A Call to Cultivate Primary Teachers' Representational Practices in Order to Promote Students' Scientific Literacy

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Introduction

There is now a national and international focus on increasing engagement in science, technology, engineering and mathematics (STEM) study and careers, from primary school to university and beyond, due to declining student interest in these subjects (Lyons, 2006). Declining interest and enrolments in the senior non-compulsory science subjects is an Australian (Lyons, 2005) and international (OECD, 2006) phenomenon and is proposed to be due to a curriculum that is out-dated and lacking relevance, as well as a shortfall of training for teachers' technological and pedagogical content knowledge (Tytler, 2007). An emphasis on improving teacher education and professional learning in these areas is necessary in order to engage the interest of today's students and raise awareness around the importance of contributing to the scientific developments and innovations of tomorrow.

Students' avoidance of senior sciences has several likely flow-on effects such as lower tertiary enrolment in science, fewer science professionals, and a public that lacks sufficient scientific literacy to make informed decisions about the impacts of science, particularly contemporary science, on society and their own lives (Hilton, Kanasa & Nichols, 2009). Add to this that there is a greater demand for STEM skills due to the rapid growth in scientific knowledge and understanding that have led to the development and applications of contemporary science and technologies such as, nanotechnology, biotechnology, bioinformatics, robotics and communication technologies. These contemporary sciences merge traditional science disciplines with other STEM subjects.

Schank & Wise (2006) advocate that teaching of cutting-edge science topics engages students, reinforces core science concepts, and gives students a better idea of how the traditional disciplines tie together. A report published by the Dolan DNA Learning Centre (1997) in the US states that "the growing importance of the modern sciences demands a society of modern [science] literates". Discussing 'new' science literacy, Campbell (2003:98) noted "if students are to be literate in modern [science], then teachers will need to be aware of the impact that new information is having on all areas of [science]. This confluence of needs for information and interdisciplinary learning has led to a unique time in [science] education."

Unfortunately, many science curricula are disconnected from these innovative and cutting-edge sciences and are still rigidly discipline-based (Nichols, 2006). This is a concern because if teachers and the science curricula are to re-engage students in science then the teaching and learning strategies need to better reflect how scientific knowledge is constructed and the curricula need to incorporate contemporary science content in a relevant way. With continual expansion of contemporary science knowledge, teachers recurrently face pressure to rapidly reshape their understandings (content knowledge) of and classroom practices (pedagogy) or in other words their pedagogical content knowledge of the new concepts and technologies emerging from scientific research (Nichols, 2006). But there is no significant theoretical or empirical guidance on how to do so.

With the continual growth of scientific knowledge come questions about which modes (i.e. text, visual, gesture, spoken language) of communication best represents what content, and whether changes in the representation of knowledge, amount to changes in student knowledge. The new Australian National Science Curriculum objectives emphasise the transmission of scientific knowledge and the training of scientific ways of communicating (questioning, talking and writing like a scientist). As a result, research is now...
needed that focuses on changes in the communicational environment within the science classroom, most prominently in the contemporary sciences. But how is this to be approached?

**First step – develop primary teachers’ pedagogical content knowledge:**

Primary teachers face enormous challenges in teaching science. These challenges are associated with the very high number of key learning areas that they are responsible for teaching, their limited exposure to domain-specific content knowledge (Osborne, 2006), understanding of scientific inquiry (Bryan, 2003), their low self-confidence in teaching science (Schwarz, 2009) and the limited time allocated to science in primary schools (Howes, Lim & Campos, 2008). Therefore primary teachers require additional support to develop their pedagogical content knowledge (PCK) in science. The core process of PCK is the way that subject matter is transformed for teaching. This occurs when teachers understand the subject matter and find ways of representing the content to make it comprehensible to learners (Shulman, 1987).

However, the nature of contemporary sciences places pedagogical, content, and technological demands on primary teachers as the content is often abstract and complex, requiring the use of multiple and digital representations to make it accessible to learners. Therefore, in order to teach contemporary sciences, primary teachers need to develop technological and pedagogical content knowledge (TPCK) which Mishra and Koehler (2006) describe as knowledge and understanding of the relationships between technology, content, and pedagogy that allows them to construct appropriate, content-specific strategies and representations. To facilitate the introduction of complex science topics, teachers need to choose and use content-appropriate and multiple visual representations such as text, drawings, diagrams, graphs, tables, pictures and sound-in animations to promote students’ interpretation, understanding, appropriate choice of, and even creation of, representations of a topic (Lazaros & Spotts, 2009). This skill, that of analysing multiple representations, choosing the most content- and pitch-appropriate ones, sequencing them, explaining them, creating them and choosing the most apt learning and teaching strategy to support their use for meaning making is referred to as the teachers’ “representational competence” and will be discussed further in another section of this paper.

