

*Towards Building Authentic Understandings of Contemporary Science Practices
for Science Educators*

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Abstract

ReMSTEP is a collaborative initiative involving four partner universities funded by the Australian Government Office for Learning and Teaching. The project aims to promote the reconceptualising of Mathematics and Science Teacher Education Programs by fostering partnerships between scientists and educators to improve confidence and competence in teaching STEM education. One response developed by the Faculties of Science and Education at Monash University has been the design of a masters unit to assist pre-service and in-service science teachers to explore the practices of contemporary science and examine how varied understandings can influence science communication. This unit was designed to encourage teachers to explore their current understandings of the Nature of Science (NoS) and to contrast their views with those known to be widely held by society (Cobern & Loving, 1998). Teachers are challenged through constructing visual representations about contemporary science practice which reflect their altered understandings of NoS and provide insights into the thinking that shaped their design. In order to build authentic understandings of contemporary science practice each student ‘shadows’ a research scientist and engages them in conversations intended to explore the scientists’ views of NoS and practice as mapped against a framework of five levels of science cognitive engagement. Preliminary findings suggest that teachers were initially uncomfortable with the challenge of constructing visual representations to express ideas. Teachers were also surprised how diverse the views of NoS can be, even among scientists and their peers, and that these views can directly impact on ways of communicating contemporary science practice.

Keywords: STEM Education, The Nature of Science, Contemporary sciences practices

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Introduction

In Australia and internationally there is wide acceptance of a consistent downturn in the participation rate across the secondary and tertiary sectors of students engaging in the study of science, mathematics technology and engineering (Kennedy, Lyons & Quinn, 2014; Mack & Wilson, 2014). Research by Engineers Australia in 2015, confirmed that Australia has always had a varying but substantial reliance on skilled immigrant engineers, however it also showed that the most recent resources boom from 2007 to 2013 created a particularly strong demand which exceeded the local supply of Australian graduates. Australian Census data (Engineers Australia, 2015) revealed that 51.6% of practicing engineers in 2006 were born in Australia and this had reduced to 46.1% of the workforce by 2011. Attracting engineers from overseas to meet the changing demands of the Australian industry labour market has been effective, although this approach became increasingly more difficult during the boom period due to a growing world shortage and rising salaries. Australia experienced a boom in the engineering labour market until 2012 when the sector underwent a serious downturn. After this, there were frequent media reports about the difficulties new engineering graduates were experiencing in finding jobs that inevitably resulted in reported reductions in lower level engineering salaries. In 2014, the number of applications for engineering places in Australian universities fell for the first time in almost twenty years (Engineers Australia, 2015). It still remains unclear if this reduction was an effect of the tightening labour market near the end of the mining boom or a consequence of the reducing engagement by Australian students with STEM education or a combination of both.

Background

As reported by the Australian Office of the Chief Scientist (Office of Chief Scientist, 2014), there is growing acceptance by industry employers that scientific and mathematical competencies are essential for productive participation in a growing competitive knowledge based economy. This report stated that 75 per cent of the fastest growing occupations required science, technology, engineering and mathematics skills and knowledge in order to be internationally competitive. Twenty first century workplaces will increasingly rely on employees having skills in digital communication, information technology and knowledge of mathematical competencies essential for analytical and financial modelling. Longitudinal results from the Programme for International Student Assessment, PISA (ACER, 2001; Thomson, De Bortoli, & Buckley, 2013) showed that Australian students' performance in Mathematics and Science literacy experienced a decline between 2000 and 2012, equivalent to a reduction of more than half a year of schooling. Likewise, in a review of outcomes of school education in Australia by the Australian Council for Education Research (Ainley & Gebhardt, 2013), a comparative analysis of 2012, PISA and NAPLAN data shows that student performance is weakening among both low and high achieving students.

