Doing with ideas: the role of talk in effective practical work in science

Nikolaos Fotou and Ian Abrahams

ABSTRACT In both primary and secondary schools the widespread use of highly structured 'recipe'-style tasks means that practical work is generally effective in enabling students to do and see what the teacher wants (the domain of objects and observables). While primary teachers have been found to allocate a similar proportion of their lesson time to procedural instructions as their secondary colleagues, their practical tasks tend, on average, to be shorter than those used by secondary teachers. The use of shorter tasks means that primary teachers have more non-practical whole-class time to talk to students about the meaning of new scientific words and, when necessary, scaffold new scientific ideas (the domain of ideas), both of which are necessary if teaching is to be effective in developing conceptual understanding. In this respect, secondary teachers need to be more like their primary colleagues in being aware of the role of talk within practical work as an effective means of developing secondary school students' conceptual understanding of scientific words and ideas.

We use the term 'practical work' as an overarching one to refer to all types of science teaching and learning activity in which students, working either individually or in small groups, are involved in manipulating and/or observing real objects and materials as opposed to virtual objects and materials. It is useful to think of practical work as having two distinct 'domains': the domain of objects and observables, and the domain of ideas. While the distinction between these two domains has been discussed in detail previously (Abrahams, 2011), it can be easily summarised by stating that, for some activities, the teacher only wants the students to do things with objects or materials – maybe so that they will see a phenomenon or an event, and remember what they saw and/or develop a practical skill. Such activities, described as 'hands-on', can therefore be thought of as taking place within the 'domain of objects and observables'. In a similar manner, 'minds-on' activities, those in which the teacher wants the students to learn the meaning of scientific terminology and scientific ideas, can be seen to take place within the 'domain of ideas'. Practical work that occupies both domains therefore incorporates both doing *and* learning and can be thought of as being both 'hands-on' and 'minds-on'.

While previous research (Millar and Abrahams, 2009) found that 'hands-on' work in secondary practical lessons was very effective, there was less evidence of effective 'minds-on' work. In contrast, research into the effectiveness of practical work in primary science (Abrahams, Reiss and Sharpe, 2014) found that, as primary teachers of science devote, on average, more whole-class time – in a form widely referred to as 'carpet time' – to talking about the meaning of new scientific words and scaffolding new scientific ideas, their lessons were both 'hands-on' *and* 'minds-on'. As a consequence of this more equitable distribution of whole-class lesson time, primary teachers were not only just as effective in getting their students to produce the intended phenomena as their secondary colleagues, but were often more effective in terms of getting their students to develop their conceptual understanding.

Doing with ideas

Primary teachers who are not science specialists have reported their own difficulties in understanding scientific ideas and the meaning of certain scientific terms, as well as, in some cases, a lack of confidence in teaching science (Harlen and Holroyd, 1997). As a consequence of their own difficulties with some aspects of science, it has been found that many of them appeared better able to empathise with the difficulties that their students face when learning about new ideas and the meaning of new scientific terms than were many secondary subject specialists (Abrahams and Reiss, 2010). Indeed, one consequence of this was the fact that, on average, primary teachers have been found to allocate more whole-class time to 'doing with ideas' (that is, a 'minds-on' activity) than their secondary colleagues (Abrahams, Reiss and Sharpe, 2014). This in turn led, in many cases, to them devoting that additional time to introducing students to the meaning of new scientific terms and, when necessary, scaffolding new scientific ideas, both of which are necessary if teaching is to be effective in developing conceptual understanding.

While 'doing with objects and materials' is self-explanatory, 'doing with ideas' is less self-evident. This refers to the mental process of thinking about objects and materials, as operationalised and evidenced through *talk* between students or between students and their teachers, using scientific terminology and theoretical entities or constructs that are not themselves directly observable. Getting students to think about objects and materials using particular scientific ideas can be difficult, as these do not present themselves directly to students' senses. Furthermore, certain scientific words, used to talk about some scientific ideas, can themselves be unfamiliar and/or strange, for example inertia, kinetic, photosynthesis and titration, or, while familiar, have alternative, well-established, non-scientific meanings, such as force, work, cell and organic; their use can, without proper explanation of their meaning by the teacher, cause further confusion.

