

Socio-Scientific Issues: A transdisciplinary approach for engaging pre-service teachers in Science and Mathematics education

Problemas socio-científicos: Un enfoque transdisciplinari para reforzar la formación en educación en Ciencias y en Matemáticas de los futuros profesores

Problemas sociocientíficos: um enfoque transdisciplinar para reforçar a formação em educação em ciências e matemática dos futuros professores

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Over the past decade, primary/middle pre-service teachers at the University of South Australia have been employing socio-scientific issues (SSIs) as the basis of planning meaningful and connected science and mathematics experiences for students in low socio economic schools. We have used the philosophic and pragmatic challenges associated with exploring SSIs to help our pre-service teachers conceptualize ways in which they, as teachers of science and mathematics, can better help their students to understand how they can live and operate in a more socially and ecologically just world. This case study of a cohort of primary/middle undergraduate students utilizes two sources of data to evaluate the efficacy of these learning experiences in meeting the desired outcomes; firstly, a debriefing analysis following a formal 'roundtable' assessment of pairs of pre-service teachers, and secondly, a collection of direct student evaluation data by means of an online survey. The outcomes show that the challenges presented by adopting these strategies were particularly acute in the professional journey of non-specialist primary and primary/middle pre-service teachers, and meeting these challenges directly through participation in authentic experiences incorporating, place-based voluntary learning, environmental pledges, and transdisciplinary approaches to long-term planning had some demonstrable success, particularly in connecting planning to student life worlds.

Keywords: Science education, Mathematics education, Socio-scientific issues, Social justice, Transdisciplinary education, Teacher education.

A draft of this paper was presented at Australasian Science Education Research Association Conference (ASERA) Wellington New Zealand, July 1-3rd 2013.

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ISSN: 2254-3139
www.rinace.net/riejs/

Recibido: 22 de marzo 2014
1^a Evaluación: 20 de mayo 2014
2^a Evaluación: 5 de junio 2014
Aceptado: 28 de junio 2014

Durante la última década, los maestros en formación primaria/secundaria de la Universidad de Australia del Sur han venido empleando temas socio-científicos (ISQ) como base para la enseñanza del currículo de Ciencias y Matemáticas de manera significativa para todos los estudiantes, especialmente para aquellos de escuelas con menor nivel socioeconómico. Hemos utilizado los desafíos filosóficos y pragmáticos asociados con la exploración de las SSI para ayudar a nuestros futuros docentes a conceptualizar formas en las que, como maestros de Ciencias y Matemáticas, pueden ayudar mejor a sus estudiantes a entender cómo se puede vivir y actuar de una forma más social en mundo ecológicamente justo. Este estudio de caso cuenta con una cohorte de estudiantes de grado de Primaria y utiliza dos fuentes de datos para evaluar la eficacia de las experiencias de aprendizaje desarrolladas durante el curso. En primer lugar, un análisis de la información aportada tras una evaluación formal de una "mesa redonda". En segundo lugar, una colección de datos directos una encuesta online a los estudiantes. Los resultados muestran que adoptar estas estrategias de enseñanza de las Matemáticas y Ciencias genera desafíos para aquellos futuros docentes de Primaria/Secundaria no especializados. Así mismo, los resultados muestran que estos desafíos pueden paliarse a través de la participación en experiencias auténticas que incorporen el aprendizaje voluntario basado en el contexto, compromisos ambientales y enfoques transdisciplinarios para la planificación a largo plazo del currículo. Estos últimos tuvieron un cierto éxito demostrable, sobre todo en la conexión de la planificación de los mundos de vida de los estudiantes.

Descriptores: Enseñanza de las Ciencias, Enseñanza de las Matemáticas, Problemas socio-científicos, Justicia social, Educación transdisciplinar, Formación del profesorado.

