Characterising reasoning in science classrooms

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Current interest in argumentation has promoted a particular version of reasoning in science developed from Toulmin's model, which is in line with traditional perspectives on reasoning as syllogistic and verbal in nature. These perspectives have driven discourse analyses of videotaped classroom dialogue to generate evidence of levels of reasoning in classrooms, and teacher support of reasoning. However, researchers have also been interested in non-formal reasoning as a critical aspect of idea generation in science, including model based and analogic reasoning, and reasoning through representation – construction. In this paper I will use video evidence from classroom to argue the need for a multi-perspectival view of reasoning, to adequately describe the nature of quality learning and teaching in science.

Context of the paper

The Australian Research Council funded project: "Exploring quality primary education in different cultures: A cross-national study of teaching and learning in primary science classrooms (Equalprime)" is exploring the impact of cultural context on the practice of teachers of science in primary schools in Taiwan, Germany, Sweden and Australia. The particular focus of Equalprime is to

- explore the commonalities and differences in practice that relate to the different cultural-historical traditions of these countries, and
- identify discursive practices that provide opportunities for quality reasoning and learning.

The major focus of the study is therefore reasoning. This paper explores the way reasoning might be characterised, in a way that will support the comparative analysis of classrooms.

Reasoning in science education

Reasoning in science has traditionally been construed as involving relations between ideas and evidence and the ways these are coordinated. Thus, studies in the psychological tradition have been concerned with developmental aspects of the recognition and coordination of ideas with evidence in formal co-variation situations (Koslowski, 1996), and the capacity of children to make this idea-evidence distinction

(Sodian, Zaitchik & Carey, 1991). In science education, growth in reasoning capability has been associated with the sophistication of epistemological positions ((Driver, Leach, Millar, & Scott, 1996; Tytler & Peterson 2003; 2005). In these cognitive traditions, reasoning has largely been characterized in terms of formal, syllogistic reasoning processes (deductive, inductive, abductive) that involve logics based on linguistic entities. This view draws strength from reference to the processes by which ideas in science are justified and debated, and the formal structures of scientific papers. Questions have been raised, however, concerning whether these formal logical processes adequately capture the reasoning processes that underpin quality learning in science, or indeed the reasoning inherent in the epistemic (knowledge building) processes of science itself.

Recent work in cognitive science has questioned many assumptions about the nature and processes of cognition. Klein (2006) argues that there has been a shift in cognitive science views away from a view of knowledge as stored, stable mental constructs, where language functions as a "a by-product of thought" (p. 149), to an acknowledgement of language and representation as central to framing thought. These views align with socio cultural interpretations of learning and knowing that form the basis of a classroom approach based on representation construction (Hubber et al., 2010; Prain & Tytler, in press). For this, we draw on semiotic analyses of classroom learning (Lemke, 2004), and perspectives on learning as inculcation into discipline-specific literacy practices (Moje, 2007).

There is a growing literature on the role of representation, especially visual representation, as central to epistemic practices in science (Gooding, 2004; Latour, 1999). A considerable body of research confirms the central role of representational manipulation in generating, coordinating and justifying ideas in scientific knowledge building processes. Gooding's (2004, p. 15) account of Faraday's notebook work leading to conceptualizing interactions between electric current and magnetic field, and the design of the first electric motor, highlights the central role of representational refinement and improvisation in reasoning towards a plausible account of patterns in these phenomena. There is a strong case to be made that Faraday's development and modification of representations were critical to clarifying and instantiating his theoretical understandings and were part of non-formal reasoning processes by which new ideas were created.

How can this process of reasoning through representation be instantiated in science classroom practices? In this paper we present the results of an analysis of reasoning through student representation construction work, from a recent project involving video capture of classrooms of teachers who worked closely with researchers to develop the approach. From this, we argue a need for multiple perspectives on reasoning in science.

