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Front cover: Track cycling research: wind tunnel tests of clothing and rider position sometimes use a mannequin secured in the riding position. Drag is measured with a force platform on which the bike is mounted.
Photograph courtesy of Lindsey Underwood.

engaging students in science

How we use contexts and the part we expect them to play in conceptual learning and in engagement with learning may need to be rethought, as *Rosemary Hipkins*, NZCER explains:

Introduction

At the Science Education Research Symposium (SERS) in November 2009, participants in the introductory panel discussion were asked to give their thoughts on the problem of student *engagement* in science. Issues and questions that kept popping up included the following: Is there actually a problem with keeping students engaged? How do we know? (What is our evidence?) What do we do about it? Why should we change? (What could happen if we don't?) Anyway what do we actually mean by engagement? Discussing these issues and questions over the course of the two days of SERS brought up a range of related questions: What do we mean by the "nature of science"? What difference (if any) should it make to teaching and learning in science? What do good explanations look like? What are our expectations of what students will gain from their science learning? Listening to the debate flow back and forth, I pondered on the many ways we could answer such questions, depending on what we actually mean by terms such as engagement and explanation.

In this article I'm going to use three small learning episodes, each of which is just a moment-in-time snapshot but raises an interesting learning dilemma, to try and address some of the above questions – if only by asking even more questions! I think we need much wider debate about the issues I plan to raise, so this article is just a 'toe in the water' of what I hope might become a debate amongst teachers, not just our small science education research community.

The 'engaging' nature of practical work

The first incident I have chosen was documented during the Learning in Science Project (LISP) (for a discussion of the implications for teaching questioning skills see Osborne and Freyberg, 1985). I was aware that the observer in question was Ross Tasker, the first project officer for the Hamilton-based LISP team and by all accounts an extraordinarily good researcher of classroom action. Sadly Ross died in January 2009, so this is my small salute to his legacy, and that of the whole LISP team.

Observer:	What are you doing now?
Keith:	Heating this.
Observer:	I see, what for?
Keith:	Well (races off to desk on other side of room bringing back book). We are doing No. 5.
Observer:	What did you do before you started heating it?
Keith:	These ones here (points to Nos. 3 and 4 of instructions).
Observer:	Can you tell me what you have found out?
Keith:	We got this yellow stuff.
Observer:	Can you tell me the purpose of this activity?
Keith:	No…not really.

This incident popped into my mind at SERS when someone claimed, with a certain level of passion, that practical work must be continued because it is so *engaging* for students (we were discussing the challenges of new lab safety regulations at the time). This has a ring of truth. All of us know how attention-grabbing practical work of a certain sort can be. The messier, noisier, more dramatic it is, the more students like it. The *entertainment* value is without doubt, and students often see this as science's point of difference from other subjects. But what is the *educative* value of memorable practical work? Let's assume that Keith was burning sulphur, although we can't be sure. Burning sulphur, with its purple flame, yellow and brown mess, and distinctive smell, is certainly a memorable experience for students and it is highly likely that Keith was engaged in the moment. But what would he take away from this learning, if all he could say was that this was "number 5" of a series of steps? Who *owned the sense of purpose* for this activity?

Fredricks, Blumenfeld, and Paris (2004) carried out a comprehensive review of research on student engagement. They identified three discrete dimensions: behavioural engagement, emotional engagement and cognitive engagement. They said that each of these exists as a continuum of possible responses from compliance in response to extrinsic factors to deep intrinsic engagement with learning for its own sake:

- Students show they are behaviourally engaged by being involved and participating. This engagement is more likely to be extrinsically motivated when the student is mainly responding to input (e.g. from the teacher or a 'fun' activity). Behavioural signs of more intrinsic engagement include autonomous and self-regulated participation.
- Evident interest and enjoyment are indicators of emotional engagement. Again this can be in response to extrinsic factors but becomes more internally motivated when the learning is valued by the student as worthwhile and/or challenging and therefore worthy of their personal effort and attention.
- Cognitive engagement at a surface level occurs when students show what they have learned, when requested to do so, via a task shaped by someone else (i.e. learning as a performance). As cognitive engagement deepens, they are more likely to want to demonstrate deeper thinking and they may choose to use metacognitive strategies such as goal setting, study strategies, setting and solving own problems and challenges etc.