Durante a última década, os estudantes em formação para o trabalho com alunos dos Ensino Fundamental e Médio da Universidade da Austrália do Sul vem empregando temas sociocientíficos (ISQ) como base para o ensino do currículo de Ciências e Matemáticas de maneira significativa para todos os estudantes, especialmente para aqueles de escolas com menor nível socioeconômico. Utilizamos os desafios filosóficos e pragmáticos associados com a exploração das SSI para ajudar a nossos futuros docentes a conceitualizar formas nas que, como professores de Ciências e Matemáticas, podem ajudar melhor a seus estudantes a entender como se pode viver e atuar de uma forma mais social no mundo ecológicamente justo. Este estudo de caso conta com um coorte de estudantes das primeiras séries do ensino fundamental e se utiliza das fontes de dados para avaliar a eficácia das experiências de aprendizagem desenvolvidas durante o curso. Em primeiro lugar, uma análise da informação adquirida depois de uma avaliação formal em uma "mesa redonda". Em segundo lugar, uma coleção de dados diretos obtidos por entrevistas online realizada com os estudantes. Os resultados mostram que adotar estas estratégias de ensino das Matemáticas e Ciências gera desafios para aqueles futuros docentes dos Ensino Fundamental e Médio não especializados. Da mesma forma, os resultados mostram que estes desafios podem ser minorados através da participação em experiências autênticas que incorporem a aprendizagem voluntária baseada no contexto, nos compromissos ambientais e no enfoque transdisciplinar para o planejamento a longo prazo do currículo. Estes últimos, tiveram um certo êxito demonstrável, sobretudo na conexão e planejamento dos mundos de vida dos estudantes.

Palavras-chave: Educação em ciências, Educação em matemática, Problemas sociocientíficos, Justiça social, Educação transdisciplinar, Formação do professorado.

Introduction

Traditionally, the teaching of science and mathematics has not been an area of strength for primary/middle pre-service teachers. The drivers for this are multifaceted, and not confined to Australia where this paper was written. Many pre-service primary teachers have perceived poor level of subject knowledge, which when coupled with a personal disconnect with the subjects, give rise to debilitating low confidence and reduced levels of teaching self-efficacy, (Fensham, 2008; Goodrum, Hackling & Rennie, 2001; Goodrum, Druhan, Abbs, 2012; Tytler, 2007). In some cases this has resulted in cautious, safe and uninspiring teaching. A pedagogic strategy adopted here in South Australia aimed to lift the pre-service teachers' self-beliefs, raise their teaching performance, and crucially, enhance their understanding of teaching philosophies and practices which have a socially-just foundation. This two-part strategy primarily involved positioning the learning experiences within authentic socio-scientific issues (SSIs) and nurturing transdisciplinary approaches to connect their science and mathematics teaching. These approaches have not been a recent innovation but have built on a long tradition of socially critical curriculum development and an institutional commitment to serving students from low socio-economic communities.

This paper aims to achieve two outcomes, (i) document an innovative approach to enhance the confidence and performance of pre-service teachers who engage with science and mathematics teaching through a focus on socio-scientific issues and (ii) to seek reflections from pre-service teachers through an online survey, to evaluate the success of the approach, and utilize the outcomes formatively in enhancing the experience and performance of future cohorts.

1. Background and context to the pedagogical approaches

1.1. History

Following a review of the teacher education provision at the University of South Australia, Reid and O'Donoghue (2001) reaffirmed the School of Education's commitment to serving and supporting schools that found themselves in challenging circumstances, and particularly those schools that drew a large proportion of their students from socially disadvantaged communities. Many of these communities were in the northern suburbs of Adelaide, and were brought to notice by Pat Thompson's (2002) book "Schooling the Rustbelt Kids".

This renewed teacher education commitment aspired to prepare professionally competent teachers who had honed the values, skills and understandings necessary for insights into learners' wellbeing, and who were committed to social justice, futures thinking, sustainability and education for community living. These priorities and characteristics were developed through engagement with robust, inquiry-based perspectives. The aims were informed by a range of interconnected literature and based on the premise that all schools and communities were undergoing rapid changes, both locally and globally, and drawing only upon existing or past practices was unlikely to meet the needs of schools' immediate and longer term futures (Beare & Slaughter, 1993; Fensham, 2003; Slaughter, 2010; Smith, 2002; Sterling, 2001; Sterling, 2004).

Science and mathematics educators took up these challenges, and in many ways were torchbearers, by embedding the School of Education's aspirations systemically into their suite of mathematics and science courses. This was achieved by embracing three ideas: (i) forming strong conceptual and pedagogical links between science and mathematics through interdisciplinary approaches, including the fostering of explicit transdisciplinary connectivity through carefully selected social justice conduits which cultivate critical pedagogical thinking within and between each subject; (ii) considering and interrogating the nature and role of Socio-scientific issues (within both science and mathematics education classes) to promote critical and responsible thinking and decision making, and (iii) encouraging explicit student actions to arise out of the workshops to impact directly on the students' life choices and community responsibilities.