Analysing reasoning in science classrooms

Analysis of student reasoning in science has often involved the development of hierarchical coding categories. One such coding, that of 'epistemological reasoning', focuses on reasoning involving different presumed relations between ideas and evidence. The different, hierarchical reasoning categories were developed by Driver, Leach, Millar and Scott (1996) and modified into a coding scheme for tracing student approaches to investigation by Tytler and Peterson (2003). These categories are:

- *Phenomenon-based reasoning*, where explanation and description are not distinguished, and the purpose of experimentation is to 'look and see'
- *Relation-based reasoning,* where explanation is seen as involving the identification of relations between observable or taken-for granted entities rather than the searching for an underlying cause
- *Concept-based reasoning*, where explanation is cast in terms of conceptual entities that represent an underlying cause or deeper level interpretation, where experimentation is guided by hypotheses, where the role of disconfirming evidence is acknowledged as significant.
- *Model-based reasoning*, "where theories or models are evaluated in the light of evidence, and the relationship is recognized as provisional and problematic".

However, as we will argue, reasoning through representation or modelling can occur in a number of guises that do not admit to such a neat separation.

Shemwell, Hardy and Beinbrech (2010) developed a coding scheme that amalgamated our approach (Tytler & Peterson, 2003) with an argumentation overlay, distinguishing between:

- Claim-Based reasoning: a statement of what something will do in the future (prediction), or is happening in the present or past (conclusion or outcome)
- Data-Based reasoning: a claim backed up by a single observable property, and
- Evidence-Based reasoning: a claim supported or backed up by statements describing a contextualized relationship between two observable properties or a contextualized relationship between a property and an observable consequence of that property

These reasoning schemes have proved useful for analyzing the quality of reasoning moves in a cross cultural study involving classroom sequences in Germany and the U.S., and teacher strategies that support this. However, from our perspective such schemes have a number of crucial limitations:

- The identification of argumentation elements is difficult in the cut and thrust of conversations in real classrooms, where the status of statements can be ambiguous and contextual;
- what counts as evidence can be problematic — such schemes privilege formal idea-evidence relations and do not easily account for analogy or metaphor, anecdote, or perceptual evidence;
- the assumption that argumentation is the predominant mode of generating explanatory resources for students has been challenged (Ford & Fordham, 2006; Shemwell & Furtak, 2010) and, critically;
- the type of reasoning described here is both syllogistic and natural language based, and reasoning through representations and models, as with the Faraday example given above, does not fit the scheme.

In this research, we analysed the video record of a number of lessons involving a representation construction approach, which included data on teacher – student interactions and student interactions in small groups, to a) look for examples of where we felt students were reasoning using representations, and b) identify the particular affordances of the representation that supported the reasoning. We then attempted an extended perspective on reasoning that would capture the key elements of the reasoning moves associated with representation construction challenges.

As an example of student reasoning using representation construction, we analyse below the process by which two students, Jesse and Paul, observed, discussed, constructed design drawings, constructed a model, and communicated a developing understanding of centipede movement. The model construction task was to focus on explicating movement, and Figure 1 shows the boys' drawings of aspects of the centipede structure, including a design leading to a segmented model with elastic joints, and on the right the model itself.