A more recent study (Kennedy, Lyons, & Quinn, 2014) compared subject enrolments of year 12 students in New South Wales between 1992 and 2012. They found that although there was an increase in participation by more than 30,800 students in 2012, there were 8,000 fewer students studying physics, 4,000 fewer studying chemistry and 12,000 fewer studying biology compared with 1992. These reductions are similarly

reflected in other states in Australia. Earth Science, the least popular science subject was the only science course analysed where participation rates were shown to increase and this interest was attributed to the resources boom active at this time. The percentage of students studying advanced and intermediate mathematics also declined over a similar period but the proportion of students selecting entry-level mathematics grew by 60 per cent. The number of students (Mack & Wilson, 2014) shunning both mathematics and science has also risen, from 2.1 per cent (male) and 5.4 per cent (female) in 2001 to 5.9 per cent (male) and 14.6 per cent (female) in 2014. Similar trends have also been observed for Information Technology participation in schools (Ainley, Kos & Nicolas, 2008).

There has been wide speculation as to the reasons underpinning this decline in student STEM engagement and although this is seen more or less as a worldwide trend (Langen & Dekkers, 2005; Henriksen, Dillon & Ryder, 2015) little research has been able to authoritatively identify the key contributors in effect across international contexts. Australian sector experts identify a range of possible reasons for this decline. These include a deficit of enthusiastic, confident, and competent teachers in the early years to an Australian secondary system which offers too many subject choices in the senior years. Others lament a local tertiary entrance scheme which consequently rewards the brightest of our final year secondary students for selecting less difficult subjects in which they have greater opportunities to achieve outstanding results to maximise their University admission scores. Less attention appears to be paid to the possible combined impact caused by higher education fee creep, diminishing employment opportunities and declining industry incentives caused by the more widespread use of fixed contracts and increasing downward pressures on salaries within the industry.

In an interview conducted by John Burgher, (Burgher, 2014) with Prof Iwona Miliszewska, Australian Council, Deans of Information and Communication Technologies, suggested a comprehensive, multi-pronged approach encompassing many ideas similar to those proposed by other industry experts, to encourage greater student interest in STEM engagement by;

- Enhancement of compulsory STEM education through a major revision to the national curriculum that resolves to increase the study hours and content of STEM classes in both primary and secondary schools. The goal of this initiative would be to improve the quality of basic STEM education nationwide, generating and stimulating interest in scientific topics and thus creating a broad support base for STEM in Australian society.
- Introduction of programs to nurture and train the best and brightest STEM talent by enhancing 'elite' education; such programs would lay the foundation for a STEM 'elite track' from secondary to tertiary levels of education.
- Facilitation of university-to-career transitions by supporting job placement of graduate students and post-doctoral researchers who complete degrees in STEM fields.
- Specifically addressing the under-representation of women in STEM education and careers by launching targeted initiatives supported through both public and corporate sector funding.

In acknowledgement of this deepening problem the Australian Government announced its *Students First-Restoring the focus on STEM in schools initiative* (Australian Government, 2015) that committed \$12 million to restore the focus on and increase student uptake of science, technology, engineering, and mathematics subjects in primary and secondary schools across the Nation. It consisted of 4 key initiatives:

- Providing innovative mathematics curriculum resources for primary and secondary school students, focusing on inquiry-led teaching.
- Supporting the introduction of computer coding across different year levels in Australian schools leading to greater exposure to logical and computational thinking.
- An innovative approach to education based on the successful ‘Pathways in Technology Early College High School’ program originating in the United States of America, and
- The introduction of summer schools for STEM students, to increase the number of girls and disadvantaged students (including Indigenous students and those from regional and remote areas) engaging with STEM.

Additionally, there was also a focus on the preparation of prospective STEM teachers through a number of targeted learning research grants. One of these grants was the ReMSTEP project.

The ReMSTEP Project

As part of this National initiative, the Australian Government Office of Learning and Teaching (OLT) provided funding in 2014 for two years to four collaborating universities. The University of Melbourne, Deakin University, La Trobe University, and Monash University were charged with exploring how pre-service teacher (PST) education programs could be enhanced in ways to better provide PSTs with greater competence and confidence in their teaching of science and mathematics. In particular, the focus was on examining productive ways of integrating the specialist knowledge of practicing scientists, researchers, and STEM specialists into the school curriculum and teacher classroom practice in order to create greater engagement and subject relevance for students. The project entitled, Reconceptualising Mathematics and Science Teaching Education Programs, (see www.remstep.org) shares the vision of the Chief Scientist of Australia (Office of Chief Scientist, 2014). This vision advocates that learning and teaching STEM competencies should introduce students to aspects of contemporary science, technology, engineering, and mathematics practices in ways that students and teachers find exciting and socially relevant, rather than following a curriculum that represented STEM subjects as apparently divorced from any real world applications or social contexts.