There are a number of different types of teacher–student talk (and teacher-stimulated and supported student–student talk) that teachers can use to help their students make links between the 'domain of objects' and the 'domain of ideas'. Among these approaches, the use of analogies and metaphors has the potential, in some situations, to be an effective means to this end. While they form the focus of this article, we would emphasise that this is not the only way available to the teacher to make these important connections.

The role of analogies and metaphors in 'doing with ideas'

Analogies, generally speaking, consist of a familiar situation (the base), which is already understood, and an unfamiliar situation (the target) about which new knowledge is desired to be acquired, and an analogy 'works' by mapping elements from the former onto the latter. In this sense, talk involving analogies can help students make links between their pre-existing knowledge and the new concepts that are being taught. In a similar manner, metaphors provide a simpler way (compared with analogies) of thinking about an unfamiliar situation on the basis of a direct comparison with something that is already familiar. While analogies and metaphors can both be used to compare two different things with each other, they each do so in different ways. In this respect, an analogy is normally a detailed comparison that draws on various features of both the base and the target to illustrate similarities between them, which can then be used as a basis to infer additional similarities to other aspects of the base–target system. In contrast, a metaphor is a much shorter expression – normally no more than a sentence – that directly equates two things without making any statement about the basis of the claim that is being made. [Note: While we use the term 'metaphor' because this has been widely used in the literature, we feel that it would be more appropriate to use the term 'simile', as science teachers, in our experience, very rarely claim that one thing *is* something else but rather that it is, in some sense, *like* something else.]

Talk using analogies and metaphors could, we suggest, provide an opportunity to facilitate the development of students' conceptual understanding in a manner similar to the talk that occurs in 'carpet time' in primary science lessons, which enables students to use whole-class time to focus primarily on doing with ideas. Such an approach has the potential to strengthen the link between things observed when doing practical work and scientific theory.

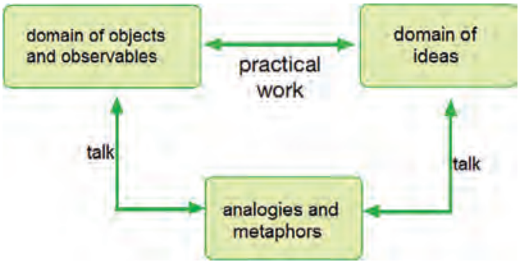

Figure 1 Analogies and metaphors: helping to strengthen the bridge between the two domains

In this sense, analogies and metaphors can provide an opportunity for abstract entities to be made visible or they can function as simplified descriptions of the observations made (Gilbert, 2004), providing students with the opportunity to talk about what they have seen in terms of the ideas intended by their teacher. For example, when carrying out a practical task to investigate the effects of concentration, temperature and surface area on reaction rate, the ‘school dance’ metaphor (Niebert, Marsch and Treagust, 2012) can be used to help make the link between students’ observations and abstract scientific concepts about unobservable particle collisions. In this metaphor, students dancing in a room represent moving particles, with student–student meetings representing atom collisions. In this manner, the students can be helped to think and talk about their observations of the change of the rate of reaction with temperature using a metaphor in which the speed at which the students run around the room is compared with temperature. An increase in the speed at which the students move increases the chance of collision between them (an expected result) and, in such a way, students are encouraged to use the dance as the base to metaphorically compare and think about any increase in temperature as resulting in an increase of the kinetic energy of reactant particles and, as such, it would be expected to lead to an increase of the reaction rate.

In a similar manner, the familiarity that most students will have with the idea of water flowing through a pipe makes it suitable as an analogy for current ‘flowing’ through the wires of an electrical circuit (Gentner and Gentner, 1983), providing an opportunity to talk and think about the unfamiliar concepts of voltage, current and energy in terms of a more familiar everyday example. For instance, students can use the flowing water analogy to understand and explain their measurements of current in simple circuits, in which the same potential difference is applied across equal lengths of resistance wire made of the same material but of different thickness, by comparing the latter to the width of a pipe and the former to the flow of water through that pipe (Figure 2).