What can we say about Keith in the light of this summary? Clearly he was *behaviourally* engaged, and probably emotionally also, but we could speculate that his willingness to carry out the work was purely extrinsically motivated. Cognitive engagement appears to have been minimal, if not non-existent, and his behavioural engagement did not appear to have any intrinsic dimension or he would have been able to explain what he personally was trying to achieve by the actions he was carrying out.
I think this episode raises lots of questions about what engagement looks like and *who it matters for*. If students are active and on task, can we take this as sufficient evidence of their engagement? (It certainly makes life easier for teachers, as we all know to our cost when we don't achieve it.) But should we be aiming for something more, and if so what and why?

Please don't think I'm arguing here that students don't need to do practical work. In another telling moment at SERS, one contributor expressed sadness that 'inquiry learning' is now depriving many younger students of hands-on investigations in favour of a dominant focus on information-based research. If we don't want children's active explorations to decline yet further, we do need to be clear about the *educative* purposes we have for specific practical episodes.

I don't think entertainment value, on its own, is a strong argument, especially given the complexities and uncertainties of life in the 21st century, for which we need to prepare our students as best we can. Contemporary education researchers (Gilbert, 2005; Young, 2009) say that school is where, in our complex networked society, students are most likely to be introduced in carefully structured ways to powerful types of knowledge, *and how it is organised*. The learning experiences we shape and support need to help students understand something bigger about the complex conditions of knowing in the world of the 21st century, with all its uncertainties and risks. With this in mind, could we introduce a 'nature of science' dimension to this and other similar practical activities to help students like Keith learn something meaningful about the work science does in constructing ways we see the world? What would it look like if we did add such a dimension? How would Keith know this was what he was supposed to be learning? The way we should develop the Nature of Science strand was another area of strong debate at SERS, and these are questions you might like to explore as you unpack the nature of science strand of the curriculum and its relationship to traditional science content. (See also Miles Barker's article in this edition.)

Playing the explaining game?

My next small episode comes from a research our NZCER science team undertook to inform the development of Assessment Resource Bank items related to the concept of interdependence. This episode has already been discussed elsewhere (Hipkins, Bull, and Joyce, 2008). My plan here is to reframe that earlier discussion to pose some questions about relationships between engagement and *explanation* – that stalwart of traditional assessment questions!

Figure 1 shows how one Year 8 student completed a simple outline drawing of a stream to demonstrate his knowledge of what might be found there. (The mistake in putting the outline of a saltwater fish in the stream, which Matt has simply labelled "fish", was ours and illustrates how much we take contextual knowledge for granted when clearly we should not.) The text is the explanation Matt wrote to accompany his drawing. He was asked to describe two direct relationships and an indirect relationship between things he identified when completing the drawing.

I've shown this drawing and text to many groups now. Asked to identify something not quite right with Matt's explanations many people scratch their heads. Matt certainly understands the *nature* of direct and indirect relationships and he has heard the message of the "Waterways"[1] programme loud and clear! His *conceptual* knowledge, which is what we typically assess when we ask students to explain science ideas, is very good for his age. However, people with experience of freshwater fishing, or of streams more generally, quickly spot his learning challenge – knowledge of *context*. Trout don't eat reeds. Eels don't eat algae. Both are carnivores so Matt's whole argument unravels *in practice* at this point. Yet he does seem to know what trout look like because he didn't make our mistake of adding a dorsal fin, which we didn't know is only a feature of saltwater fish. (We certainly do now!) And, unlike many other students, Matt knew the kingfisher is a bird and correctly labelled its outline. Somehow his new conceptual knowledge and his existing contextual knowledge have not come together in a critically integrated way so that he could describe valid consequences of certain actions in the world.

Matt has created a flowing lucid explanation. But who has he done this for, and why? This question circles us back to the engagement dilemma. Probably Matt has answered only because he was asked to do so. He has played the explaining game exactly as he expects that he should. Unlike Keith, there is certainly evidence that Matt is cognitively engaged, but again it seems likely this is extrinsically motivated. The explanation he has shaped was an answer to someone else's question – it appeared to have no authentic purpose for Matt. We can possibly say that Matt would have been more likely to check his own contextual assumptions if he wanted to use his knowledge to address an issue of real concern for him. But we can't be certain about this, having fallen into the same trap ourselves!

