as opposed to the comparison group's errors that were made after instruction. As the unit progressed, building on concepts tackled through earlier activities and discussion, there were opportunities for such errors to surface in the class and were directly addressed by the teacher. This might account for the fewer number of content errors in the diary entries in inquiry.

The difference in conceptual clarity is not entirely surprising given the difference in students' engagement with the material being taught, as is seen from the quantitative analysis of diary entries. This difference in cognitive engagement is also evident in their descriptions of teacher's action as 'told', 'taught' and 'explained'—descriptions that were qualitatively very different in the two groups (Table 5). In the comparison group they tended to be used in a summary fashion with no detail—'the teacher taught us density', 'taught volume' or 'she told us about different parts of fish', whereas in inquiry *what* was told or taught was specified and described, often in rich detail—'she told us why the volume depends on the size of the object', 'she taught us how SI units are derived' or

> she taught us more about parts of fish—I saw many parts heart (red colour) [with a small drawing], liver [with drawing], liver was covered with fats, lateral line, observed scales in which there were rings like round patterns and scientists can know their ages only by looking at scales of the fish … there is also a swim bladder which is white in colour and is filled with gases … (Use of the word 'told' to describe instructions such as 'she told us to ask questions' were excluded from the count).

The difference in the time needed to transact the units in the two modes of teaching (Table 2) was larger in the case of the unit on density. So there is some merit to the argument, often used against adoption of teaching through inquiry, that it is more time-consuming. At the same time, our findings suggest that the time and attention in inquiry is well spent especially for complex concepts such as density that are known to be difficult for school students. The advantage of time saved by teaching the traditional way was far outweighed by the lack of conceptual clarity among the students.

Differences in Students' Conceptions of Learning

There were instances of students' independent reasoning in the traditional group although fewer in number (Table 5): 'More the volume, lesser is the density. The bitter gourd had more volume but less density so it floats in water and the carrot had less volume but more density so it sinks'.

> We saw that when we put a raw egg in pure water, it sank but when we put the same egg in salty water it floats because when we put salt in water, the salt combines with water molecules and increases the density and thus, the egg is able to float.

However, more often than not the learning described in their entries was a mere recall, prone to errors, of facts, definitions and laws covered by the teacher; 'Amount of matter in an object is called mass. When gravity pulls on the mass the object is said to have weight. The formula to find the weight of an object is kg x force (9.8 N)'.

> The teacher also taught us the Archimedes' principle. The Archimedes' principle states that any object which is wholly or partially immersed in a fluid is buoyed up by a force is equal to the weight of the fluid displaced by the object.
> In Biology class, the teacher explained about scales which are present on topmost layer of the fish body and our teacher told us that scales are made up of connective tissue and they are arranged like tiles of the roof.

Note that these students expressed what was learned mostly through formal, conventional statements reproducing canonical knowledge. This indicates that students in this group frame learning in their classroom as 'doing the lesson' (Jimnez-Aleixandre, Rodrigues, & Duschl, 2000) wherein the teacher has social and epistemic authority in what is 'correct' and the students are more focused on simply repeating explanations from the textbook or teacher (Audet et al., 1996) rather than on constructing or articulating explanations. These kinds of students' epistemologies, that is, the tacit conceptions of what knowledge, reasoning and learning in science entail

(Scherr & Hammer, 2007) are reported to be linked to the adoption of memorisation and reproduction of information as learning strategies (Edmondson & Novak, 1993; Purdue & Hattie, 1999). Such a conception of learning as acquisition and reproduction of facts also points to a conception of science as self-evident or objective truth (Edmondson & Novak, 1993)—there is uncritical acceptance of the content under discussion even if it is at odds with students' own conceptions.

In contrast, in the inquiry group a higher number of summaries of what was learned were based on experiments, demonstrations and class discussions (Table 5) indicating a frame of 'doing science' (Jimnez-Aleixandre et al., 2000) wherein students assess an idea as 'true' by whether it makes sense to them and is based on evidence and arguments. Students' statements such as '**We were deciding** (emphasis added by author) which kinds of objects float and which ones sink', 'We convinced the teacher of our answer', 'Then we raised doubts [sic] which **teacher** and **we answered**' (emphasis added by author) reflect students' internalisation that they shared epistemic authority with the teacher. In a recent paper, Siry (2013) discusses the importance of this shared authority in involving students in, and encouraging, scientific inquiry. Also, these students described what they had learned in a personalised way, in their own words, pointing to internalisation and a better understanding of the content. Their endeavour to construct and articulate explanations, often in collaboration with others, is evident in the higher number of instances of students' own reasoning to answer a teacher's question, explain an observation, infer from an experiment or as resolution of a class discussion: 'We had to find out the volume of the object from the water displaced. **As per my observation** (emphasis added by author), the volume depends on the size of the object, but in one case it was not true'. 'Today teacher brought some objects, she dropped them in water and **through this experiment** (emphasis added by author) we learned that there is no effect of air in making an object float or sink'.

> Teacher took 3 cuboids of thermocol of different sizes—small, medium, large with the same number of nails, and she placed it in water. So **from this we can understand that** (emphasis added by author) the thing which has more volume will float and less volume [sic] will sink in water. Today we discussed that [sic] why does a fish have black scales and white scales at the bottom. This is because, if a predator is at the bottom of the fish & the lower surface of a fish will be white, this will be invisible because it will match with the sunlight falling on the ocean.

'We figured out the area of the room and compared it with the area inside the lungs'.

