Future directions in representing learning in Biology

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Abstract: This is a reflective piece on the process of identifying the difficulty students have with underlying biological concepts, a discussion about how educators can metacognitively construct a range of representation strategies (visual, auditory, kinesthetic, analogical) to help students increase their conceptual understanding and where we are yet to go in the future. There has been much discussion about consciously appealing to different modes of learning by presenting difficult concepts using a range of representations, but this has been done in an ad hoc manner, with choice of visual, analogy or 'wet lab' dependent on precedent, intuition, or convenience using the cornucopia of strategies we feel confident in, rather than pedagogically sound rationale. It has been known for sometime that certain representations (such as analogies) cause conceptual difficulties for students and it is unlikely that one representational strategy alone will be the panacea for creating the visual imagery students need to develop the accepted scientific conceptual framework. Multiple representations of the same concept may also confuse students because they cannot translate or link the representations we use into their conceptual framework. For example, students may not visualise and link scale and dimension of the microscopic and submicroscopic worlds necessary for understanding enzyme action, if they are presented with a macroscopic-scale model followed by observing the macroscopic outcomes of a biochemical reaction in a 'wet-lab' with a mental submicroscopic visual model of an enzyme discussed in a lecture or animated in an on-line environment. We can use structure mapping theory, in the future to represent and linking representations based on identified misconceptions and threshold concepts to increase students' conceptual understanding.

What is known does not work: Misconception and representation in learning

There is an enormous body of literature stretching over decades on the naïve conceptions that students come to the science classroom with, how these naïve conceptions influence what and how students learn and just how difficult it is to change student misconceptions into a deep understanding of more scientifically accepted conceptions (Duit and Treagust 1998; Gabel 1994; Tytler 2007). The counter intuitive and symbolic nature of many physics and chemistry concepts has made them a focus in the misconception literature. More recently it has become apparent that the best quality biology students at elite institutions (even when taught by universally admired academics), fail to understand the conceptual foundation in key content areas of Biology even after passing through multiple conventional biology courses (Wandersee, Mintzes and Novak 1994). The realisation that summative assessment tests fail to measure whether misconceptions persist at the end of a particular unit of study has led to the development of inventories to diagnose student conceptual understanding; three examples are the Force Concept Inventory (Hestenes, Wells and Swackhamer 1992), Brief Electricity and Magnetism Assessment (Ding Chabay, Sherwood and Beichner 2006) and most recently the Biology Concept Inventory (Garvin-Doxas and Klymkowsky 2008). There has also been a renewed emphasis on the misconceptions and thresholds in concepts (Meyer and Land 2005). To date, however, there is a simple lack of evidence that the pedagogies of constructivism and classic conceptual change (von Glasserfield 1987; Posner, Strike, Hewson and Gertzog 1982) with their focus on conceptions have been effective (Tytler 2007). Perhaps these pedgogies have not delivered on their promise because of the narrowness of the cognitive approach which ignores the influence of context, motivation and emotion on learning and assumes learning is rational and that misconceptions are stable (Tytler and Peterson 2004; Tytler 2007).

Given constructivism and classic conceptual change have not fulfilled their promise, there has been a call for a shift in focus to representation (Tytler 2007). As opposed to the presentation of formal explanations (Tytler, Peterson and Prain 2006), students use a range of multi-modal representations to learn (visual, auditory, kinesthetic) including audio, animations, multimedia, role play and analogies to improve their conceptual understanding (Ross and Tronson 2004, Ross, Tronson and Ritchie 2006; 2008; Yeung, Schmid, George and King 2007). This focus is not new. For decades, multi-modal representations have been the staple of learning and teaching in science at tertiary levels. Students often journey between differing representations of a concept in a lecture, a

'wet lab' and an interactive on-line tutorial or multimedia animation. All of these representations are aimed at creating a visual image of the concept under investigation. Yet even with the experience of a range of multi-modal representations, the evidence we have is of students progressing to higher levels in their undergraduate degrees with fundamentally incomplete or wrong conceptual understandings within Biology (Meyer and Land 2005; Garvin-Doxas and Klymkowsky 2008; Ross, Taylor, Hughes, Kofod, Whittaker, Lutze-Mann and Tzioumis in review).