The integrated nature of the science and mathematics teaching was a deliberate and conscious design choice, particularly in the four-year undergraduate program, which is the focus of attention of this paper. Not only did the integration allow all pre-service teachers to build their confidence and competence to plan science and mathematics learning experiences in increasing complexity (Paige & Lloyd 2012), but they also explored the interconnections between the two disciplines. This was done through focusing on the nature of scientific and mathematical activity, particularly in developing inquiry skills and strategic thinking. Further philosophical and pedagogical connections were made through the exploration of transdisciplinary and socially critical issues. One example of such an interdisciplinary approach was the explicit and systematic linking of science and mathematical methodology courses. In this instance the science and mathematics were woven together through a number of specific organizational and pedagogical features that will be explored in some detail below. The workshop themes also increased in complexity, with first of the four years being mainly disciplinary, progressing onto interdisciplinary connectivity in the second year, and in the final two years, onto a transdisciplinary approach with a focus on Educating for Sustainability (EfS) (ARIES, 2013; Paige, Lloyd & Chartres, 2008).

1.2. Clarifying terms: interdisciplinary and transdisciplinary

In this paper terms such as interdisciplinary and integrating curriculum are used to describe an approach to teaching and learning that goes beyond a single discipline; where the disciplines work collaboratively, using both ways of knowing and methods in an attempt to develop understanding in both disciplines. An example of this occurs early in the program where scientific investigations into components of an electrical circuit are complemented by the use of indirect measurement and mathematical strategies to calculate daily electrical use of a common appliance such as hairdryer, which is then subject to ecological scrutiny. Schmidt (2008) argues that "bounded, distinct and non-relating body of knowledge are no longer appropriate for a world characterized by complexity and rapid change", (cited in Jones, Selby & Sterling, 2010:24). The term transdisciplinarity is also used in this paper and is as Balsiger (2004) states 'a scientific approach to understanding the world with a strong orientation towards societal problems'. Pohl (2011:618) adds to this definition by stating that

Transdisciplinary research is one that is useful to use in a collaboration of academic as well as non-academic thought-styles, and based on the understanding of research that develops a comprehensive, multi-perspective, common-good oriented and useful approach to solving a socially relevant issue.

Transdisciplinary approaches deal with real world topics and generate knowledge that not only addresses societal problems but also contributes to their solutions (Balsiger, 2004). An example of a transdisciplinary approach occurs where students connect to place by exploring a significant tree through three different ways of knowing (mathematical, scientific and sustainability knowledge). Further examples include participating in an 'act of green' and undertaking a voluntary placement in urban ecological setting. The transdisciplinary approach with a focus on educating for sustainability contributes very powerfully to our exploration and understanding of SSIs. For us there are two key connectives; firstly there is the inclusion of a socially just issue, and secondly, there is an element of personal action that arises from the students' confrontation with the issues. In the next section we extend on the notions of a transdisciplinary approach to teaching and learning with a focus on socio-scientific issues.

1.3. Identifying Social-scientific Issues (SSIs) as a crucial element for our students' course experiences

According to Skamp (2012:44) "SSIs are usually scientific topics that are controversial and engage students in dialogue, debate and discussion. Moral reasoning and an evaluation of ethical concerns are involved in attempts at making resolutions of the issues". Engaging the pre-service teachers with SSIs provide two key elements in the implementation strategy. Firstly, they provide a convenient and powerful conduit for connecting science and mathematical concepts to real-life, ethically-complex and multi-solutioned issues. Secondly, they provide a genuine and authentic means to facilitate the interdisciplinary and transdisciplinary connections between the study and teaching of science and the study and teaching of mathematics.