Monash University’s involvement in the ReMSTEP project offers exciting opportunities as it involves the development and researching of new PST programs to better address the social relevance of science, technology and mathematics and importantly the sharing of these research findings across all four universities. This paper explores just one of these new initiatives resulting from collaboration between the Faculties of Education and Science at Monash University. The Monash ReMSTEP project team was keen to develop new opportunities for PSTs to experience and better understand many of the contemporary practices of science and mathematics used

widely across a range of industry sectors. The assumption underpinning this initiative was that teachers who are more informed and better able to discuss these practices with greater confidence should be able to achieve greater classroom engagement and improved student interest and attitude towards future study of STEM subjects. The new master of teaching unit (equivalent to 288hrs of study) was devised with a number of key objectives consistent with the ReMSTEP project and incorporated successful reflective pedagogical approaches informed by past evidence-based science education research undertaken by the Faculty of Education.

Key objectives identified for this unit are to encourage PSTs to;

- Understand how sciences¹ knowledge, processes and communication shift over time through the influence of social and technological change.
- Explore the diverse and changing understandings of the Nature of Sciences (NoS) while challenging participants to re-conceptualise and articulate their own personal contemporary view.
- Investigate first hand contemporary practices of science and examine how new knowledge created has significantly changed to become more inter-/multi- and trans-disciplinary, e.g. Nanoscience, and Bio-informatics.

Each of these is briefly discussed. The first objective underpinning the unit focuses on how sciences knowledge changes over time and is influenced by technological and social change. Much of the knowledge and practices of science and mathematics are tentative and undergo constant reappraisal and update. Some ideas prove to be more enduring than others, however all remain open to question. The creation of new technology can often have substantive impacts on how new knowledge is generated and in turn this can influence the directions of subsequent technology development and applications. The idea that sciences knowledge and contemporary practices are tentative and changing is not widely explored in science or mathematics classes in secondary schools where content is often conveniently delivered as definitive and enduring. Present textbooks are more likely to be revised to accommodate changing government curriculum initiatives rather than contemporary changes in science knowledge, such as new or revised understandings or the impact of technological advances. For example, the recent debate over Pluto and changing the classification of what should constitute a planet in our solar system may be seen by some as revealing an indecisiveness or weakness of sciences' ability to have enduring knowledge and authority.

¹sciences includes mathematical knowledge

However the debate by astronomical research scientists over the need for change in a historical classification system provides insights into the dynamic nature of sciences and the need for sciences to constantly reassess and accommodate changing understandings based on the acquisition of new evidence. To ignore such instances of debate and review is to ignore a critical aspect of how sciences are undertaken and that all scientific knowledge remains open to question and revision.

The second objective identifies that contemporary practices of science and mathematics and the new knowledge arising from such practices, has largely now changed to become more inter-/multi- and trans-disciplinary in nature. Increasingly more sciences research is now being undertaken at the fringes between the traditional

subject disciplines. This requires researchers to have broad understandings across a number of what were once seen to be independent fields of specialisation. Emerging areas such as Nano-science, Nanotechnology, Bio-informatics, regenerative and imaging technology, require complex understandings of multiple disciplines. However, despite this mix of traditional discipline areas, the key processes by which sciences are undertaken and the overarching constraints remain equally applicable. This unit aims to make the processes of sciences and their associated skills more explicit for PSTs and emphasises the importance for teachers to also make these explicit to their students as a part of their regular classroom practice. It seeks to identify the importance of science, mathematics and associated technology as a way of knowing and exploring our world where cross-discipline understandings have the potential for convergent investigation to generate richer understandings and reveal unseen complexity and interdependence.