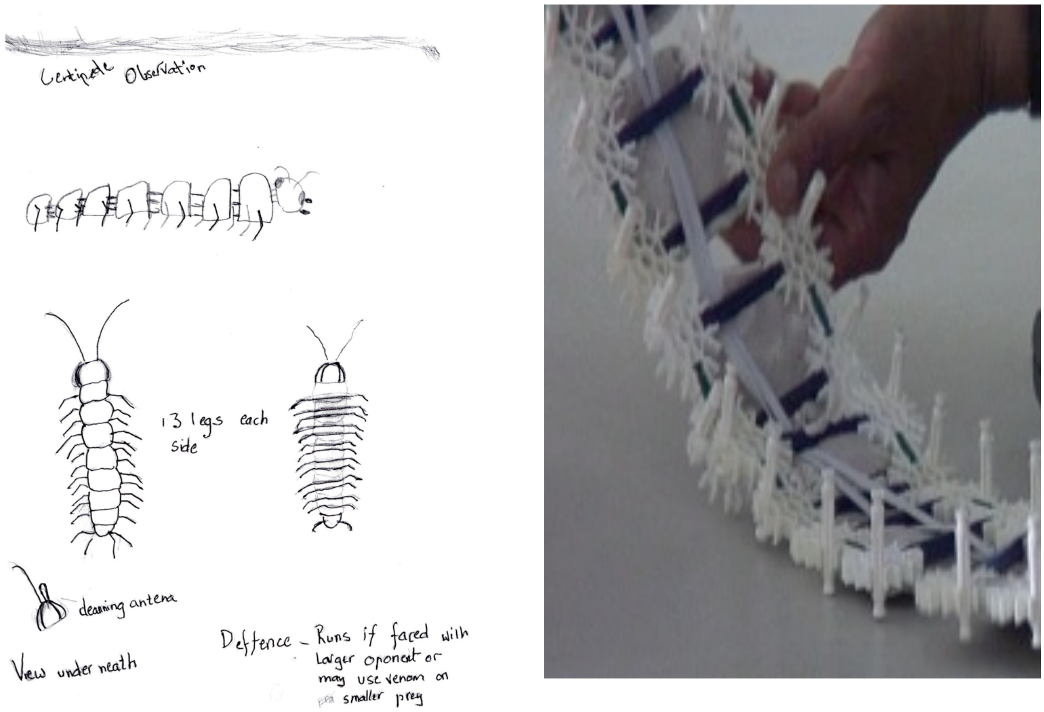

Figure 1: Student drawings of a centipede, including a design drawing leading to the model on the right designed to interpret the animal's movement

They boys describe their model:

Jesse moves his hands in a sideways undulating movement: "… so instead of moving in straight lines, it moves (he gestures to signify the undulation) so we used elastic so it could move properly"

In reporting to the class, they draw on gestures to indicate the undulating movement of the centipede's legs and body.

How we found out, how it moves is (moves the model) it went like (uses right hand to simulate the undulating movement). I also think it did this (moves hands) one set of legs forward and the other (raises both hands and moves them in a left-right, left –right motion).

At this point Jesse moves very close to and just behind Paul, so as to represent the next consecutive segment. Both students then use their hands and their entire body, gesturing and moving in complete synch.

In considering the processes by which the boys gained insight into the centipede movement, we would draw attention to:

- The ways their talk, sketches, and decisions on model design worked together to support them organize their perceptions to ascertain just how the legs and body moved. The construction of drawings involved the analysis of centipede parts and selection of elements important to movement, and abstraction and synthesis of the many details of the centipede's anatomy, in much the same way as Gooding's (2004) description of dimensional reduction (to 2D) and abstraction as the first step in an imaginative visual reasoning process leading to scientific innovation.
- The way their deepening understanding is built through successive transformations across representations, from labeled drawing, talk, design drawing focusing on the nature of joints, model construction, and embodied characterization, each of which involves analysis and selection and a focusing of attention, and a synthesized abstraction of pertinent features.
- The specific affordances of the different representation tasks, in encouraging a selective focus of attention. The drawing required specificity in the relation between segments and leg attachments. The design drawing (top of Figure 1) forces attention on the characteristics of the joints. The modelling forced attention on the material properties that would allow the movement (e.g. the choice of elastic, with hard sections). The embodied representation, where the boys fell in step with each other, forced attention on details of the undulating movement of successive sections.
- The coordination of these multiple, selective representations, to construct a coherent narrative of what was happening, constitutive of their understanding.

The process by which the boys achieved an integrated understanding of centipede movement could be viewed in terms of the Peircian triad (Figure 2) in the way each representation was aligned with its referent, meaning particular aspects of centipede structure and function, and its adequacy judged in terms of its capacity to contribute to that understanding. The complete process which involves multiple representations implies a constant circling round the triad to establish multiple perspectives on centipede movement, in terms of coordinating ideas about leg and body movement, body structure and characteristics, and an embodied perception of how these fit together to achieve some sense of the centipede's movement.

In an important sense, each of these representations can be seen as a reasoned claim (although not in the Toulmin linguistic sense – see Osborne, 2010) in that it involves analysis of centipede structure, leading to selection and synthesis towards an explanatory end, and judgment about the adequacy of the account to the referent.

