REFLECTIONS FROM HANDS-ON SCIENCE WORKSHOPS FOR TEACHERS: 'LISTENING' TO TEACHERS

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We share experiences of teaching-learning from hands-on science sessions for school teachers on the topic of Heat and Temperature. We reflect on these experiences to look at issues regarding the learning of science that emerge, to critique our approach and to think about making changes in our approach and revisiting goals of the workshop sessions. We also refer to the works of Eleanor Duckworth to contextualise these reflections.

> So what is the role of teaching, if knowledge must be constructed by each individual? In my view, there are two aspects to teaching. The first is to put students into contact with phenomena related to the area to be studied—the real thing, not books or lectures about it—and to help them notice what is interesting; to engage them so they will continue to think and wonder about it. The second is to have the students try to explain the sense they are making, and, instead of explaining things to students, to try to understand their sense. (Duckworth, 1996 p. 173-174)

TEACHER WORKSHOPS ON HANDS-ON SCIENCE

We have been part of an intervention to encourage hands-on science in government schools for children from indigenous communities of Maharashtra. The programme aims to create opportunities for students to perform experiments in small groups and to promote classroom practices that give space for student-talk and conversation. Workshops for teachers on hands-on science are an important component of this programme. In these workshops, which are guided by facilitators (which included us among others), teachers are expected to do short science experiments or activities in groups, discuss their observations and the causes for the same within the group, and articulate these in front of everyone. This is for teachers to experience different pedagogical approaches which they could adopt and adapt for their respective classrooms. However, given the limited time that each team of facilitators gets with any given set of teachers due to constraints of logistics and expenses, there are unsaid demands to attain certain pre-decided learning outcomes related to the textbook content at the end of every session. These demands are also due to the fact that there is enormous pressure on teachers to make students 'learn' answers to textbook questions so as to pass written exams. Due to this, many teachers tend to not see the need to do experiments or to make students perform experiments and talk about them. So, in a sense, the onus is on the facilitators to convince teachers about the need to consider an approach different from their own.

A substantial proportion of teachers come to the workshops expecting to be lectured at, and they take some time to get used to discussing in groups and speaking about their interpretations and observations. There have been several instances of teachers running out of patience and demanding to be just told “the answer” rather than having things to emerge from the discussions. Teachers have also expressed their problems – in terms of the difficulties in having students discuss within the classroom, them having to ultimately teach to the test, students’ problems in reading and writing due to lack of familiarity with Marathi - the language of instruction, the logistics of arranging and maintaining setups for multiple groups of students, especially given systemic problems such as shortage of teachers and laboratory assistants, and the varied kinds of administrative load on teachers who are often treated as the lowest rung of the bureaucratic ladder. These are all of course connected to broader issues of government policy, assessment criteria, the recognition within the public education system of the importance of the work that teachers do, and teachers’ sense of identity, autonomy and pedagogic practice (Unterhalter, McCowan, & Rampal, 2015). The workshop sessions cannot be seen as happening in a vacuum or in any way separate from this larger context.

WORKSHOP SESSIONS ON HEAT AND TEMPERATURE

In this paper, we will share our experiences from sessions on the topic of ‘Heat and Temperature’ conducted with teachers over two different workshops. In the first workshop, held in July 2018, there were 5 groups of teachers and in the second workshop, held in November 2018, there were 2 groups of teachers, with each group comprising about 30 teachers. A single session in a workshop was of 1 and ½ hours duration and we got two such sessions with each group of teachers in each workshop. The plan for the three hours was to discuss key topics in heat and temperature from middle school science with the teachers. In each workshop, sessions on various topics ran in parallel, with different batches of teachers attending these sessions in a staggered manner. The teachers who participated in the workshop were middle and high school teachers with varying background in science, with some having studied science only till class 10 and 12 and some being science graduates and very few post graduates in science.

Most of the experiments and activities conducted with teachers were modifications of those found in text-books on hands-on science that have emerged from similar work done in the past. The session plans were partly driven by the textbook contents and were partly emergent in nature. Our team would discuss how things fared and also share these details with the larger group of facilitators at the end of the day for feedback and suggestions that could help modify the next day’s sessions. We discuss here some episodes of teachers’ engagement in experiments and discussions in smaller groups as well as in whole group. We particularly focus on the details of teachers’ ideas and articulations about certain concepts from this topic, both as examples for drawing pedagogic ideas from, and for the specific ways in which people understand these concepts. We believe that learning from these experiences with teachers might help inform the workshop and session design for future work.