Knowledge of technology (from the standard whiteboard to the advanced computer) is often seen as being isolated or separate from knowledge of content (subject matter to be taught and learned) or pedagogy (practice or methods of teaching and learning). However, technology, content and pedagogy are related to each other in complex and nuanced ways. As technologies often have requirements that can constrain the content to be taught as well as the types of representations to be used, there can be flow-on effects around pedagogical approaches. Teachers need to be aware of the interactions, connections, affordances and constraints between and among content, pedagogy and technology in order to appropriately interpret, understand, choose, utilise and create content-specific representations and explicitly relate their meaning making potential to students.

**Second step – develop contemporary approaches to cultivating scientific literacy:**

Research (Lemke 1990, Jewitt & Scott, 2002) that has focussed on the making of meaning in the Science classroom using multiple modes indicates that scientific literacy education has been ‘narrowly restrictive’ and that to support scientific literacy development students now need multiple modalities for the representation of scientific knowledge such as ‘photo images, video clips, sound effects, voice or audio, music, animation or more specialised representations’ (simulations, 3D molecular software images etc). (Lemke, 1998: 288). Meaning making of scientific phenomena requires engagement with these specialised representations because they provide access to information that would otherwise not be accessible (Burgh & Nichols, 2011). Also included are linguistic representations or appropriate scientific vocabulary that is more precise than ordinary language, some of which are ordinary words but with specific conceptual meanings such as the magnitude of an earthquake. In everyday language magnitude refers to the size or
extent of something like the "magnitude of a task". In scientific vocabulary terms, the magnitude of an earthquake is a number that characterises the relative size of an earthquake based on measurement of motion recorded by a seismograph; most commonly referred to as Richter magnitude and recorded on a special logarithmic scale (USGS earthquake glossary).

The ability to construct scientific meaning from these specialised and linguistic representations is a learned response and competency is described by the ability to interpret, understand, utilise and create representations to investigate scientific phenomena or elaborate and explain about these phenomena (Ainsworth, 1999). This sophisticated representational work that includes high level elaborations and explanations of scientific phenomena under study contributes to the development of scientific, content-specific language or discourse, is a necessary part of building a shared meaning and understanding of science conceptually and is an important part of cultivating scientific literacy.

There is now widespread agreement that primary teaching needs to focus on developing students' scientific literacy and this includes 'coming to know science through the introduction to, and the achievement of, competence' in working with these specialised and linguistic representations or working with the 'literacies of science' (Tytle, Prain & Hand, 2007, p.36). These literacies of science not only include the special language practices associated with scientific discourses but also pertain to an understanding of why they are important for thinking scientifically (Prain, 2009). Verbal language not only pertains to verbal reasoning abilities that are required to take part in scientific explanations but also includes the content-specific vocabulary and knowledge around the forms and functional characteristics of scientific representations (Osborne, Erduran & Simon 2003). For example, the Richter Magnitude Scale is a specialised tabular representation of the levels of magnitude of an earthquake. The number that characterises the magnitude increases with increasing ground-shaking motion caused by the earthquake. Prain (2009) defines the term "disciplinary literacy", coined by Moje (2007), when referring to science as the interpretation and construction of specialised representations such as models, graphs, tables and diagrams and the integration of these and other linguistic representations with the spoken or written language of science as part of the broader process of developing the literacies of science. Students must learn primarily to understand, reproduce and explain these representations of the science community if they are to develop disciplinary literacy.

The contemporary sciences bring together knowledge from traditional science disciplines with new scientific knowledge. Therefore, students learning in these areas need to develop 'trans-disciplinary literacy' in science that is not only the recognition, interpretation, application and construction of unique content-specific representations from each science discipline but also, understanding of how these overlap and bring together new meaning; including how to evaluate and communicate this new meaning. The extent to which teachers' representational practices need to change to accommodate contemporary science and technologies and develop trans-disciplinary literacy in students has never been more important. Several studies (Tytle, Prain & Hand, 2007; Prain, 2009) focus on students' competence in working with and creating representations to communicate their understanding of science, but there are no studies that have focussed on developing the technological and pedagogical content knowledge that teachers require to promote this trans-disciplinary literacy in students. Opportunities for students to develop trans-disciplinary literacy and exercise agency over their own learning is facilitated by inquiry learning where students work cooperatively together to investigate issues, ask questions, discuss observations and ideas and develop scientific explanations using multiple representations.

