Epistemic challenges: The activation of appropriate knowledge and effective reasoning in school science classes

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Abstract: This paper reports on two upper-primary school science classes. The intention of the learning module was to equip the students with knowledge regarding the scientific law of conservation of matter and for the students to be able to apply this scientific law across multiple contexts. Using epistemic challenges, to help the students reason, appeared to help students activate appropriate knowledge across contexts. This was achieved by asking the students to consider their existing knowledge and to justify their knowledge. The study used epistemic (clinical) interviewing protocols and investigated situations when students appeared to hold, and activate, conflicting knowledge resources simultaneously without noticing the inherent conflict.

Introduction

School science can be thought of as the learning of scientific *facts* and the learning of scientific *skills* (Brown, 1965; Walpole, 1999). Roberts (2007) provides two 'visions' of scientific/science literacy, which he calls *Vision I* and *Vision II*. Vision I looks within science, and can be considered as "its [science's] products such as laws and theories, and its processes such as hypothesizing and experimenting" (Roberts, 2007, p. 9). Whereas, Vision II looks outward and considers where science has a role in everyday lives; for example, "decision-making about socio-scientific issues" (Roberts, 2007, p. 9). When learning science, these two 'visions' can be thought of as learning how to be a scientist (Vision I) and learning to think about everyday situations as a citizen informed about science (Vision II). These ideas are not new and they can be traced back to (among other sources) John Dewey's (1910) suggestion that school students should be equipped with skills to ascertain the evidence required to substantiate their scientific beliefs.

> I do not mean that our schools should be expected to send forth their students equipped as judges of truth and falsity in specialized scientific matters. But that the great majority of those who leave school should have some idea of the kind of evidence required to substantiate given types of belief does not seem unreasonable. (Dewey, 1910, p. 126)

A more recent trend is to teach school science through *inquiry* (see Ruddock & Sainsbury, 2008). This inquiry method of teaching encourages students to perform the role of scientists by forming hypotheses, planning experiments, collecting data, analyzing data and drawing conclusions based on their collected evidence (ACARA, 2016; Olson & Loucks-Horsley, 2000). While this approach is designed to give students the opportunity to think and reason as scientists, research has shown that inquiry lessons are often reduced to students following a series of steps along a predetermined path leaving little room for individual student reasoning (Capps & Crawford, 2012; Kim, Tan, & Talaue, 2013; Lord & Orkwiszewski, 2006). Even when inquiry practices are incorporated into lessons, the focus on inquiry can detract from the learning of science (Roth & Garnier, 2006). This paper investigates how epistemic challenges (that is, using questions that challenge students to consider their existing knowledge and the validity of that knowledge) can enhance students' own reasoning and thereby bring about deeper understanding.

Methodology

The study draws inspiration from Socrates, as outlined by Brinkmann (2007), in that it encourages students to go beyond simply answering science questions (from information learned during a lesson) and asks students to justify their knowledge and beliefs. Using a Knowledge in Pieces (KiP) theoretical framework (diSessa, 1988), considering knowledge to be fine-grained and contextually activated, the research seeks to investigate how epistemic challenges can be used to activate knowledge that had previously been useful in a different context.

Sample

This study recruited participants from two schools (one class from each school). Both schools followed a similar curriculum timetable and therefore all participants were in the same school year (year-6) and were aged between 10 and 12 years. Both schools were embarking on a science topic of the environment and, in particular, sustainability. To reduce variability, similar ability classes were chosen from both schools. The class from school A comprised 26 students of which 22 (10 female, 12 male) agreed to participate in the study; the class from school B also comprised 26 students of which 24 (13 female, 11 male) agreed to participate in the study. The data collection activity was split into two phases: phase one included all students (n=46) and phase two, the interview phase, included 10 students from school A and 6 students from school B. The class teachers were asked to select the students and the selection criteria was based on a separate (non-science based) activity; it was, therefore assumed that the 16 participating students in phase two were a random sample from the cohort. This paper focuses on phase 2 of the data collection. The 16 students were interviewed over a number of weeks; each interview lasting between 20 and 40 minutes. The resulting individual interviews were transcribed and analysed.