Does any of this matter? How might Matt come to understand the business of knowledge construction in science if he is not challenged to check his ideas? We've been working for some time on a new Kick Start resource that explores what the Nature of Science strand of the curriculum could look like in the primary school (Bull, Joyce, Spiller, and Hipkins, in press). It includes the following quote from some well-known Canadian science educators, which could give quite a powerful steer to possible ways to reshape both Keith's and Matt's learning experiences so they might learn something about what makes science a specific way of explaining natural phenomena:

> *The real job of science is to produce better explanations – and no matter how they are formulated, explanations are structures of ideas. Everything else is secondary. Myth, common sense, and imagination also produce explanations. What sets science apart is the sustained effort to improve on the available explanations; in short, science is theory building. Careful observation, methodical testing, marshalling of evidence – these are all important parts of scientific practice, but theories are the goal and the guides. (Bereiter and Scardamalia, 2009).*

If we believe that "the real job of science is to produce better explanations" then it does matter that Matt checks the evidence he has marshalled to support his explanation. He needs to have his confident explaining challenged in ways that help him come to understand that a very important function of investigation (both hands-on and research varieties) is to test our explanations against evidence, to see if they stand up. This is an important nature of science idea and it would have been so easy for Matt to do as a next step. With our own blooper in mind, *awareness of the need to check contextual components of explanations* seems to be the main issue here (for a discussion of the implications for developing question-asking skills see Joyce and Hipkins, 2009).

It would certainly help if Matt had been invited to shape an explanation for a question or issue he cared deeply about (and we need to remind ourselves that this was not likely to be the case here – he was simply completing a worksheet on request). There is no doubt that intrinsically motivated ('authentic') learning is much more engaging for all of us. But when this idea is applied to curriculum it is often unhelpfully posed as an either/or matter: should Matt or the teacher decide what is important for him to learn?

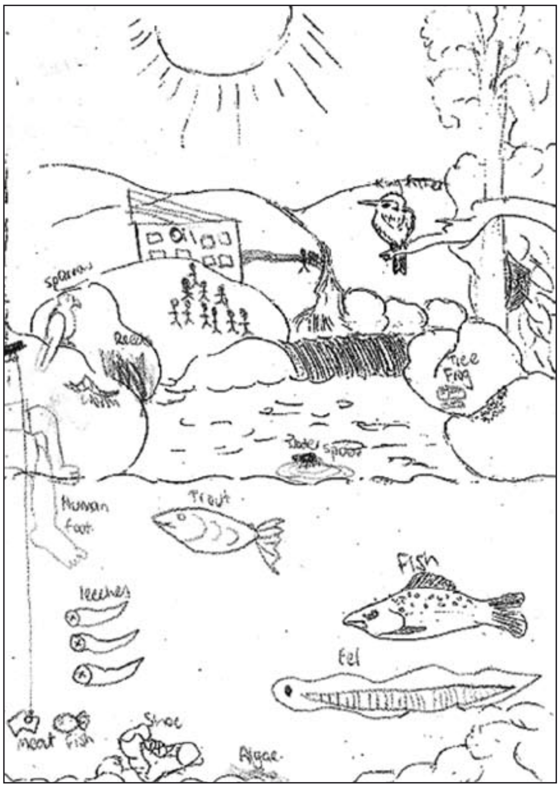

Figure 1: The algae is eaten by the eel. The rainbow trout feeds on the reeds. Companies by water drop oil waste into waterways therefore killing the trout and other fish. The reeds will overgrow, algae will spread and this will cause blockage of drains.

If we accept Young's argument that an important purpose for school is to provide students with powerful experiences and ideas to which they would not otherwise have access, (Young, 2009) then the onus is on us to convert this either/or engagement dilemma to a both/and resolution.

Matt should have opportunities to learn about the powerful concepts and skills that the adults in his education world know are centrally important to his educational growth, and to his ability to create cogent explanations for what he sees around him in the world (see Barker this edition). But he should also experience learning that gives him more control over directions and pace – that is, he should experience chances to learn about, and shape explanations for, things that matter to him. Finding a way to balance both is a tightrope all of us need to learn to walk.

Engaging contexts?

My final anecdote brings together elements of the previous two. By now Keith's and Matt's stories have come to stand for something more than the minor incident each represented in the reality of the moment. Keith, obliging if not able to explain when challenged, and Matt who is both obliging and a confident explainer come now to represent that body of 'good' students whom we expect to do what we ask and to do it well. They play the school game and "get on". Whether what they actually learn has real value for them is a moot question, as we have seen, but let's set that reservation aside and ponder this next episode.