Although it is possible that some PSTs undertaking the unit may have strong backgrounds in science, engineering or mathematical studies, including research backgrounds (or even PhD's) in related sciences or engineering fields, this is not typically the case. In addition, many PST of early years students often have more limited science and mathematical backgrounds. Given this diverse mix of sciences experiences amongst the PST cohort it was felt essential that all PSTs should undertake a visit to a contemporary research facility where they can meet with and interview practicing scientists. The intention of this visit is to provide the PST's with a 'face to face' experience in which they can chat with scientists to explore the nature of their work and familiarise themselves with the operation and practices of a contemporary research facility. The PSTs are then encouraged to share their reflective insights gained from the visits in follow up workshop discussions with their peers.

Monash University, as a research intensive university, is fortunate that it has a large number of world class “Centres of Excellence” and more than 20 expert research scientists operating across these have agreed to meet individually with a PST for at least three hours. In addition, several expert scientists from the Melbourne Museum (Australia) in specialist areas of entomology, paleontology, and plant physiology have also agreed to be involved in the program. In almost all cases the scientists have been approached to be involved in this program because they are engaged in research areas which help to demonstrate the highly interdisciplinary nature of contemporary research and they have a demonstrated track record for seeking to actively communicate their understandings of science to a wide range of audiences. Prior to the PSTs visiting the research centres the purpose of the visit is discussed and scaffolded in the unit workshops to make the intentions explicit and to assist the PSTs in constructing relevant interview questions that will explore the scientists understandings of the Nature of Sciences (NoS) and the purpose and range of audiences that they routinely communicate with. This approach is intended to assist the PSTs to maximise the learning benefits achieved from such a relatively brief visit to an authentic setting.

Examining the effective communication of science, mathematics and technology is periodically revisited throughout the unit in ways that assist in reinforcing to the PST's the importance for teachers to embed the investigation of STEM knowledge in a social context. A schema developed by Corrigan (2015), attempts to assist the PSTs in their analysis of the methods and intentions of the different types of science

communication engaged in by contemporary scientists. This approach is seen as innovative as it tries to assist the PSTs to distinguish between the broad areas of complex cognitive engagement needed for effective communication with different audiences for different purposes. The schema attempts to identify 5 areas of science cognitive engagement that scientists, technologists and researchers are likely to engage with;

- 1) **General public engagement** - this is probably the most basic level of communication, however even though the sophistication of the science knowledge exchanged is likely to be quite elementary it does not imply that it is not without challenge. Looking to effectively communicate insights into big ideas or complex processes using powerful metaphors or analogies is a creative and often demanding task which confronts many educators on a day to day basis. Predictably not all scientists are skilled at communicating with the general public which make those that are, such as Tim Flannery, Richard Dawkins and Brian Cox highly sought after by both the mainstream media and the general public.
- 2) **Informed engagement** - This describes engagement by those who are conversant with a scientific field or discipline. They are informed and seek opportunities to share and improve their knowledge and understanding amongst competent peers with similar interests or expertise. This form of engagement is practiced by amateur interest groups, student societies to professional institutes and associations, e.g. Amateur Astronomical Societies, Soil Science Australia, Australian Society for Microbiology, Royal Aust. Chemical Institute, and the Australian Academy of Science.
- 3) **Applied engagement** – This describes a broad engagement by scientists, engineers, technical designers and science communicators who apply current scientific knowledge to develop real world applications of technology or provide insights into fundamental processes of science. Their interests may include fields such as; engineering, medical imaging, robotics, polymer science or nanotechnology. They use the knowledge of science and its processes, e.g. experimental design, analysis of data and scientific modelling to test and improve technology and its applications.
- 4) **Focused engagement** – This includes engagement which deals with the routine practicalities of communication practices within and between scientific or industry research centres. Examples could include system approaches for regular reporting on project challenges and achievements to project personal, routine laboratory meetings, initiatives exploring workflow or communication practices and team reviews of technical protocols. It could also include project reporting to industry and Government, mentoring practices and career building and management within a specific research field or scientific organisations.
- 5) **Expert engagement** - This engagement involves science discipline authorities or research leaders acknowledged by their peers as experts and visionaries, e.g. Nobel Laureates, Prime Minister's Prize for Science, Eureka Prizes, Australian Institute of Physics awards, and Australian Academy of Science award winners. This could include expert analysis or commentaries on new technology or recent scientific research discoveries and their likely societal or cross discipline impact.