Preparation for the interviews

Before the interviews reported in this paper took place, the entire class of students were involved in a number of whole class activities which focused on the topic ‘conservation of matter’. This law has been attributed to Antoine Lavoisier:

> We may lay it down as an incontestable axiom that, in all the operations of art and nature, nothing is created; an equal quantity of matter exists before and after the experiment. (Lavoisier, 1793, p. 7)

This ‘law’ has stood the test of time and, over 200 years later, it is still used with two specific caveats. First, that special relativity and quantum mechanics are special cases where mass and energy interactions need to be considered. Second, that the law is only applicable to closed systems. As the students had not been exposed to scientific instruction in the special theory of relativity or quantum mechanics, it was assumed that these exceptions would not enter into the thinking process nor would be likely to cause any confusion. To confirm this, at no point during any of the interviews or during any of the class observations did any student show any signs of knowledge of either the special theory of relativity or quantum mechanics.

The whole-class activities exposed the students to the concept that matter is conserved; that is, that while the students were observing change they were not observing matter being created or destroyed. Specifically, the students observed and discussed the following four experiments where different ‘things’ appeared to disappear:

- A white powder stirred into a clear liquid (powdered sugar and water). The powder disappeared.
- A second white powder stirred into a clear liquid (mixture of citric acid and sodium bicarbonate stirred into water). The liquid bubbled and the powder disappeared.
- A candle was burned. The candle wax disappeared.
- The students were told a story of a car on a journey and by the time the journey was over, the petrol had disappeared.

Following the activities, the students were placed in small groups (mostly dyads) to discuss their observations and report back to the whole class discussion. The session ended with formal explanations of the changes observed, each used as examples of the law of conservation of matter.

The interviews

Each participating student was interviewed following the class instruction. The interviews had three distinct sections:

- Discussion regarding the student’s understanding of the law of conservation of matter.
- Discussion about the concept of ‘sustainability’.
- Discussion regarding the law of conservation of matter but in a context not covered during the whole-class instruction.

The first two sections of the interview established that the students had knowledge of the law of conservation of matter and were able to activate that knowledge in a familiar context. Once this was established, the interview progressed to a different context to gain an understanding of whether the students were able to activate their prior knowledge (in this new context) and what factors may help students to activate appropriate knowledge resources.

During the interviews, no additional instructional support was provided to the students; that is, no further guidance regarding the law of conservation of matter. Epistemic support was provided for the students. The interviews took the form of epistemic interviews where the students were challenged to explain their responses and to explain what prior knowledge was being used. The protocol for these interviews was based on clinical and epistemic interviewing techniques (diSessa, 2007; Thomsen & Brinkmann, 2009).

The final section of the interview process involved a new context – a new closed system. The isolated material system was described to the students as the planet Earth, along with everything that is in it, on it and in the atmosphere around it; this included the planet itself with the trees and other plants, the animals, the people and the air. The interview questions were structured so that use of the law of conservation of matter would be entirely appropriate; however, some of the questions intentionally raised issues which had the possibility of activating different, inappropriate (in this context) knowledge that may, perhaps, have caused the participants' knowledge of the law of conservation of matter to remain dormant. The interviews were not scripted but all followed a similar theme. First, an introductory discussion about the current school science project, focusing on sustainability and conservation of matter. Second, a discussion about the population of the Earth – a live population clock was used to show how the net number of people is increasing; it was noted in each interview that the population of the Earth had more than doubled in the past 50 years. Third, the main research question was discussed: "Is the mass of the planet more today than it was fifty years ago?" An interview segment with Peter (a pseudonym) is provided as a typical example:

Researcher:	So, if you think of the planet, which would include the atmosphere around it, everything inside there and all the people on it and everything else that's on it, has the mass of it increased [over the past 50 years]?
Peter:	*Yes*.
Researcher:	Can you explain why?
Peter	*Because all those extra people are more people, and then there's more space occupied and more weight, or mass.*
Researcher:	Is it just the people?
Peter	*No, there's the animals and there's the plants and there's the water, the air –*

As the interviews progressed and, depending on the participant's responses, follow-up questions were included; such as, "what about the things that people make?" and "what about all the stuff that people use and make?" Once the participants had had an opportunity to express their views they were asked to explain the class experiments that illustrated 'things' that appear to disappear. Before concluding the interviews, the students were again asked to reflect on the mass of the planet.