Why then does the representation path also seem problematic? Is it because we, in an *ad hoc* manner, have based the visual, analogy or 'wet lab' representation experience on precedent, intuition, or convenience using the cornucopia of strategies we feel confident in? Perhaps we need to strengthen the rationale focused on the concept and the perspective of the student as the learner. For example, enzyme structure and function in Biology is most commonly represented to students in a large scale lecture at a submicroscopic level with an abstraction of activation energy that is de-contextualised from the cell. Commonly this lecture is followed by a 'wet-lab' where enzyme function is observed and represented at the macroscopic level commonly combined with a submicroscopic visual representation of enzyme action in an animated on-line environment. The erroneous assumption we make in selecting these representations is, not the representation itself, which may be a worthwhile experience, but about the assumption that students can link these differing representations requiring translations of scale, dimensionality and dynamism to form a mental model which is an approximation to that considered currently accepted by experts within the discipline. Since these different representations often vary at the level of scale and require imagining images at the cellular level as well as mentally linking these to macroscopic observations with completely different dimensionality, and simultaneously necessitating an understanding of dynamism, is it any wonder the students fall short of full conceptual understanding of enzyme action? In another example the concepts of cellular metabolism and photosynthesis in biology require students to think and experience the cellular level (Songer and Mintzes 1994) and perhaps are best represented by model building, role play, multi media and animations (Ross and Tronson 2004; 2007; Ross, Tronson and Ritchie 2005; 2008). However, more often we provide students with 'wet lab' experiences at the macroscopic level with an investigation which involves the timing of dye in a respirometer or the counting of bubbles of gas from an aquatic plant. These 'wet lab' representation experiences are expensive in the current tertiary climate. If they fundamentally do little to change student misconceptions, then we need to find other justifications to retain them or else another way to teach these tricky concepts. Further, in many instances, laboratory exercises focus more on an exploration and experience using the scientific method or assist in the development of a manipulative skill, rather than explore underlying concepts (Ross, Tronson and Ritchie 2008). For some time the effectiveness of practical laboratories, once viewed as integral to the processes of learning and teaching in the Sciences, has been questioned (Hodson 1988; 1990; Dawson, 1994; Harrison and Treagust 2002). The notion that physical activity equates with cognitive activity is at the cornerstone of this debate. The high 'noise-to-signal' level ratio of practical laboratories may be distracting to students. Noise here being defined as the multilayers of information that students need to simultaneously assimilate in a practical class, rather than the physical 'sound' in the practical lesson, which may also be high. A high 'noise-to signal ratio' may occur when a practical lesson is based on macroscopic observations which require a microscopic or submicroscopic understanding (Harrison and Treagust 2002). Indeed students may leave the practical laboratory more confused about the concept under investigation than when they arrived (Beaver 1999).

What might work: Future directions for representation learning in Biology

It has been known for sometime that other representations such as analogies, or non literal comparisons between superficially dissimilar knowledge domains (Zook 1991) can assist understanding. Misconceptions and conceptual difficulties, however, can be created when analogies

are not matched and mapped to the familiar domain and alignable and non alignable differences identified (Genter 1980; Genter and Genter 1983; Zook 1991). Structure mapping theory has been used by several authors (Genter 1980; Genter and Getner 1983; Justi and Gilbert 2002), to point out the constraints of analogies (Glynn 1991; Thiele and Treagust 1993; Iding 1997).