Experts regularly provide key note addresses at conferences and their insightful presentations and critical analysis is regularly sort by industry, field specialists and the general media.

In addition to utilising this organisational schema, PSTs are also challenged to communicate their understandings of science using creative multimedia artefacts. The rationale for this is to encourage the PSTs to develop and practice skills in creating and critiquing visual images or multimedia which has now arguably becoming very much mainstream when using contemporary educational communication. Multimedia channels such as, YouTube.com, Vimeo.com and Vevo.com already provide access to a multitude of video resources from which educators can source and share useful multimedia artefacts. It is considered essential that PSTs are skilled to select discerningly from these rapidly growing collections with such diverse quality.

Another innovative approach used in the unit encourages PSTs to review, articulate and defend their personal view of the Nature of Sciences (NoS). This approach was initially adopted to encourage PSTs to develop and refine their views of NoS and to assist them to form a more coherent view that they felt more confident to share and discuss. Although there has been considerable research into the views of NoS held by a wide cross-section of the community, from the general public to students, scientists and science educators, there appears to be far less research literature which reports on ways of developing activities by which PSTs can effectively evaluate and articulate a coherent personal view of NoS. In initial workshops the PSTs are introduced to a provocative NoS collaborative card activity outlined by Cobern & Loving (1998). In line with the approach advocated in Cobern and Loving's paper the PSTs are encouraged to work initially as individuals and then form larger and larger groups to select or reject (by consensus) written statements about science that align with one of six broadly identified views of NoS. Through creating opportunities for peer discussion and debate, PSTs are encouraged to construct and revise their view of NoS and invited to reflect on changes in their positional understanding.

The activity has been adopted because it does not privilege one view of NoS over another or encourage all PSTs to adopt one 'currently acceptable' view, but reveals how contemporary understandings of NoS change and will continue to change over time. The NoS theme is periodically re-examined at key points throughout the unit and is seen as a mechanism for identifying and tracking changes in individual thinking about attitudes and values of science.

Research methodology

This unit has been successfully trialled and at the time of writing the unit is about to be offered for a second time. The preliminary findings from the first completion (n=16) by PSTs show promise and indicate that greater research is warranted to enable a more effective evaluation of the unit achievements and shortcomings. All PSTs were invited to participate in the research study and completed a preliminary online survey aimed at gathering data on their course pathways and intended areas of teaching specialisation. PSTs were also asked to identify how confident and prepared they felt about the range of skills they possessed and needed to successfully undertake the teaching of science.

At the completion of the unit all PSTs were invited to undertake a 30 minute individual face-to-face interview with an independent researcher. Only two (n=2) PSTs agreed to be interviewed due to course workload demands and survey timing. The interviewer sought to investigate the PSTs understandings of the course intentions and approaches and to seek feedback on how the PSTs thought that the unit objectives were achieved. A number of the research scientists interviewed by the PSTs were also approached and interviewed, but again only two (n=2) were able to meet briefly with the independent researcher, so feedback about their involvement and interaction with the PSTs was limited.

Preliminary findings

The data collected from the initial online survey (n=3) provided only brief insights into PSTs' course backgrounds and employment intentions. The PSTs that completed the survey indicated that they were choosing to undertake the unit to gain a better understanding of the contemporary practices of science and to develop additional skills and understandings which they thought would be helpful for their classroom professional practice in teaching science and/or mathematics. Not surprisingly their articulated intentions closely reflected those of the unit objectives.