Analysis

Each of the sixteen interviews was split up into separate interactions. Chi's (1997) verbal analysis protocol was employed to segment the data and all data was segmented at two levels of granularity, 'interchange' and 'idea'. The 'interchange' segments were used to provide information about *what* the student thought and the 'idea' segment was used to provide information about *why* the student held that thought. A coding scheme was developed from the themes that emerged during all interviews (Hsieh & Shannon, 2005; Robson, 2011). Different students, at different times, expressed views that the mass of the Earth was increasing, decreasing or staying the same. These views were coded:

- U (Up) The mass of the Earth is increasing.
- D (Down) The mass of the Earth is decreasing.
- N (No change) The mass of the Earth is not changing.

The students also expressed views on the causes of these changes and these fell into the following three categories:

- P (People) The increasing population has an (or has no) effect on the mass.
- S (Stuff) The things (stuff) that people make have (or do not have) an effect on the mass. Note, this included people using up the Earth's resources.
- O (Other) Other factors have (or do not have) an effect on the mass.

Combining these possible outcomes provided nine possible codes to be used when coding the data; these are UP, US, UO, DP, DS, DO, NP, NS, and NO. The first letter of the code specifies which way the mass was going; the second letter specifies the cause.

Results

The students' utterances were coded according to the developed coding scheme and then collated by considering the students ideas before they reflected on the class experiments and after to see whether their ideas had changed/developed. It became very clear that some of the students held very different views, at various points during the interviews, depending on whether they were discussing *people* or *other stuff*. Therefore, the verbal interchanges were separated so information could be gained regarding the students' separate thoughts about people and other stuff. Table 1 provides a summary of the coding results (names are pseudonyms).

Table 1: Students' ideas about effects of *People* and *Stuff* on the mass of the Earth

Student	**Before Reflection**		**After reflection**	
	People	**Other Stuff**	**People**	**Other Stuff**
Jim	Increase	Increase	-	No Change
Mary	No Change	Decrease	Increase	No Change
Michelle	Increase	Increase	Increase	No Change
Robert	Increase	Increase	Increase	No Change
Lance	Increase	Increase	Increase	Decrease
Jane	Increase	Increase	Increase	No Change
Rachael	Increase	Increase	Increase	No Change
Molly	Increase	Increase	-	No Change
Anna	Increase	Decrease	Increase	No Change
Emma	Increase	Increase	-	-
John	Increase	Increase	Increase	No Change
Stephanie	Increase	No Change	Increase	-
Peter	Increase	Increase	Increase	No Change
Susan	Increase	Increase	No Change	No Change
Paul	Increase	No Change	No Change	No Change
Lucy	Increase	No Change	No Change	No Change

It can be seen that there was variation in how students expressed their ideas regarding the mass of the Earth. The law of conservation of matter would state that, as the Earth was being considered as a closed system, the net effect of any of these factors is zero. That is, none of the factors would change the mass of the Earth. All the students, with the exception of Mary, initially thought that the mass of the Earth was increasing as the population of the planet increases. Eleven of the sixteen students also thought that other factors, such as new buildings, and computers also were increasing the mass of the planet. After reflection on the class experiments, the majority of students changed their position on other factors, but maintained that the population was still increasing the mass of the planet. It appears that these students are generally able to apply the law of conservation of matter to man-made objects, but most failed to be able to apply the law to the human population. While the science behind the problem is the same, the problem context had changed. Any increase in the *stuff* was thought of as coming from within the closed system but, it appears, *people* were considered as a special case and, in this context, for most students, the law of conservation of matter did not activate.

