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Representation Construction Approach: A Guided Inquiry Pedagogy for Science

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ABSTRACT

This paper describes the development and implementation of a guided-inquiry approach to teaching science which reflects the increasing attention given to the role of representation in learning science as well as knowledge creation in science. This representation construction approach (RCA) involves challenging students to generate and negotiate the representations (text, graphs, models, diagrams) that constitute the discursive practices of science, rather than focusing on the text-based, definitional versions of concepts. In working with teachers in the development and refinement of the approach a design-based research methodology was employed. The investigation of the approach, and teachers' experience involved video capture and analysis, and teacher interviews whilst documentation and analysis of student learning occurred through analysis of class discussion through whole class and small group video capture, collection of student artefacts, pre- and post-tests, and student stimulated recall interviews. The approach has been successful in demonstrating enhanced outcomes for students, in terms of sustained engagement with ideas, and quality learning, and for teachers enhanced pedagogical knowledge and understanding of how knowledge in science is developed and communicated.

***Keywords**: Representation Construction, Guided-Inquiry, Science*

Introduction

This paper describes a representation construction approach (RCA) to guided inquiry pedagogy that has been developed and trialled over a 9-year programme of research which students, through constructing and evaluating representations, are led to understand and appreciate, and productively employ scientific representations (Hubber et al., 2018; Tytler et al., 2013). The rationale for a representational focus on pedagogy comes from increasing attention being given to the role of representations in learning science as part of growing recognition of the representational basis of knowledge creation in science (Latour, 1999). Much of recent research has placed emphasis on students learning to use scientific representations flexibly to visualize phenomena and problem solve and to use the multi-modal representational tools of science to generate, coordinate and critique evidence (Ford et al., 2006), involving models and model-based reasoning (Lehrer et al., 2006).

An argument for inquiry-based approaches comes from a mounting concern that traditional teacher-centred approaches to science are failing to engage students and, in particular, are not developing the inquiry and problem-solving skills, and creativity, needed by citizens engaged in the twenty-first-century workforce (Chubb, 2014). There is also growing evidence that inquiry and open problem-solving approaches lead to more robust learning in science (Chi, 2009; Furtak et al., 2012).

The major features of RCA, developed and trialed by the research programme (Tytler et al. in Press), include:

1. Students construct representations in response to explicit challenges. This process involves strategic scaffolding so that students' representational work is focused and productive. The challenge involves a shared practical problem that is meaningful to students.
2. The representation work is underpinned by experimental exploration or appeal to evidence based in experience.
3. Teachers orchestrate shared discussion/ evaluation of representation work.
4. There is explicit discussion of representations and representational adequacy and their role in science knowledge building.
5. Assessment is ongoing and a core aspect of learning.

This research aimed to document the experience of the teachers in implementing RCA, and to investigate the quality of student learning associated with different aspects of the pedagogy.

Methodology

The methodology was design-based research which is, "designed by and for educators that seeks to increase the impact, transfer, and translation of education research into improved practice (Anderson et al., 2012, p. 16)". It involves an interactive process of development and trialing, and evaluating outcomes in constructing the key elements of RCA and was conducted with teachers as partners in the process.

Over the 9 year research period, which involved three Australian Research Council (ARC) funded projects, researchers from 5 Australian universities worked with primary and secondary school teachers in the middle years of schooling (Year 5 to Year 10) from at least 10 school settings. The researchers worked collaboratively with the teachers in the design of whole topics which were then taught by the teachers over a 5 to 8 week sequence. Topics included astronomy, ideas about matter, animals in the schoolyard, energy, light and sound, rock cycle, and force.

Investigation of the development of the teaching approach, and teachers' experience, was based on video capture and analysis, and teacher interviews (Hubber et al., 2010). Documentation and analysis of student learning occurred through analysis of classroom discourse through video capture, collection of student artefacts, pre- and post-tests, and student stimulated recall interviews (Tytler et al, 2013). Participation by each school lasted between one and three years (the duration of an ARC project) and involved the teaching of at least two topics. Whilst there were some teachers who taught only one topic there were six teachers who taught at least four topics over a three year period.