The principle of embracing the notions of SSIs into the science curriculum is not new. There has been an emerging literature over the past two decades, which built on earlier notions of Science and Technology in Society (Cheek, 1992), Science for Public Understanding (Millar, 2000) and aspects of teaching the nature of science (Leach, Hind & Ryder, 2003). Some key descriptions of SSIs include:

- Science teachers have an obligation to help students to develop decision-making skills to evaluate such issues so that they become informed users of science and technology and are in the position to take an active and purposeful role in society (Driver & Hodson, cited in Saunders & Rennie, 2013)
- Socio scientific issues' are points of contention regarding potential problems for the well being of individuals, societies and environments associated with fields of science and technology (Bencze, 2010; Bencze, Sperling & Carter, 2012).
- Hodson suggests that scientific literacy can contribute to a more socially compassionate and environmentally responsible democracy in which, "science can provide knowledge to develop effective solutions to its global and local problems and can foster the intelligent respect for nature that inform decisions" (Hodson, 2003:653).

What they all have in common is the focus on contentious moral issues that can engage learners in meaningful science and mathematics that can lead to "purposeful action". This crucial notion of purposeful action will be unpacked below when we explore the

concept of personal participation as an outcome of the engagement in transdisciplinary learning. The role of SSIs is also about provoking and promoting empowerment, engaging in important issues, and living a useful life in a democratic society. It's as Jenkins and Pell state, that providing a voice for students (in this case pre-service teachers) SSIs act as a vehicle for empowerment and agency (Cutter-Mackenzie and Logan, as cited in Fitzgerald, 2013:61). Sterling (2004) suggests that students become involved in 'linking-thinking' tasks by exploring ways that in which the application of science affects the lives of people including students their own age, and that they take a shared responsibility in the consumption and production of materials and their relationship in maintaining a sustainable environment.

We argue that the appropriate use of SSIs has the potential to promote key themes associated with making the world a more equitable place in which to live. This is particularly important in relation to the access to resources, equality of opportunities and fair treatment. SSIs can also be utilized as a means through which scientific and mathematical education ideas can illuminate such debates by casting a critically numerate and scientific eye over the issues within the context of pre-service teacher education. Although traditionally, SSIs were something that were considered to be an important element within a young person's science education, or in our case, a means of flavouring the students' scientific experience, we found that SSIs provided an equally appropriate vehicle through which to channel critical aspects of the study of mathematics education. One lever through which this can be achieved is in the use of a critical numeracy lens, which Forrest (1997) and others (Frankenstein, 2001; Osler, 2007) informed the direction of aspects of the mathematics experiences. Pre-service teachers have explored how they use and choose mathematics in their work, study and personal lives to make informed decisions and to ask critical questions about whose interest is being served. For example they were challenged to generate questions and collect data about water use, explored ways to reduce their ecological footprint, and evaluated the impact of implementing associated behavioral changes to their life-style choices. Such mathematical activity also connected with the associated water-based investigations occurring in their science studies. In this way, we were able to utilize the nature of SSIs to orchestrate a backwards and forwards shuttling between the mathematics and science classes to develop and enhance a strong and explicit pedagogical link between the two disciplines.

The challenge for pre-service teachers, and indeed for all teachers, is to connect their teaching with real-life meaningful events and issues, or as Jenkins (2000) argues in the case of the science curriculum, if we do not connect school science with contemporary issues, we leave students confronted with

...two seemingly conflicting, if perhaps overlapping, visions of science: one constructed and institutionalized in the school curriculum, and another which is much less secure and develops from their own, rapidly enlarging experience of the social, physical and emotional worlds which they inhabit (p. 209).

Our view has been that if the science and mathematical curricula are to connect to students' life-worlds in ways that identify with critical socially related issues (Eckersley, 2002; Lloyd, 2004), then we must go beyond the technical and the particular and embrace a much broader understanding of science and mathematics curricula. Frankenstein (2001) argues that mathematics is made more accessible through real-life contexts through an interdisciplinary mathematics and social studies curriculum.

Prominent science educators have also argued this view in recent times. For example Hodson (2003) argues that science education should include the learning of science knowledge, the learning about how science knowledge is constructed (the epistemological), the application of science knowledge, and engaging in social-political action (Hodson 2003:655). Similarly Fensham (2003) argues that:

... the concept of Science for Citizenship must now be located in the multiple societal contexts within which citizens are involved – at home, in their neighbourhood, in their work, at leisure, and as members of local, regional and national communities (p. 8).