Our own research has shown that students frequently make predictions about novel situations and explain their ideas by drawing on analogous cases they have observed in their daily lives (experiential knowledge). For example, in one of

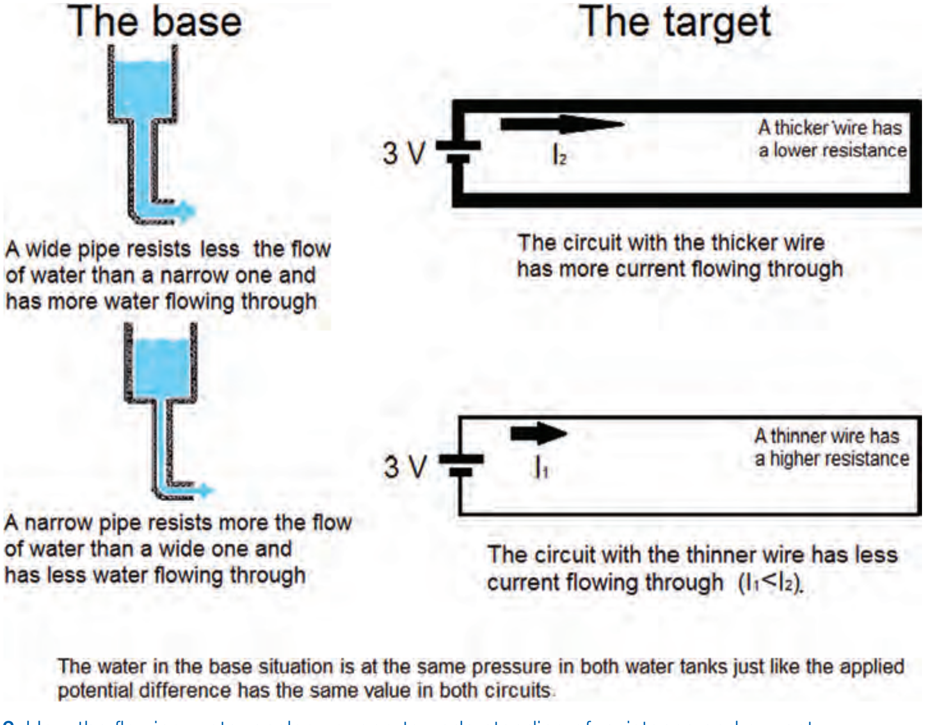

Figure 2 How the flowing-water analogy supports understanding of resistance and current

the questions that we used, students were asked to make a prediction (neglecting air resistance) as to which of two identically sized boxes, one of which contained an elephant and the other an ant, would reach the ground first if dropped from a small height. Their predictions about this novel situation, almost always erroneous, were frequently found to be based on having seen heavy and light objects falling from the same height, with the heavier object being seen to reach the ground first. For example, one Greek student predicted that: '*The elephant drops faster because it is much heavier. I've seen that happening a lot. I have seen an olive and a leaf hanging from an olive tree and when they dropped the olive went faster*.' Overall, the findings of the study indicated that analogical reasoning derived from students' experiential knowledge pervades their thinking and affects their understanding. Therefore, teachers need to be more aware of the impact that common experiential knowledge – often sustained over a long period of time – can have on students' thinking, in order to help them better understand the strengths, weaknesses and appropriateness of the analogies and metaphors that they use.

All the examples above illustrate ways in which talk, involving analogies and metaphors, can provide a scaffold by which students can be helped by their teacher to understand abstract scientific concepts, from the perspective of personal experiences that have already shaped the way in which they understand the everyday world around them (Fotou and Abrahams, 2015).