During a unit workshop review session the PSTs (n=14) provided feedback on a number of aspects of the unit. The majority of the PSTs reported finding the creation of the multimedia task highly challenging and generally rewarding. Many PSTs discussed how they did not feel confident about creating and critiquing visual representations compared with the traditional and more widely practiced critical essay approach to assessment. This lack of confidence was also reflected in the number and frequency of clarifying questions fielded by the unit lecturers regarding the implementation of this assessment task. This view was similarly reported by the PSTs that were interviewed of feeling apprehensive and ill equipped to undertake this creative task. In general it was acknowledged that the PSTs lacked confidence in addressing the task of designing and critiquing visual images or multimedia.

One of the surprising findings was the acknowledged impact that the collaborative discussions on NoS had on building the PSTs' confidence and ability to communicate a coherent and more contemporary view of science. Many of the PSTs spoke of how their thinking and view of science had changed during the unit from one in which they originally privileged understandings of science or mathematical content to one with a broader understanding of the processes by which science is undertaken. This acknowledged shift was evidenced by a number of PSTs in their writing for assessment tasks and during workshop discussions within the unit. There were no opportunities to investigate or witness the implications of this changed view on their professional practice.

On reconceptualising a personal view of NoS, the PSTs reported; greater self-confidence in constructing and justifying a personal coherent view of NoS and an improved ability and confidence in discussing and communicating NoS understandings across a range of professional settings:

Student (2) – “You know you always start this going, oh [I] already know this, [but] ... really talking about it [NoS] and kind of expanding that

understanding was really good. ... I came out [after the unit] with a fairly different kind of conception...than I started with of what science is and what's core to it".

Student (1) – "Questioning and actually reflecting on ... what I think about science and what other people think about science and trying to figure out ... what you know, what a coherent view is because a lot of these things aren't ... necessarily explicitly looked at ... "

Student (2) – "If I was doing an interview for a science position I think it gives me a better understanding to talk about science education in a way that I think would stand out to employers, compared to people who hadn't done this unit or something similar".

Several of the PSTs also reported that since visiting a research facility and talking to 'real' scientists they now felt that they had improved understandings of contemporary science practices and how science is undertaken by scientists. Many of the PSTs acknowledged that before their site visits they knew very little of how 'big' science is undertaken in world leading Centres of Excellence and their views were limited to highly contextualised educational experiences in undergraduate labs or even earlier high school settings:

Student (1) – "Yeah that was really good. I enjoyed ... the interview part [of] the site placement and talking to a working scientist and finding out what they value ... the importance of creativity and collaboration and what they ... know".

Student (2) – "There was a few things that ... I wouldn't have thought was important [before doing the unit] that when I got to do ... the interview [with the scientist] towards the end of the subject ... a lot of things came up that we'd talked about ... and it was ... confirmed ... by the working scientists".

Student (1) – "For example in science education our experiments work ...[this] is not what it's like in actual science. You don't know the outcome of ... the actual experiment".

Conclusion

The researchers acknowledge that the preliminary findings from the single unit offering are quite limited. However, the general findings from the interviews, workshops, and assessment tasks suggest that many of the approaches and activities used throughout the unit were largely successful in achieving many of the intended unit outcomes.

A surprising finding was that encouraging the PSTs to re-conceptualise their personal view of the NoS proved much more effective and engaging than originally anticipated. Participants were keen to revisit these ideas throughout the course and to actively explore and debate alternate views. The changing personal view of NoS as

articulated by individuals at various times throughout the unit also provided insights into how their views of NoS and contemporary sciences were changing over time. This provided a powerful insight into the impact that robust discussion and debate can have on changing long held views.

Constructing a coherent contemporary view of NoS also appeared to provide participants with language and confidence to engage in professional discourse which challenged and further enriched their understandings of sciences. Several participants self-reported improved confidence and competence in their professional practice when exploring science with their students as a way of knowing and understanding the world.

The research centre site visits and interviews with practicing scientists were also reported to be highly informative and although the conversations and experiences were diverse, the workshop discussions proved very rich in building contemporary views of science practices.

The preliminary findings raise many questions about the success and impact of this unit on shaping PSTs views of NoS and adopting teaching that a contemporary view of sciences and their authentic practices. Further research will be undertaken when this unit is next delivered.

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