From a mathematical perspective Chartres, (2008:1) states that:

Learning mathematics may result in empowerment, citizenship and democratic participation or it may result in disempowerment, marginalisation and exclusion. Critical mathematics education and ethnomathematics are two developments where there are possibilities to implement a more equitable mathematics education and mathematics education for democracy and citizenship.

Hodson (2003) builds on the socio-political perspective and suggests that scientific literacy can contribute to a more socially compassionate and environmentally responsible democracy, “science can provide knowledge to develop effective solutions to its global and local problems and can foster the intelligent respect for nature that inform decisions” (p.653).

The suggestion of broadening Science, Technology and Society to include environmental education, extending scientific literacy and critical numeracy (Radicalmaths, 2014) to encompass political literacy, prioritizing the affective, and making greater use of community based learning opportunities are all attributions that reflect a transdisciplinary approach as illustrated earlier in this paper. Seen in this way, a transdisciplinary approach utilizing SSIs tackles the complexity of science and mathematics; it challenges knowledge fragmentation as well as focusing on real research problems. It brings a complexity to classroom practice when there is also the need to develop conceptual understanding, skills in the synthesis of ideas from a number of discipline areas, and dispositions to want to take social and ecological action. So the challenge for us as science and mathematics educators at the University of South Australia was to take these ideas of transdisciplinary approaches to solving real problems using SSIs and explore what they should look like in a primary/middle classroom. Before we do this we will briefly outline how SSIs links to the Australian Curriculum.

1.4. Links to Australian curriculum

There are other Australian context-specific reasons why it is valuable to utilise the potential of SSIs both as a pedagogical device and targeted content knowledge. The new nationally developed Australian Curriculum (ACARA, 2014) provides three potentially useful opportunities to embrace the utility and importance of SSIs.

Firstly, within the curriculum document, the science content is constructed into the three content strands of “Science Understanding”, “Science as Inquiry Skills” and “Science as a Human Endeavour”. As one could imagine, the first two strands are familiar to most science teachers; however, it is within the third strand of Science as a Human Endeavour, (SHE) where the opportunities for serious consideration of the importance and impact of SSIs really present themselves. Given the newness, and in many ways, the alienness of the SHE strand, examples of good positive classroom practice are only just beginning to emerge and disseminate across and between schools.

The SHE strand is a particularly welcome addition to the science curriculum, and the only regret from us, as science and mathematics educators, is that the ACARA curriculum didn't take the much needed and brave decision to introduce a strand entitled "Mathematics as a Human Endeavour" which would, according to Hardy, Chartres and Paige (2013) have provided a much needed refocusing and re-prioritising of the mathematics curriculum. The mathematics content is constructed around three content strands, number and algebra, geometry and measurement and statistics and probability and four proficiency strands, reasoning, problem solving, fluency and understanding. The content strands, which teachers are naturally drawn to when constructing their plans do not naturally lead into a consideration of SSIs or critical mathematical thinking. However, the four proficiency strands provide of much richer, but sadly, a much more neglected opportunity.

Secondly, there are opportunities for implementing SSIs through what the ACARA Curriculum calls the General Capabilities; these are identified as "knowledge, skills, behaviours and dispositions that, together with curriculum content in each learning area and the cross-curriculum priorities, will assist students to live and work successfully in the twenty-first century" (ACARA, 2014:52). There are a total of seven General Capabilities, literacy, numeracy, ICT competence, critical and creative thinking, ethical behaviour, personal and social competence and intercultural understanding. Those most relevant to socio-scientific issues are critical and creative thinking, personal and social capability, ethical behaviour and numeracy.

Thirdly, ACARA identifies explicit Cross-Curriculum Priorities, which are Aboriginal and Torres Strait Islander histories and cultures, Asia and Australia's engagement with Asia, and Sustainability. The sustainability priority provides 'authentic contexts for exploring, investigating and understanding science' (ACARA, 2014). A focus on socio-scientific issues provides for each of these three elements and their application to real world experiences that pre-service teachers can use as a framework for planning a SSI unit of work that they can trial in their school placements.