Discussion

All students, bar one (Mary), started with an initial view that the increasing population was increasing the mass of the planet. Mary's responses during the interview were unusual in that her intuitive view conflicted with the law of conservation of matter. However, Mary had prior knowledge that the earth is balanced in its orbit; any extra mass would “throw it off course” and therefore she balanced the Earth’s resources being “taken away” against any extra mass of people, thereby keeping the planet in orbit.

Approximately 20% of the participating students initially responded with the belief that the increasing *stuff* did not affect the mass of the planet. This rose to approximately 90% of students (who expressed an opinion) after reflecting on the prior class experiments. Generally, most students who did not already apply the law of conservation of matter, at the start of the interviews, were able to do so after reflection when, and only when, considering *stuff* on the planet as distinct from *people*. When asked to consider the increasing population, nine of the sixteen students (approximately 55%) maintained their initial position, after reflection on the law of conservation of matter, that the increasing population was increasing the mass of the planet. Approximately 20% of the students did not express an opinion after reflection. These could either be considered to have not changed their opinion, or could be removed from the data set. Either way, approximately 70% of the students held onto their views that the increasing population was somehow outside of the system. *People*, it would appear, are considered (by the students) to be a special case and this appears to activate different knowledge resources. It appeared that students’ prior knowledge was in conflict with their current thinking about conservation of matter – the students appeared to be activating prior knowledge that *people are special*. This *people are special* idea can also be seen in studies of evolution. Evans (2001) showed that beliefs about both animal evolution and creation, while in conflict, could be held simultaneously for different animals; “some participants ... endorsed evolution for nonhuman species while reserving creation for human origins” (p. 242). This observation is reinforced by the ‘did it evolve?’ question (Evans, 2008), where across the age range (from children aged 6 to adults), those who were happy to accept evolution for butterflies, frogs, and mammals were less happy to accept evolution for humans.

Overall, the sixteen students interviewed expressed opinions about two problem contexts either before or after reflection. This created 64 opportunities for students to activate their knowledge of the law of conservation of matter. Of these 64 opportunities, students activated appropriate knowledge on 20 occasions, and of these, the vast majority occurred after the students had been challenged to consider the experiments observed earlier. It should again be noted here that at no point during the interviews was additional instructional support given; that is, the students were not given any additional science information. They were asked to reflect on their existing knowledge and were challenged on their thinking. These *epistemic challenges* were, in most cases, sufficient for the students to be able to activate appropriate prior knowledge.

Conclusions

It appears that the *problem context* has a significant bearing on how students activate (and therefore use) knowledge when thinking about the law of conservation of matter. In this study, the students were asked to use their prior knowledge regarding the law of conservation of matter in two different problem contexts; the problem context changed from considering more *stuff* to considering more *people*. As the problem context changed, the students activated different sets of knowledge resources. When considering *stuff*, the students were, in general, able to appropriately activate the law of conservation of matter, but when considering *people* they inappropriately activated other knowledge resources that displaced the law of conservation of matter.

It is noted that inappropriate activations were observed at moments when students were prompted to integrate knowledge formed in different circumstances. Multiple knowledge resources formed from the formal taught environment appeared to activate either appropriately or inappropriately and one displace the other. However, knowledge formed across different circumstances, such as knowledge from both taught and every-day experiences, also appeared to activate appropriately or inappropriately, but were able to be held simultaneously without displacement.

Providing students with epistemic challenges (that is, challenging students on their reasoning and asking students to reflect on what they already know) can enhance appropriate knowledge activation and enhance reasoning in school science lessons. Examples of these epistemic challenges are, “tell me more about that”, “why do you say that?”, “can you explain why?” and “start with something you already know”. When embarking on a learning program that involves students integrating both taught knowledge and everyday experiential knowledge, students may activate conflicting knowledge resources that lead to confusing results. It is at these points that epistemic challenges may prove beneficial in helping the students sort out their own solutions to these complex issues.

The findings of this study could be extended by seeking answers to when and why ‘sticky’ inappropriate knowledge elements are activated. This is especially important as, while inappropriate knowledge activations are sometimes obvious (the student gets things wrong), the student may be holding conflicting knowledge from different sources. He or she may appear to be activating appropriate knowledge resources but in fact be using simultaneously activated inappropriate knowledge resources.

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