Result and Discussion

A key element of RCA is for students to construct representations, which might be multi-modal in nature in response to tasks referred to as representation challenges. The nature of a representation challenge is diverse, and how a challenge is orchestrated is a core skill in the teaching and learning process. In some cases a challenge or series of challenges might begin a topic, for instance in introducing the arrow convention of force through a series of tasks in which students initially struggle to communicate the action of force leading them to confidently use force diagrams to explain everyday actions such as opening a container (see Fig. 1) (Hubber et

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al., 2010), in representing the relations between particles in a solid to explain specific properties such as stretching a rubber band, or softening of a piece of chocolate on warming (Hubber et al., 2013) (see Fig. 2) , or in planning and constructing a 3D model of a small animal found in the school yard to explain its movement (Tytler et al., 2009) (see Fig. 3).

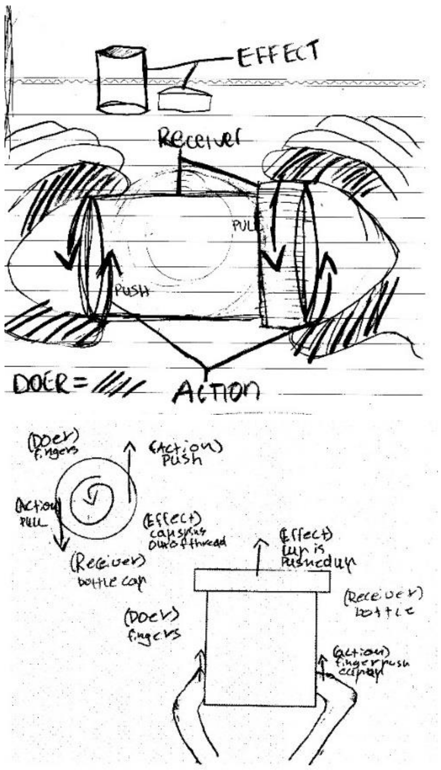

Figure 1. Two Year 7 student responses to a challenge to represent the forces involved in opening a screw top container.

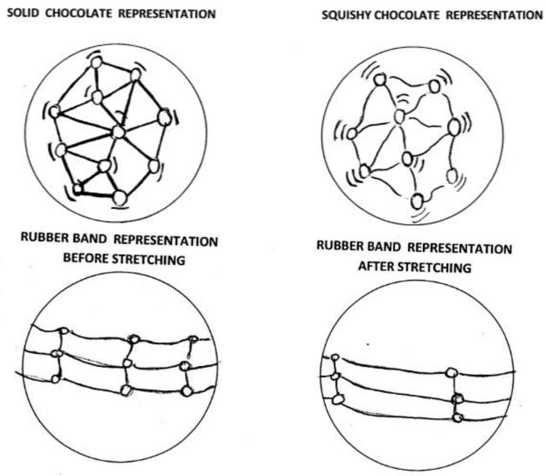

Figure 2. Two Year 7 students' responses to challenges to explain specific properties of solid matter.

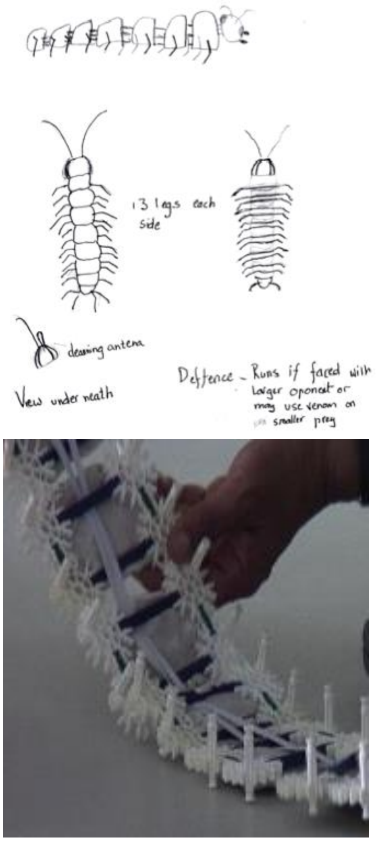

Figure 3. Year 6 student's notebook entry and 3D model in response to a challenge to explain how a small animal, like a centipede moves.

In other cases teachers might plan a sequence of challenges involving representational re-

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description across modes, such as a sequence of activities in which students develop their understandings of particle models of evaporation using role-play, drawing, or discussion of a 3D demonstration. In cases where the scientific model is more complex, students may begin by re-describing, or re-representing, an existing model in response to a specific challenge, such as explaining from a space view why the Sun does not set in Antarctica during summer when shown a photographic image of Antarctica with the Sun in various stages of setting (Hubber, 2010).