An experiment on the thermal expansion of air

Among various experiments on modes of heat transfer and expansion in the three phases of matter, teachers performed an experiment to observe the expansion of air. A small ‘injection-bottle’ made of glass was used for this experiment. (This is a demonstration developed by Umesh Chauhan, a retired teacher who was part of the Hoshangabad Science Teaching Programme) A hole was made in its rubber cap and an empty ball-pen refill was inserted. A drop of coloured water was put in the refill. Upon holding the bottle in one's palm, the drop moves up the refill away from the bottle. The experiment was first demonstrated to the teachers and then they were asked to perform it within their smaller groups with each group given separate apparatus. Then, a question was posed to the teachers- "What do you observe and why do you think it happened?" - which they were supposed to discuss within their group of five people for about 15 to 20 minutes and then each group's discussion was to be shared with peer-groups.

One teacher tried to build a microscopic picture of expansion - "*When we see air expanding upon heating, what's actually happening is that the molecules of air themselves expand"*. This picture seems to attempt to accommodate the macroscopic expansion of the air in the bottle that can be sensed/seen with the 'atomic-dogma', namely that 'all matter is composed of atoms'. This corresponds to the 'continuity' assumption (Talanquer, 2006 p. 813) "that matter can be continuously divided into smaller pieces. These pieces or particles of matter have the same qualitative properties as the macroscopic object... they expand and lose weight when heated", as well as with the heuristic of 'similarity' used for reasoning about causal relationships: 'If the properties and behavior of atoms and molecules are the cause of the observed macroscopic phenomena, these invisible particles should share the features of the things we can observe (color, density, motion)' (Talanquer, 2006 p. 814).

It is interesting that this microscopic understanding of matter, shared by the teacher, is common among students (Talanquer, 2006). Maybe there are many more 'naive' ideas or theories, which are common among teachers as well as students. 'Listening' to teachers could bring forth such ideas, that could be taken up for further discussion, experiments and thought.

On the expansion of air, another teacher wondered - "*Will the air keep expanding forever if we keep on giving heat?"* We think that this was a leap of imagination that tried to extrapolate much beyond the immediate situation that we were looking at. We are of the opinion that wondering about asymptotic/limiting behaviour of phenomena is a sign of deep thought and reflection. We were aware that the thermal expansion coefficient of an ideal gas is inversely proportional to the temperature, but none of us (facilitators) had ever considered this perspective. We feel that taking this particular path into the relation between the flow of heat and the resulting expansion might suggest engaging and meaningful investigations and ideas.

Another teacher thinking about the mechanism of heat transfer said, "*I wonder how the heat goes from my palm to the air inside the bottle - is it by conduction or by convection"*, and then offered an answer after a while - "*Heat goes into the bottle from the palm by conduction as the bottle is at a lower temperature than our hand. The air comes in contact with the bottle and heats up."* The latter phenomenon, namely of heat flowing from the bottle to the air within, is a non-standard scenario for convection. The textbook-demonstration of convection (that the teachers had performed before this experiment), involved a heat source at the bottom of a beaker that sets up convection currents in water, while in this case, the heat source (the palm) is all along the horizontal walls of the bottle; thus the pattern of the convection currents will be complex.

The teacher was attempting to use his understanding of different modes of heat transfer to make sense of a more complex scenario. We could have undertaken an investigation into these details with teachers as an example of the nature of scientific phenomena, that they do not come in a neat compartmentalised form.

In one of the sessions during the second workshop, which was held during the winter, it was observed that the air inside the bottle was not expanding immediately after holding the bottle in one’s palm. A teacher got up without speaking to keep her group’s bottle in the sunlight by the window and all of us witnessed the subsequent expansion of the air within. This was a spontaneous decision taken by the teacher to use a source of heat that was readily available. It might have been worthwhile to talk about the teacher’s experiment and how it was different from what facilitators had planned, to compare and contrast the processes in the two cases. One of the facilitators kept the bottle back in the shade and the drop came down slowly. A few people wondered in passing why it takes more time to cool down and contract as compared to the expansion on heating. Perhaps this could have been a chance to discuss and investigate the nuances of heating by radiation, comparing the rates of heat transfer by conduction and radiation and questions like - does the air heat up directly by sunlight or does the bottle heats up by radiation and then transfers the heat to the air within, or a combination of these two.