However worthy are the aspirations for embedding the exploration of SSIs into the curriculum of young students, there are real, and sometimes profound difficulties. Many of these are concerned with the slow process of changing teachers' existing practices, addressing levels of teacher confidence (and competence), access to rich professional development opportunities, and the availability of high quality and easily employed resources. The literature reflects many of these difficulties, for instance, Levinson and Turner (2001), amongst others, suggests that constraints, such as lack of guidance, lack of pedagogical knowledge, little understanding of ethical frameworks for ethical thinking, a lack of classroom resources and realities of constraints in the classroom, are all interacting factors that contribute to a lack of progress in addressing SSIs. So given this, it is quite a task to expect pre-service teachers to be able to implement such ambitious aspirations during their placements or early in their practice as qualified teachers. What follows below is an example of one attempt to achieve such aspirations.

2. Method

2.1. A case study

Consistent with most universities in Australia, the largest proportion of student engaging in teacher education undertake a four year Undergraduate program (at this university 2500 students currently), whilst a much smaller proportion (350 currently) undertake a two year Masters program. This paper focuses on a cohort of 152 pre-service teachers who followed the undergraduate primary/middle program. This cohort are trained to teach students aged between seven to 14 years and who gain experience with, and are eventually qualified to teach in, both primary and secondary schools. One of the distinctive features of this program is a deep concern for the challenges and opportunities of middle years' education.

Within the program, these pre-service teachers travel two pathways; one route is concerned with preparing for generalist primary school teaching, whilst the second route is concerned with preparing them for a two subject teaching specialization in lower secondary school. The generalist component engages the pre-service teachers in a number of science and mathematics curriculum courses. The pre-service teachers complete four semester long courses, one in Years One and Two of their study, and two courses in Year Three. Most of the courses were an integrated science and mathematics preparation; whilst in Year Three the students undertook two parallel courses, one in science and one in mathematics. The nature, content and philosophy of these two courses are of particular interest here. In the fourth year students elect a pathway course, which is taken by students who wish to specialize in the teaching of science and mathematics which will qualify them to teach these subjects to lower secondary students. These pre-service teachers also undertook 'degree-level' study in mathematics and science in another part of the university. This research followed one cohort of pre-service teachers as they completed the final two years of their program.

The Year Three science and mathematics teaching provided the students with a distinctive, and possibly, unique experience. A conscious and explicit decision was taken to align and associate the science and mathematics courses and join them at five levels of connectedness. Firstly, the students' enrolment into classes was controlled in such a way that they were required to attend the same class for both science and mathematics. Secondly, the same academic tutor taught both classes. This created multiple opportunities for interdisciplinary connections, as well as asserting powerful pedagogic messages. Thirdly, content sequences, workshop tasks, and transdisciplinary social justice conduits were applied authentically to connect both courses. This was particularly evident through a workshop task and roundtable assessment presentation called "A Place in Time", which will be explored below. Fourthly, the two courses had common reading forums, where the students explored key literature in science and mathematics education, some of which scrutinized the same issues from the viewpoint of the two different subjects. Finally, the students undertook formal assessment tasks that were shared across the two courses. The common assessment tasks cemented the explicitness of the interdisciplinary and transdisciplinary nature of the two courses through its formal requirements.

2.2. Documenting the students' experiences

What follows below is an overview of practices experienced by the pre-service teachers when addressing a range of socio-scientific issues during their Year Three and Year Four courses. The total experiences of the students will not be rehearsed here but two examples will be chosen to illustrate the practices and outcomes of the teaching for each of the last two years of the program.

2.3. The Year Three experience: connecting two courses (Science and Mathematics)

SSI issues were chosen to allow the exploration of local, national and international perspectives on social justice. A Place in Time is an SSI approach to thinking and working scientifically and mathematically with a focus on ecological and social sustainability. In this series of workshop tasks, which were common to both the mathematics and science courses, the students selected a significant tree on the university campus, and through using three lenses, (i) scientific, (ii) mathematical, and (iii) sustainability, collected data about their tree in order to know their tree in all its grandeur and beauty. They then worked out a way to take positive and personal action associated with some aspect of the life of their tree.