It is important to note that a key element of all representational challenges is to have some evaluation of the student-generated representations. Challenges in the classroom usually lead to evaluative discussions amongst the students or in class discussions by the teachers. The evaluation and critique of representations extended to the canonical representations of science. In this way RCA develops in students their meta-representational competence (diSessa, 2004), which denotes such capabilities as the ability to invent novel representations, the ability to critique existing representations, and knowledge of the functions that representations perform. For example, in introducing the topic of Astronomy the teacher asked the class to critique the globe as a canonical representation of Earth in space. The class discussed aspects of Earth that were represented by the globe as well as aspects of Earth that were not represented (see Table 1).

Table 1 Class critique of a globe

What does the globe represent?	What does the globe NOT represent?
The axis is tilted.	Clouds/atmosphere
Shape (round)	Gravity
Earth rotates (spins)	Day and night cycle
Land and sea	Size of Earth
	Inside the Earth

Pre- and post-testing of students in classroom where RCA was adopted have indicated substantive learning gains. Whilst there was anecdotal claims from the participating teachers as to an enhanced engagement and learning by the teaching approach the research did not apply an experimental design to support such claims. However, comparisons of the pre- and post-testing of core astronomy concepts in two of the research schools were made with a separate international study (Kalkan et al., 2007) who used the same instrument. The Kalkan et al. (2007) study involved 100 pre-service primary and secondary education teachers who participated in a semester length course in astronomy. A measure of comparison of pre- and post-test results is the normalized gain index, <g>, the ratio of the actual average student gain to the maximum possible average gain: $\langle g \rangle = (post\% - pre\%) / (100 - pre\%)$, reported by Zeilik et al. (1999). Gain index values can range from 0 (no gain achieved) to 1 (all possible gain achieved). The mean gain reported by Kalkan et al. (2007, p. 17) was described as a “respectable 0.3”. In contrast, the mean gain for the two schools in the RCA research was significantly higher at 0.52 and 0.63.

A key finding of adopting the RCA was that the record keeping of the students in their workbooks was more like journals that reflected their developing ideas in multiple modes (see Fig. 4).

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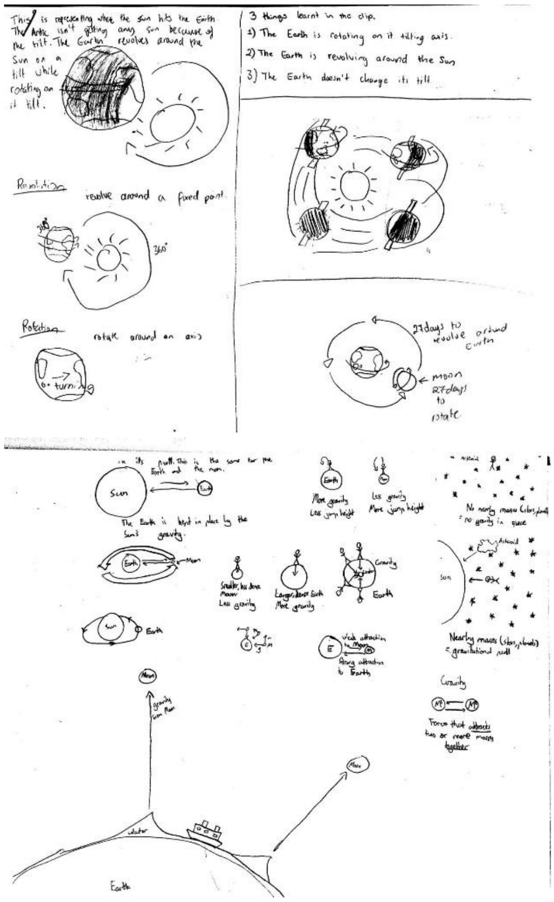


Figure 4. Two Year 8 students' journal pages in the topic of Astronomy

From an assessment perspective RCA involved students and teachers in a continuous, embedded process of assessing the adequacy of representations, and their coordination, in explanatory accounts. For the teachers the representational work undertaken by the students, whether it be in responses to representational challenges or class discourse in discussing representation, was a powerful formative assessment instrument. This gave the teachers deep insights into the students' developing ideas which they were able to use in guiding them through further representational works to an understanding of the canonical representations. For example, Figure 5 shows a students' response to a challenge to explain, using particle ideas, the phenomenon that chocolate become soft when heated. The alternative conception that the particles take on the macroscopic property of chocolate is evident.