Thus, a salient feature of students' learning through inquiry emerged, apart from the differences in conceptual and affective aspects discussed earlier, that they have internalised, implicitly, the inquiry approach to learning science – 'we did this experiment to find out if … ', 'after much discussion we concluded that … '.We believe this is particularly significant because these aspects were not explicitly verbalised to students but were picked up by them from the way the classes were taught: classroom discussion and argument were used as an integral part of the teaching strategy, initiated through questions; activities and experiments were designed to be investigative, with further lessons being built on students' conclusion drawn from the activity. Thus students' diaries of the two groups reflected an epistemic difference in their conceptions of learning science—whether it is 'explained nicely' or it is 'thinking how' and 'to figure out [something]'—see the entries under 'Source of what was learned' and 'Expression of own involvement' in Tables (1) and (5).

Limitations and Methodological Concerns

We acknowledge the limitation of small sample sizes in our study. Along with this, the specific situational context (out-of-school, summer classes) may also reduce generalisability or transferability (Lincoln & Guba, 1985) of findings. However, we have attempted to provide rich, thick descriptions of the classroom interactions through extensive quotes from students' diaries which contribute to the transparency and credibility of our findings. We hope that this will help the reader decide on the transferability of the findings to other settings.

Students' conceptual understanding could not be independently assessed using pre- and post-intervention tests. This could have corroborated our findings and helped in establishing diaries as an effective stand-alone tool for assessing concept acquisition.

A methodological issue that is a concern in comparative studies such as ours is whether both groups in the study should be taught by the same or different teachers. On the one hand, it may be argued that aspects of a teacher's personality may well affect outcomes in the classroom, and therefore comparison of outcomes between groups taught by different teachers is not advisable. On the other hand, it could be argued that teachers would have a proclivity to teach through a particular teaching mode and therefore may be biased against the other. Both approaches have been taken by researchers; in the study by Wilson, Taylor, Kowalski, and Carlson (2010) the same teacher taught through commonplace and inquiry methods while in the study by Cobern et al. (2010) different teachers taught the two groups that were being compared. Our stance is that the same teacher cannot do justice to teaching in both the modes, and outcomes will be affected by bias due to the teacher's preference. Indeed, teachers in this project who were trained to teach through inquiry reported that they cannot switch to traditional teaching even if needed (Kawalkar & Vijapurkar, 2013). We have focused in our study on what the teacher does in class; after all, the often intangible qualities of a teacher's personality mediate outcomes through the way they are manifested in the teaching practice. Having two different teachers in each of the modes takes care of the influence of the teacher's individual personality to some extent. Also, as we have reported, teachers in both groups were well liked by their students and were perceived by them as friendly and good at teaching.

Concluding Remarks and Implications

There are several advantages of using classroom artefacts to study science teaching and learning (Martinez et al., 2012). They can capture important components of the teaching–learning process that classroom observations and tests cannot. Our analysis of one such artefact—students' diaries—of inquiry and traditional classrooms in this study brought out several aspects of teaching as well as learning in these settings, many more than we had anticipated. The open-ended and reflective nature of the entries also enabled a more nuanced look at the meaning and outcomes of the classroom experience for students in these groups. A spectrum of outcomes, and clear differences in those outcomes between the two modes of teaching, emerged through this analysis —conceptual, affective and epistemic.

Students' conceptual understanding and the classroom events that led to their conceptual clarity became evident from diary entries, as did the nature of their difficulties with a particular concept. While most assessments test a concept after the teaching, that is, the final stage the student arrives at, regular diary entries of what students are learning provide information about students' emerging conceptions. Open-ended, reflective diary entries, being spontaneous and generative (unlike responses in tests), have the potential to truly assess learning, and can thus be useful for formative assessment (although in our study they were not used for that purpose). Although diary writing is not a common practice at all in India, this artefact was easy to introduce and yielded rich results on several aspects of teaching and learning science. Note that the diary entries brought out significant differences in the conceptual understanding of the two groups of students in our study though there was no difference in their academic performance in school exams. As Hestenes, Wells, & Swackhamer (1992) point out, 'even in more widely administered standardised tests performance can be good if students are taught to the test'.

It has been pointed out, and we agree, that the goal of teaching science is not merely to help learners acquire conceptual clarity, but also to develop a favourable attitude towards science and to inculcate a way of thinking—to develop scientific habits of mind (Alberts, 2008). The diaries, serving equally well as evidences of such concurrent affective outcomes, indicated that inclusion of activities and demonstrations in class led to a high degree of self-reported enjoyment by students of both cohorts. However, genuine emotional and cognitive engagement with the content taught was observed to a markedly greater extent in students taught through inquiry. Our analysis also brought to light other important outcomes of inquiry: the development of a conscious awareness of learning, a questioning attitude (students asked several questions probing and building on the content taught) and a learning approach in which they based their explanations on evidence and argument rather than on authority. However, this study can still be relevant even in contexts where acquisition of conceptual clarity is the goal of teaching science.

Beyond conceptual clarity and affective outcomes discussed above, researchers have pointed out that the inquiry vs. direct teaching debate is also about 'a "feel" for science and hence some appreciation of the nature of scientific inquiry' (Cobern et al., 2010, p. 92). Our study provides support to their proposition that though traditional, direct instruction might require less time for some topics, it does risk sending the message that science is simply a body of knowledge to be learned. Teaching through inquiry models scientific inquiry and thus offers significant advantages over traditional teaching. The excerpts given throughout this paper from diaries of students taught through inquiry reflect the essence of scientific inquiry in the classroom (Marshall, Smart, & Horton, 2009; NRC, 1996, 2000)—that students were engaged in investigating questions, came up with explanations based on evidences, then communicated conclusions with convincing arguments. We hope that the array of outcomes that emerged through students' diaries in this study contribute to garnering support for teaching science through inquiry.

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Notes

1. Emphases in all the students' responses are added by the authors and the text in square brackets are authors' comments.
2. Reproducing the student's editing

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