Third step – develop primary teachers' representational competence:
The key to students overcoming the representational and conceptual challenges of learning about contemporary sciences and developing literacies of new sciences is the teachers' representational
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competence or ability to negotiate appropriate representational tools and explicitly rationalise to students the importance and application of these tools in a content-specific way. Tytler, Prain and Hand (2007) argue that complex concepts in science can be learned by upper primary-aged students but the challenges are representational and conceptual. They suggest that the key to students overcoming these challenges may be the teacher’s ability to negotiate appropriate representational tools or, in other words, depends on the teacher’s level of representational competence. Further, conceptual and representational challenges of complex science topics are inseparable in that development of students’ representational competence (the recognition, interpretation, appropriate use of, and construction of content-specific representations) builds conceptual understanding and students’ connected use of visual and verbal representations to elaborate their understandings. The key to successful learning of the complexities of science is through sophisticated representational work, engaging with representational practices of science and the capacity to work in different representational modes and understand the meanings across modes. In order to learn complex phenomena in science, students need explicit instruction in the forms and functions of various components within and across different representations. However, unless teachers are trained to develop these representational competency skills, this will not be achieved.

Tytler (2007) proposes that the role of the teacher is to work with students’ ideas, scaffolding them to establish the powerful discourses of the scientific culture and scientific ways of viewing the world. This is particularly important given the key role that socio-cultural theory argues language plays in the shared construction of meaning and understanding (Mercer, 2008). While teachers’ practices are essential for supporting students in scientific inquiry, such as the construction of scientific explanations, McNeil & Krajić (2008) found that there is wide variability across teachers in how these practices are implemented and

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this variation influences student learning of scientific explanation. Many teachers often only define scientific explanations and model how to construct them rather than discuss the rationale behind them or connect scientific explanations to everyday life; techniques which often result in better student learning of scientific concepts. Teachers need to be trained in skills for representing and communicating contemporary and traditional scientific concepts and in providing explanations of the forms and functions of these representations in order to build student explanatory skills through the use of multiple representations.

Student explanatory skills are built by learning to engage critically and constructively with others’ ideas, challenge and counter-challenge proposals, and discuss alternative propositions. Mercer, Dawes and Wegerif (2004) found that when students are taught to talk and reason effectively together and apply these skills in the study of science they make greater gains in measures of individual reasoning, provide more explanations and justifications to each other, and obtain significantly higher scores on knowledge and understanding of science than students in matched control classes. Since representational competence builds conceptual understanding, if students are explicitly taught to talk and reason together about scientific concepts using appropriate scientific representations it stands to reason that they will make even greater gains in their knowledge and understanding of science. This sophisticated representational work that includes high level elaborations and explanations of contemporary scientific phenomena under study contributes to the development of trans-disciplinary literacy.

Summary:

The ideas presented in this paper highlight the transformative role teachers play in the emerging sciences, identify the technological pedagogical content knowledge or TPCK required to teach science effectively, emphasise the power of developing disciplinary literacy to promote scientific thinking, and advance knowledge on the teaching of contemporary sciences. Knowing the transformative role teachers play in explicating the representational and conceptual challenges of contemporary sciences, the TPCK required to teach effectively, and the disciplinary literacy skills needed to facilitate scientific thinking will advance knowledge and substantially contribute to the evidence-base for constructing curricula in contemporary sciences (Figure 1).

![Diagram](image.png)

**Figure 1:** The relationship between the representational challenges (RC) of contemporary sciences, the TPCK required to teach it effectively, the disciplinary literacy skills needed and the construction of curricula.
This paper proposes that training primary teachers to develop the reflective and practical skills needed to better visually and verbally represent and communicate traditional and contemporary science concepts will:

Enhance primary teachers’ classroom strategies and competencies for choosing, using and explaining visual and textual scientific representations;
- Improve primary teachers’ confidence in teaching science in particular contemporary areas of science;
- Positively impact students’ development of scientific concepts and learning;
- Improve students’ scientific argumentation skills by improving their capacity to ask and answer questions, construct evidence-based explanations using visual and verbal representations, and communicate and justify findings to promote high quality conceptual discussions
- Positively impact on students’ engagement and interest in science.

References:

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