Implications for teachers

If analogies and metaphors are to be used effectively in science teaching to help students effectively 'do with ideas', then the teacher's role in deciding what analogies and metaphors are to be used is crucial. The central role of the teacher arises because, as we have already suggested, analogies and metaphors function as a result of students being familiar with them and able to transfer information from a familiar base to an unfamiliar target situation. An appropriate analogy or metaphor is therefore one that presents new, unknown, concepts to students using ideas with which they are already familiar (Glynn, 1991). In this sense, the use of analogies and/or metaphors that are unfamiliar to students may fail to provide them with a base situation that they can then use to help them understand the new, unfamiliar, scientific concepts. Therefore, an analogy or metaphor that is unfamiliar to the students constitutes an inappropriate analogy/metaphor, not only because it does not serve its purposes but also because it can result in a misunderstanding of both the observations made and the scientific concept to be taught. Niebert *et al.* (2012) suggest that an example of an inappropriate analogy is the flight plan analogy, which has been used to introduce the properties of chemical equilibrium to students. This analogy is designed to get students to compare the details required to produce a flight plan – including, for example, wind speed and direction, total payload, altitude – with the details required for achieving chemical equilibrium, such as temperature, pressure and concentration. However, as Neibert *et al.* (2012) point out, this analogy is inappropriate in the sense that, as a base situation, it is unlikely to be familiar to the students and so is unlikely to provide the basis from which the students would be able to understand the target situation (in this case chemical equilibrium).

It is therefore important when facilitating student talk that teachers are careful to introduce, as base situations, analogies and metaphors with which students are likely to be familiar. Similarly, it is important for the teacher to ensure that the chosen analogy or metaphor, while familiar to the student, does not have the potential to mislead. For example, when burning magnesium ribbon, it can be seen that an attempt to use the familiar example of burning wood or paper as the analogous situation would be inappropriate in that, while students are likely to be familiar with burning wood or paper, the residue, or ash, of such carbon-based materials weighs less than the initial material. Drawing on such an inappropriate analogy has frequently been found to lead students to erroneously predict a decrease in the mass of the magnesium ribbon after being burnt (Fotou, 2014). Similarly, analogies can sometimes be problematic as a consequence of a subtle difference in the meaning of the same words used in the base and target situations. For example, when using a flowing water analogy to help explain current in an electric circuit, part of the analogy is between the electrical on/off switch and the tap in the water system. However, having set up the analogy, there is the potential to introduce, as Glynn (1991) notes, a confusion for students in that, while we use the same word, 'closing', with respect to the electrical switch when we denote turning the current on, 'closing' the tap in the water system stops the flow of water. It is therefore important that teachers not only recognise the value of analogies and metaphors, but also recognise that those same analogies and metaphors can, however inadvertently, lead to unexpected confusion if the analogy is pushed too far.

While the use of analogies and metaphors can support of the development of conceptual understanding, Dagher (1995) has pointed out that there is also the possibility that students will accept these analogies and metaphors as explanations in themselves, rather than using them to help their understanding of the scientific explanations. It is therefore important for teachers to ensure that students are clear about the strengths and limitations of analogies and metaphors and that it is only in certain limited conditions that the similarities between the base and the target situation exist; eventually every analogy and metaphor breaks down (Glynn, 1991). For example, in the flowing water analogy, teachers should clarify the limitations of the analogy as, without such limitations being made explicit, there is no reason for the student not to implicitly assume that as a break in the hosepipe (base) results in the leakage of water, so a crack in a wire (target) results in the leakage of electricity.

Yet, as Kearney and Young (2007) have argued, the effectiveness of analogies and metaphors in strengthening the link that practical work can provide between the domain of objects and observables and the domain of ideas depends not only on the extent to which the teacher ensures that the students are familiar with the base situation and its similarities to the target situation, but also on the extent of their ownership of that process. One way of trying to facilitate such ownership involves dialogic discourse (Scott, 1998), in which the role of the teacher (see Figure 1) is to encourage/facilitate the students' use of analogies and metaphors as a means of talking about, and reflecting on, the practical work they undertake and the observations they make, as well as the relevant scientific ideas.

Analogies and metaphors have the potential to be used at all stages of practical work. For example, teachers might ask students, when using a predict-observe-explain approach, to discuss the analogies upon which they drew when making their predictions. Similarly, post-practical discussion in which students are given the opportunity to generate their own analogies to explain their observations can help teachers see whether, and the extent to which, the scientific concept taught is understood.