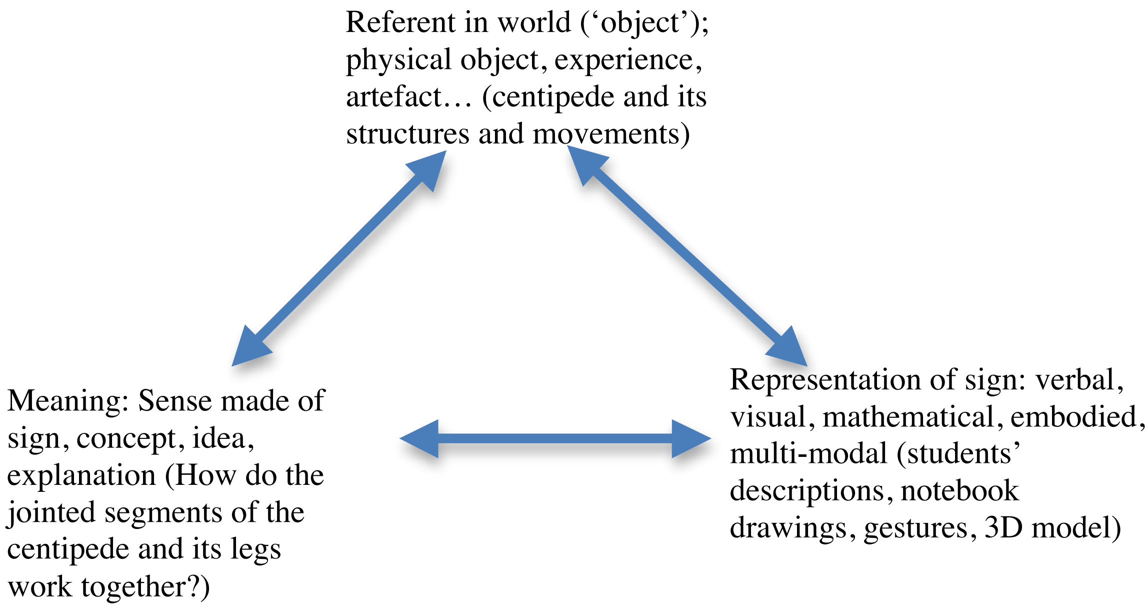

Figure 2: Peirce's triadic model of meaning making

In challenging students to represent animal movement, teachers in this approach do not explicitly encourage claims, or challenge for evidence, but rather challenge students to think carefully about the coordination of the representation with the phenomenon:

> The people that are going to be representing [movement of] worms somehow, you are going to really **think** how you are going to show [movement], and what kind of [pause] equipment [pause] material you are going to use to represent that?

How might we make the case that the construction of an understanding of centipede movement involves instances of reasoning? How might we characterize that reasoning?

We need to acknowledge that the case is somewhat circumstantial, since we do not have access to a running account of students' thinking as they performed the representation construction and the observations and coordination associated with that. We do have evidence of groups of students constantly checking back and forth between animals and their drawings as they refined, asked questions, hypothesized and resolved aspects of structure and function (see Tytler, Haslam, Prain & Hubber, 2009). The centipede drawing required close observation and analysis of the animal's structure to ascertain which parts were pertinent to the movement and how they worked together in movement, such that the selection of key features involved in movement was achieved and represented. In the second, design drawing, the key feature of the nature of joints, and their abstracted representation, was the focus. Thus, we argue that the drawings involved close and focused observation and analysis of the animal and it's movement, to select and chunk and analyse the perceptual information in a manner that Eberbach and Crowley (2009) characterize as a scientific mode of observation. The act of drawing itself similarly involved selection of what to represent and how, as pertinent to movement, in a process of symbolic abstraction, organization and synthesis of these elements into a coherent visual account.

A more complete analysis of learning sequences (Tytler, Prain, Haslam & Hubber, in press) involving reasoning through represention construction identified the use of representations:

- To guide exploration and investigation, such as organising perceptions, organising data generation, identification of patterns in data (tables and graphs), and identifying structures and mechanisms (drawing and modeling), and
- To develop, refine and make sense of conceptual perspectives, such as developing and refining representational features, selecting and refining representations to explain or problem solve, aligning and coordinating representations, making judgements about representationsl adequacy, and engaging in meta-representational reasoning.

Methodological implications for a cross cultural comparative study

These analyses have drawn attention to the fact that reasoning occurs in more ways in science classrooms than can be captured by traditional discourse analysis focused on linguistic versions of reasoning. They imply a number of principles pertinent to cross country comparison of reasoning in science classrooms:

- The need to include a range of reasoning constructs to make comparisons across countries
- The difficulty of developing coding that researchers in each country can reliably apply
- In making judgments of teacher support, the need to capture not only dialogue, but also details of the nature of the task and its framing
- The need to take a more ethnographic approach based on visual data of student representation construction or interaction with artefacts, and of teacher interactions, rather than counting categories
- The need to capture both the formal and informal reasoning of students working on projects, supported by the task and the teacher.

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