In a different session, one of us overheard a conversation between two teachers: “*Don’t press the bottle too hard, it might break*”. “*No, no. If I hold it tight, the contact will be better*”. This remark seems to be grounded in some everyday experience about thermal contact (such as applying a warm compress or even an ice pack), and discussing about this could have helped unravel the details of the mechanisms of heat flow, such as the dependence on the area of contact in this case. We feel that we might have missed several such ideas expressed within groups, ideas that people did not deem worthy of expressing in front of everyone.

While trying to explain the reason for the upward motion of the drop when the bottle is held in the palm, one of the teachers came up with an explanation: “*Hot air is lighter, so it rises and pushes the drop up*”. Our colleague, Umesh Chauhan, showed a counter-experiment to the teacher - to hold the bottle upside down and to see that the drop goes down after a while, moving away from the bottle. This was supposed to be evidence to claim that all the air inside the bottle expands, however we couldn’t spare time for a discussion on this experiment (So we are not sure how the teachers interpreted it). Some teachers also placed the bottle horizontally and repeated the experiment, which was an attempt to eliminate the effect of gravity, and saw that the drop still moves outwards. This was an instance of teachers extending an experiment to try to separate the effect of gravity from thermal expansion and it was noticed by one of us. However, we missed the opportunity to bring this to the notice of the entire class, which might have led to a more detailed understanding and discourse about the phenomenon. It is possible that teachers in other groups too might have tried their own modifications of the setup to test out their reasoning, but they perhaps did not deem it important enough to share with others (or our approach gave the impression that their ideas do not matter).

As an extension to this experiment, we did another one to observe contraction on cooling. We asked the teachers to repeat the experiment and then to dip the bottle (which now has air at a temperature slightly higher than room temperature) in a mug containing water (from a bucket that had ’normal’ water that had been in the room since it was filled from the tap in the morning). All of the groups noticed that the coloured drop in the refill moves in the opposite direction indicating that the air which had been heated by our palms contracts after being cooled. A teacher observed that the coloured drop in the refill moves to a position distinctly lower than its original position from where it started in the experiment on heating by holding the bottle. Someone remarked that this means that the 'normal' water which had been in the room since morning wasn't at room temperature. This turned out to be a minor revelation, as most of us shared the notion that all objects in a "room" are at room temperature. This discussion could have led to investigating the reasons for the same, or to think about the heating and cooling of different objects over 24 hours, and the mechanisms involved.

Thought experiments on mixing water

Our colleague, Kamal Mahendroo posed thought-experiments to the teachers that involved mixing water. These were modifications/extensions of those cited in literature (Driver, Guesne, & Tiberghien,1985, p. 62) and were about the relation and the difference between heat and temperature.

One of these thought experiments went as: 'We have two containers each having one litre of water at 20 degrees Celsius. What will be the final temperature and total heat content of the mixture if we mix the two?'

Most of the teachers said that the temperature will remain the same. Some teachers pointed out with conviction that their students will say that the final temperature will be 40 degrees, as they typically tend to add up numbers in any word problem. The work of Stavy and Berkovitz (1980) on this particular result has revealed details of how students try to reconcile their 'qualitative-intuitive/verbal' and 'quantitative-numerical' understanding of this phenomenon.

The teachers suggested three ways to make students see the problem in this answer- 1) to actually make students touch the water and feel for themselves if the water feels hotter after mixing, 2) use a thermometer and 3) give them a counter-example: If we mix hot water and cold water we get lukewarm water, say for having a bath. It's not like we get warm water by mixing two containers of cold water. (Stavy and Berkovitz (1980) discuss the finer details about the effectiveness of the use of cognitive conflict in this and related scenarios).

Thus, teachers were expressing not just their own beliefs, but they were also reflecting about how their students might think around these questions and what kind of replies students might provide. So their engagement with the concepts was at multiple levels.

For the second part of the question on thought experiment, 'what will be the total heat content of the water after mixing', we asked teachers to compare the heat content of the mixture with X (where X is the heat content of the one litre water at 20 degrees in one container) - whether it will be less than, greater than or equal to X. The teachers seemed unanimous that the heat content of the two litres of water after mixing will be equal to X - at least the majority of people supported this view, with a few unsure people who chose not to speak up. Upon being asked to explain their answer, a few teachers said that just like the case of temperature, heat too will not add up and will remain the same - i.e. the heat content of two litres of water is the same as that of one litre of water at the same temperature.