Conclusion

While practical work in the laboratory offers important opportunities to link science concepts and theories with observations of phenomena, for this to be effective requires that students are helped not only to do and see what the teacher wants but, equally importantly, to think about their observations in a particular way. In such tasks, students are likely to require assistance to develop, for example through the targeted use of analogies and metaphors, the ideas that make sense of the phenomena and lead to learning. Indeed, as scientific ideas do not emerge unaided from the production and observation of phenomena, there is a need to provide a scaffolding process that provides the initial means by which students are helped – and we suggest that analogies and metaphors can play an important part in that process – to 'see' the phenomena in the same 'scientific way' that the teacher 'sees' them. For practical work to be more effective in developing conceptual understanding, we suggest that lesson plans need to state explicitly *how* teachers intend their students to learn about those ideas, and the nature of the analogies and metaphors that they intend to use.

References

Abrahams, I. (2011) Thinking about practical work. In *The ASE Guide to Secondary Science Education*, ed. Hollins, M. Hatfield: ASE.

Abrahams, I., Reiss, M. J. and Sharpe, R. (2014) The impact of the 'Getting Practical: Improving Practical Work in Science' continuing professional development programme on teachers' ideas and practice in science practical work. *Research in Science & Technological Education*, **32**(3), 263–280.

Abrahams, I. and Reiss, M. (2010) Effective practical work in primary science: the role of empathy. *Primary Science*, **113**(May/June), 26–27.

Dagher, Z. R. (1995) Analysis of analogies used by teachers. *Journal of Research in Science Education*, **32**(3), 259–270.

Fotou, N. (2014) *Students' Predictions in Novel Situations and the Role of Self-Generated Analogies in Their Reasoning.* Unpublished doctoral thesis, University of Leeds, UK.

Fotou, N. and Abrahams, I. (2015) Students' reasoning in making predictions about novel situations: the role of self-generated analogies. In *Insights from Research in Science Teaching and Learning*. Book of selected papers from the European Science Education Research Association (ESERA) 2013 Conference, ed. Papadouris, N., Hadjigeorgiou, A. and Constantinou, C. P. Dordrecht: Springer.

Gentner, D. and Gentner, D. R. (1983) Flowing waters or teeming crowds: mental models of electricity. In *Mental Models*, ed. Gentner, D. and Stevens, A. Hillsdale, NJ: Erlbaum.

Gilbert, J. (2004) Models and modelling: routes to more authentic science education. *International Journal of Science and Mathematics Education*, **2**(2), 115–130.

Glynn, S. M. (1991) Explaining science concepts: a teaching-with-analogies model. In *The Psychology of Learning Science*, ed. Glynn, S., Yeany, R. and Britton, B. Hillsdale, NJ: Erlbaum.

Harlen, W. and Holroyd, C. (1997) Primary teachers' understanding of concepts of science: impact on confidence and teaching. *International Journal of Science Education*, **19**(1), 93–105.

Kearney, M. and Young, K. (2007). An emerging learning design based on analogical reasoning. In *Proceedings of the 2nd International LAMS Conference 2007: Practical Benefits of Learning Design*, ed. Cameron, L. and Dalziel, J. pp. 51–61. Sydney: LAMS Foundation.

Millar, R. and Abrahams, I. (2009) Practical work: making it more effective. *School Science Review*, **91**(334), 59–64.

Niebert, K., Marsch, S. and Treagust, D. F. (2012) Understanding needs embodiment: a theory-guided reanalysis of the role of metaphors and analogies in understanding science. *Science Education*, **96**(5), 849–877.

Scott, P. H. (1998) Teacher talk and meaning making in science classrooms: a Vygotskian analysis and review. *Studies in Science Education*, **32**, 45–80.

Nikolaos Fotou completed his PhD in Science Education at the University of Leeds and is currently working at the University of Lincoln.

Ian Abrahams is Head of School of Education and Professor of Science Education at the University of Lincoln. Email: iabrahams@lincoln.ac.uk