We (the NZCER science team) have been working on developing a new assessment tool to help teachers determine next learning steps in certain areas of the nature of science related to the key competency thinking. As I have already noted, science centrally involves checking our assumptions and explanations against the evidence of the real world. We have created a nationally benchmarked assessment tool called *Thinking with Evidence* that is designed to give teachers of Years 7-10 students formative assessment information concerning how well their students can do this already – and where their next learning steps might be. The 160 items across the four tests are all set in contexts that we chose because we thought they would be interesting for students and would help them engage with the questions, so that they would take the opportunity to show us what they could do. As part of the development process around 8000 students from 62 different schools took part in the trials. My final anecdote comes from feedback comments made by teachers whose classes participated.

A number of teachers commented on how engaged some students had been, especially those they had not expected would try so hard. Feedback from these teachers often expressed concerns about the reading level of the information in the tests, yet the statistical analysis of all the responses showed us that students did rather better than anticipated across the board. One teacher commented on a group of students (mainly boys) who had achieved at a much higher level than their reading track record would have predicted. What's going on here? We're not sure yet and we want to do more work to answer our own question. We think that the types of questions we asked tapped into a different way for students to use their knowledge and skills and clearly some of them rose to that challenge, when their past track record might have been predicted them to be disengaged. (We also note in passing that, like both Matt and Keith, all the trial students were answering questions that someone else asked them to address, not working to their own agenda!) We don't know where the balance lies between tapping into a different type of learning skill and being more engaged to begin with, but we suspect there are strong cross-links between these.

Research predicts that seeing links between what is taught and these types of real issues and concerns is key to ongoing student engagement (for a summary see Bolstad and Hipkins, 2008). What we can say for certain is that the contexts in the questions we shaped were chosen for their links to real word issues and concerns. These were not necessarily contexts students would know about in advance, but they all raised issues and questions that matter for more than just providing a chance to assess learning. Examples included whether or not New Zealand should introduce dung beetles as part of our efforts to clean up farming practices, the bodily challenges of surviving in space, and how to avoid getting dengue fever if you visit affected areas of the Pacific. Perhaps the most important point to make is that the contexts were *integral* to the item sets. Without them, the questions we shaped simply could not have been asked. This stands in contrast to what I think about as the 'candy wrapping' way of using contexts to support learning – the intended learning is essentially unchanged but the context wraps around the outside to provide an attractive veneer of 'relevance'. Many of us tried this out when the 1993 curriculum was introduced. It was a lot of work and sometimes confused students about what was important (Hipkins and Arcus, 1997). I now think we need to rethink how we use contexts and the part we expect them to play in conceptual learning and in engagement with learning. That's another question you might like to discuss as part of your ongoing curriculum planning and debates.

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[1] An educational initiative of the New Zealand Royal Society, in conjunction with regional councils (www.royalsociety.org.nz)

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commitments stand as conditions for the possibility of that cultural form, and to wrap into philosophy or science the task of evidencing or otherwise warranting those commitments will on that account fail. However strongly disposed I am, given my culture, to think that nature completes my situation, still I will struggle to fit meaning itself or mindedness or ethics or mathematics, or anything of which the original touch of infinity is defining, quite under its fold.

Naturalising intentionality, naturalizing ethics, naturalising mathematics, all to me seem fraught philosophical projects, however fully the impulses resonate with me that draw other philosophers into such pursuits. Yet the agony when naturalism is tried, but founders, is to me no inducement to have truck with the supernatural. Rather, I see the naturalising urge as an original instability of my culture (and yet a creative one). Some aspects of the vaulting investment in reason itself are much like faith, and God as metaphor is even helpful in some degree as explanation of their directedness. Yet the condition in question, being thoroughly cultural, seems to me not in the end to tell about the world as it is in itself. It tells at most about us, we Westerners, who are in the circumstance of philosophy, and science.

Newton's consideration of time seems to me on this account not the best philosophy but nonetheless a giant step towards it. As a philosopher he examines honestly and fairly the conceptual presuppositions concerning time of the empirically learned, robustly evidenced laws of motion that he himself enunciated. It is faithful to that science to defend as he does a transcendental (or 'absolute') conception of time, yet Newton steps beyond what is necessary, or scientifically warranted, to fashion his high transcendentalism as directed to God. A more critical perspective is possible, by which Kant would help issue in the Enlightenment.

Still, of the four alternatives mentioned at the beginning, the assessment of Newton's consideration that time is absolute must be that this represented good science and good philosophy. All very Western in the bearings which define it, Newton's consideration that time is absolute represents in its day high sensitivity to conditions for the possibility of physics as exact science.

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