We resorted to an indirect example to problematize this conclusion by presenting them with the following situation- Suppose that every day you heat ten litres of water (that is at room temperature) on a kitchen gas-burner to make it hot enough for your bath. One day, you have a guest and you have to heat twenty litres for bathing using the same kitchen gas-burner. We posed the questions- Which of the two would take more time to heat? So, in which of the two cases did you supply more heat? Several teachers remarked that the ten litres as well as the twenty litres were both at about the same final temperature, but we had supplied more heat to the latter. The second one was a kind of a leading question, to hurry up reaching the destination we wanted the teachers to reach. We feel that although this helped us in meeting our session goals, there was insufficient time given to teachers to reflect on and express their ideas about heat and how it is different from temperature. In that context, we do not know if teachers were able to make sense of the idea of heat as energy.

At this point, most people started questioning their previous conclusion about the heat content in the thought experiment. Amidst the now seemingly unanimous opinion of the class that the heat content of the two litres of water will be greater than X (with some people saying that it should be 2X), a teacher who had not participated in the discussion thus far, pointed out that generally when we speak of heat we are talking about either supplying heat to an object or taking it away from it. That we rarely talk about the heat content of an object per se. We acknowledged that this was a perceptive comment about the nuances of how the middle-school science textbook treats the concept of heat. It is treated quantitatively while discussing heat being supplied and being taken away (in the formula that involves the specific heat capacity and the change in temperature), while the description is qualitative while talking about heat as a concept by itself (‘the total kinetic energy of all the molecules’). Coming at the end of the session, we were not able to engage in this discussion further, beyond mentioning the idea of the Absolute Zero of temperature and considering the total heat supplied to some matter to raise its temperature from absolute zero to a certain value, say room temperature, with the possibility of phase transitions happening along the way.

In the other workshop with a different set of teachers, we presented a thought experiment which was a variant of the one described above. It went as follows- ‘We have two containers each having a litre of water, one at 20 degrees and the other at 40 degrees. We can suppose that the heat content of the water in the two containers is X and Y respectively, in some units. If we mix the two, what will be the temperature and the heat content of the mixture?’

All the teacher groups said that the temperature will be 30 degrees, with some teachers saying that it may not be exactly 30 degrees but slightly lower (they felt that some heat will be lost in mixing). Most people seemed convinced that the heat content ‘Y’ of the water in the second container is greater than the heat content ‘X’ of the water in the first container as the temperature of the second container is higher. However there were no clear responses about the heat content of the mixture. We put forward three cases and asked the teachers which one is true- the heat content of the 2 litres of water (after mixing) is less than X, between X and Y, or greater than Y. Here too, the reasoning went along similar lines as the other thought experiment and people chose “between X and Y”, saying that it should be the same as in the case for temperature. We asked them that if things are the same for both heat and temperature, what is the difference between the two or rather what is the need for these two separate terms. There was a range of responses, from textbook definitions to stating the facts like the units are different, to locating a difference in temperature and heat in terms of cause and effect with conflicts about which of the two being the cause and which the effect. After this discussion, to resolve things, our colleague posed another thought experiment - ‘A container has one litre of water at 20 degrees and another container has a thousand litres of water at the same temperature. What is the heat content of the water in each container?’ to which the teachers answered that it is the same, say X calories in both.

At this point, we asked the teachers to consider the following scenario- ‘Suppose we take out a litre of water from the thousand litres. If the heat content of both was X, will the heat content of the 999 litres that is left be zero? If not, then can we keep on extracting a litre of water and creating X calories of heat?’ This example seemed to create dissonance and one teacher mentioned “*Heat is a form of energy*”, which we wrote down on the whiteboard. Following this, there were numerous attempts by the teachers to reformulate the idea of heat content in the light of it being a form of energy. We found it an appropriate moment to write down the description from the textbook:

> *What is the difference between heat and temperature? We know that a substance is made of atoms. The atoms in a substance are always in motion. The total kinetic energy of the atoms in a substance is a measure of the heat contained in that substance, while the temperature of a substance is related to the average kinetic energy of atoms.*

At this point, a teacher came up with a narrative to explain this difference to children:

> *Suppose that in a class of 10 children, each child has 20 chocolates, so there are 200 chocolates in all. In another class of 10 children, each child has 40 chocolates, so this class has 400 total chocolates. Now we make the children from the two classes sit together and ask them to keep all their chocolates on the table, after which we divide the chocolates equally among the 20 children. The total number of chocolates (600) signifies the heat content and the number of chocolates per child (30), the temperature.*

When we shared this with some of our colleagues, one of them was dismissive about the teacher’s use of the analogy of chocolates as he felt that it creates an incorrect/incomplete picture of temperature as well as misconceptions about heat and temperature, and their units. While there is truth in this, we feel that this particular attempt by the teacher to understand and to spontaneously create an analogy that is appropriate to explain to his students, is an example of a ‘wonderful idea’ (à la Duckworth, 1996) and a sign of reflection and deep engagement. We feel that this metaphor of chocolates per child brings out the idea of temperature being “*the intensity of heat*” (as put by a teacher), or as their textbook calls it - “related to the average kinetic energy of atoms”. However, it is far from clear what sense students and teachers make of “the kinetic energy of atoms” or its average. We believe that it would need more engagement and deliberation to build conceptual understanding of this idea.