With representation holding such promise as a tool to deal with student misconceptions, the future may include using structure mapping theory to evaluate the representations of concepts we use to create a cognitive representation or visualisation of a real-world biological concept for students. To do this we need to decide on the learning outcome and identify basic concept issues and procedural thresholds (Davies and Mangan 2007). Having decided on the learning outcome(s) and the barrier(s) of understanding, the next step is to determine the mode(s) of representation (Justi and Gilbert 2002). Following this, the representation is experienced by students and expressed using the mode of representation. After these experiences, an explicit discussion of the representation(s) with the students and a mapping of the similarities and differences with the concept can lead to improved learning outcomes (Ross, Tronson and Ritchie 2008). The evaluation of the cognitive outcome of the representation(s) must include an assessment which provides a valid measure of what students know and do not know in order for teachers to develop sophisticated clinical judgments about students understandings of significant ideas and processes and for educators to discuss the limitations of the representation(s), rather than simply measure educational progress (Treagust 2006; Figure 1).
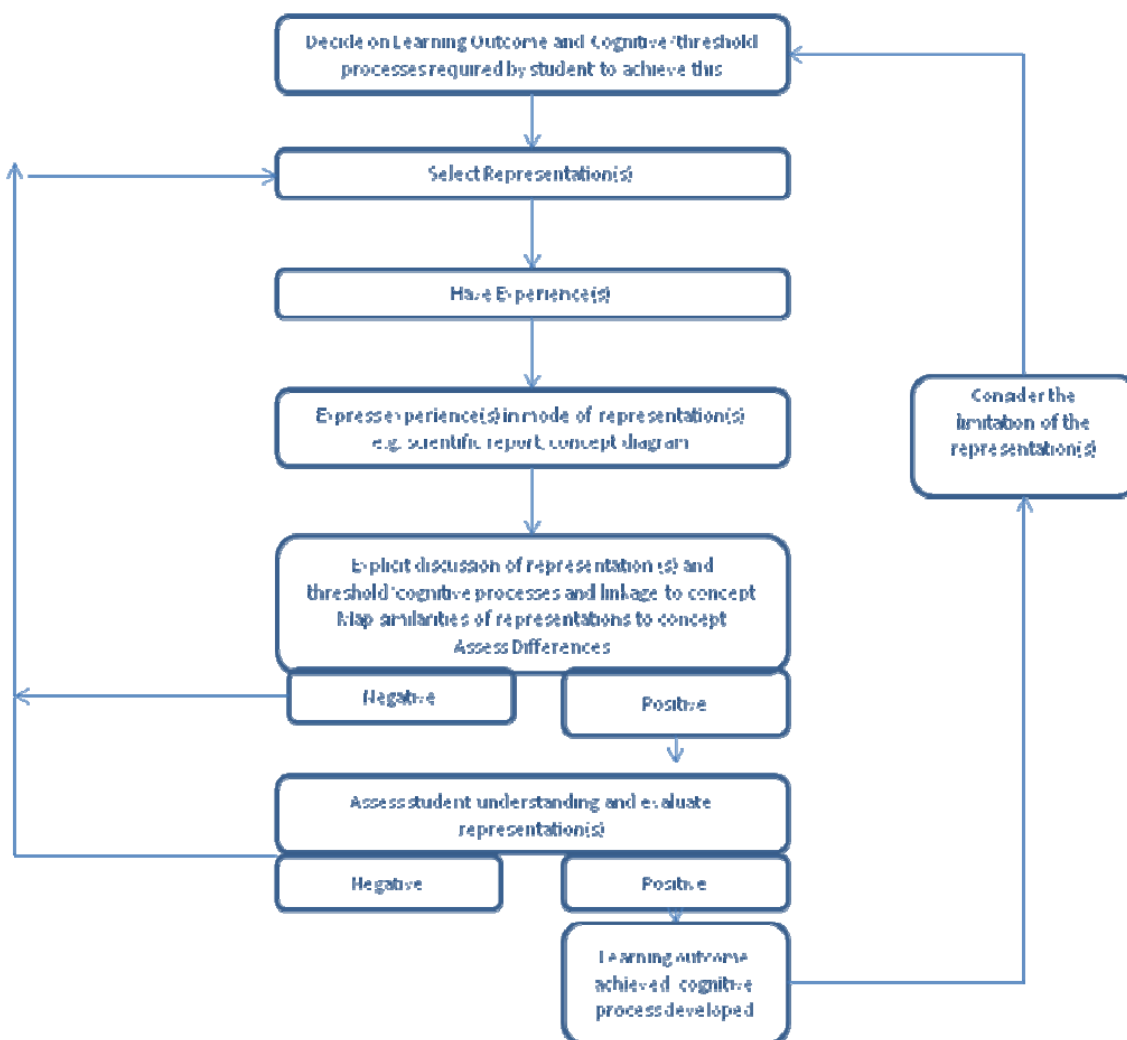

Figure 1. Representation framework (modified from Justi and Gilbert 2002)

Conclusion

It is unlikely that any one representation alone will be the panacea for conceptual development in Biology. We need, however, to pay more attention to aligning various representations we use with learning outcomes and with assessment which is diagnostic. It could be that more is not better, and that multiple representations of the same concept may confuse students because they cannot translate or link the representations we use into their conceptual framework. We do need, however, to take a meta representational view of our practice and how this is influencing students' cognitive development.

Acknowledgments

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