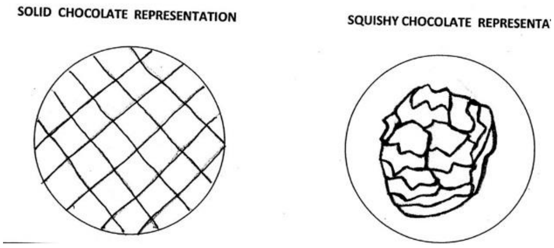
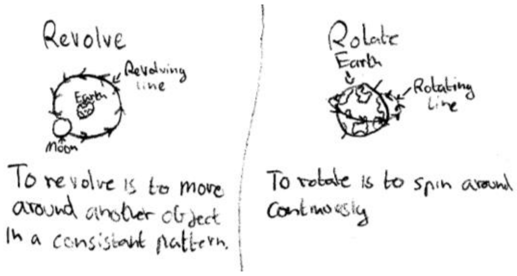


Figure 5 Year 7 students' response to explain a specific property of matter

In relation to summative assessment students were given tasks that extended beyond the traditional written tests to include multiple modes of representation in which students' showed their understanding. Examples of such representational forms as model-building, creation of digital animations, role-play and posters. The teachers found that the ample provision of space given for students to respond to paper-based tests questions afforded the students the opportunity to express their understanding in a variety of representational forms. For example, Figure 5 provides three students' responses to a topic test question where they were given the context that one of the moons of Jupiter was found to rotate and revolve around the planet and asked to explain the difference between rotation and revolution. Each of the responses given in Figure 6 are scientifically correct and reflect a view that one does not need to privilege text responses over other forms. The provision of a space for the students gave them the permission and authority to use multiple modes of representation in expressing their understanding.



to rotate is to spin. Rotation is done on the spot. To revolve is to orbit or go around something. To revolve you need two objects: one to be revolved around and the other to revolve around the first object. So Europa must spin or rotate at the same time as it orbits or revolves around Jupiter.

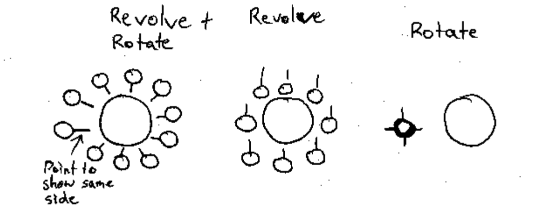


Figure 6. Three Year 8 test question responses

Conclusion

The RCA as a directed inquiry pedagogy requires students to interpret and construct representations of scientific concepts, claims and processes. By representing some aspect of the world about them, students engage in the processes of knowledge construction of science as well as gaining scientific knowledge. RCA allows students to experience the actions of scientists in the manner in which they construct explanations of the world and therefore addresses calls for school science to better represent the epistemic practices of science.

The RCA places demands on the pedagogical skills of the teacher beyond those needed for transmissive approaches. For example, the skills to provide a representation-rich environment and opportunities for students to negotiate, integrate, refine and translate across representations. Teachers require good subject content knowledge that entails an understanding of the key representational resources underpinning science topics and an understanding of the role of representation in teaching and learning science. The approach requires of teachers a capability to run open discussions and develop the insights needed to guide the classroom tasks and conceptual negotiation.

The adoption of representation construction approaches does open up new directions and emphases for teachers to pursue in their teaching. For example: a change from students using their notebooks to transcribe distilled science knowledge provided by the teacher to the use of notebooks as learning journals. Also, the affordances associated with the representations constructed by the students as giving the teacher insights into the students' developing understandings. For the teachers there is also a new emphasis in developing students' meta-representational competence in additions to developing their conceptual understanding of science.

Representation construction as a guided inquiry approach was born from extensive research in science classrooms. However, many of the ideas inherent with the approach have synergies with inquiry-based approaches in other disciplines, such as mathematics. Dreher et al. (2016) point out that representations and their connections play a key role for experts in the creation of mathematical knowledge and for learners to build a conceptual knowledge in the mathematics classroom. Mathematical objects are abstract, and so experts as well as learners must use representations when dealing with them (Duval, 2006).

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