LISTENING TO TEACHERS EXPLAIN

The excerpt from Duckworth's essay at the beginning of this paper mentions giving learners the opportunity to directly interact with phenomena, and then allowing them to explain how they understand things, as two central aspects of teaching practice. We realise that while we did not set out to meet these criteria very explicitly in our work, they seem very much relevant for the way we design or plan sessions. In the context of the rich ideas of teachers that we encountered, we feel that we were not able to give them justice in terms of time to listen to and engage with them and to give them opportunities to explain their sense-making in detail. These realisations by us (as facilitators), which were somewhat obscure, became more apparent in the course of reflecting and writing this paper, and reading around these issues.

While advocating for allowing learners to explain, Duckworth speaks about the results of the way of teaching-learning (Duckworth, 1996 p. 182-183):

> *First, in trying to make their thoughts clear for other people, students achieve greater clarity for themselves. Much of the learning is in the explaining. Second, the students themselves determine what it is they want to understand. It is not only the explanations that come from them, but also the questions. Third, people come to depend on themselves: They are the judges of what they know and believe.. Fourth, students recognize the powerful experience of having their ideas taken seriously, rather than simply screened for correspondence to what the teacher wanted.. Fifth, students learn an enormous amount from each other.. Finally, learners come to recognize knowledge as a human construction, since they have constructed their own knowledge and they know that they have. What is written in a book is viewed as somebody else's creation, a creation produced just as they produced their own. Its origin is not of another order.*

Further discussions and investigations into phenomena originating from the thoughts and ideas expressed by teachers in the sessions have the potential to realise the results given in the above extract. The final point is in turn related to the nature of science as not merely a body of knowledge but also a process of human inquiry which is a work in progress, not knowledge handed down by authority figures but that constructed by people through their deep engagement with physical and social phenomena (Rose, 2006, p. 143; Singh, Shaikh & Haydock, 2019). Teachers who did not feel comfortable speaking in public had the chance to discuss with their group members, and we saw glimpses of this explaining and learning from each other in the sessions. However, our insistence on moving on and not pausing to listen to teachers' ideas fully, perhaps gave the message that their ideas are not important or we might be reinforcing beliefs such as the ultimate authority of the textbook, of experts. **Unless we 'listen' to teachers, unless teachers realise that their ideas are important and relevant, we as educators cannot meaningfully engage with them.** We feel that if we are able to create conditions for teachers to take their own and others' ideas seriously in these sessions, perhaps they might start doing the same with their own students at school. Unless teachers themselves get a chance to engage in and appreciate a process of inquiry, they would not be able to help their students experience it. This would mean that we set aside substantial time in session-plans for teachers to explain their ideas, to work on them further, and "to slow down closure, in the interests of breadth and depth" (Duckworth, 1996 p. 76).

It is important for teacher-educators and for teachers to realise that workshop sessions are not going to 'make the concepts clear' or 'cover the topics'. We need to recognise both knowledge construction and improving teaching-learning practice as continuous on-going processes. This calls for giving teachers more autonomy and responsibility as workshop participants, besides moving towards beliefs about knowledge construction that are more in line with the way people learn. Also, teachers need consistent support and time to reflect and to keep working on these processes (Rodgers, 2001).

Using textbooks, blackboard teaching or say, reading about the historical development of scientific concepts are important parts of learning. However, "..putting ideas in relation to each other.." (Duckworth, 1996, p. 81) and "..(to) come to understand subject matter inside out.., becoming aware of the web of connections within it, and the connections between one area of content and another" (Rodgers, 2001, p. 479) is work that needs to be done with patience and joy. We believe that fixing systemic issues such as assessment criteria, teacher and student autonomy, government policies on public education, equity in access to quality education (NCERT, 2005), is a battle that will have to be fought in parallel with assisting teachers to work on their practice autonomously, collegially and collaboratively.

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