The critical dimension of numeracy as a mathematics lens allowed the students to engage with, pose questions on, interrogate, make decisions about, and to plan and take actions in regards to one of a number of significant issues (Chartres, 2008). These issues were connected in some way to the students' physical, biological, social, cultural, political or spiritual environments, and provided a local, national or a global perspective. The experience offered the students a rich context to explore the critical dimension of numeracy through the issues of place and sustainability. This criticality helped to foster and promote the necessary transdisciplinary links with the scientific lens and the sustainability lens, which were connected through their 'big' issues associated with equity, democracy and social justice. Opportunities were constructed to move the students' thinking from the specific to the general, for instance, whilst students were estimating the height of a tree, or its number of leaves, or the area of shade cast by its canopy at different times of day, they not only carried out the process of estimating but evaluated their models and methods for estimating. There were also opportunities to move from narrow-space thinking concerning questions raised, for instance, about competition for resources through observations of the ecological balance involving their tree, to a broadened consideration of balance and resource competition which incorporated environments, people and purposes, including those of indigenous histories and issues of shrinking green spaces. It was such questioning and reflections that led directly to the planning and action taking at a personal, group or community level.

The Place in Time workshop task presented a rich opportunity for formal assessment, where the students presented their tree explorations and actions in a round table format. The university campus was built on the traditional lands of the indigenous Kaurna Peoples, who were custodians of the land for over 40,000 years, and this important local history provided opportunities for students to engage with a wealth of complex critical social issues; such as how the land was used and by whom before the university was built. Not least, these tasks allowed students to gain some understanding of 'indigenous ways of knowing and understanding' that are largely unfamiliar to them and different from dominant western ways. Although today's pre-service teachers are increasingly

aware of our Aboriginal cultural history there is still a gap in understanding that needs to be addressed. Engagement with such ideas led naturally onto an exploration of other important Aboriginal knowledge like the ‘indigenous night sky’ where a non-western view of geometry can be explored such as the location of constellations of dark-sky which provided a natural calendar and direction of travel.

In contrast to a consideration of local issues through a Place in Time, international issues linked to SSIs occurred through a study of fibres and fabrics. Two of the workshops focused on properties of material, and particularly how fabrics are made, including the differences between knitted and woven fabrics. This led the students onto a consideration of sweat-shops for producing cheap goods for international consumption, which then eventually led to the action component where pre-service teachers volunteered to knit 20cm x 20cm squares which were later sown together and sent overseas to an African Orphanage.

2.4. The Year Four experience: one integrated course for 4 hours per week for 13 weeks

This cohort elected a pathway in science and mathematics having completed a minor (a series of four degree-level mathematics and science courses) previously. The class was involved in weekly workshops with an SSI inclusion that included voluntary placed-based experiences in urban ecological settings and environmental pledges. Several workshops focused on the history and philosophy of science and mathematics with student pairs researching and adding information about key scientists and mathematicians to a timeline. Guest lecturers presented on such topics as ethno-mathematics, Numeracy mentoring program, Critical Praxis teaching models, science and mathematics for middle schooling and the Australian Curriculum and Educating for Sustainability (E4S). The students’ final assignment involved planning a year’s program for mathematics and a year’s program for science as well as developing a transdisciplinary unit of work based on a contemporary social issue. The course was a precursor to their final placement and many students were able to implement the transdisciplinary unit of work, if not in its entirety, then partially in their school setting. This fourth year course is an issues-based course that has had different emphases each year but which always focuses on socially just pedagogy. Here we report two examples, Pledges: Acts of Green and Volunteering.

3. Examples

3.1. Pledges: acts of green

Students were required to make an environmental pledge at the beginning of the semester. The aim was for them to select an aspect of their life where they could make some reduction in resource use. Key areas included reducing water consumption, reducing distance travelled in the car through using public transport and car pooling and avoiding using single use containers. Having identified their pledge students then collected data over the duration of the 15 week course. The outcomes were shared in the last workshop and some of these are presented below.

I pledged to decrease my time in the shower. I started with a usage of 840 litres per week and reduced to 152-172 litres per week. (Student 1)

My personal action for the pledge was to reduce my carbon footprint. So instead of driving during this time I chose to walk and use public transport. During my action my average travelling distance was 200.4km per week. I did this for 13 weeks, so my total travelling distance was 2306.2km. Before my action, I drove 177.8km every week, and now I only drive 42km, so I reduced 135.4km driving distance per week. Before my action, every week my car's carbon emission was 2.60 tonnes of CO₂e per year. Now, my car's carbon emission is 0.62 tonnes of CO₂e per year, and through use of public transport my carbon emission was reduced to 0.11 tonnes of CO₂e. So, I reduced 1.87 tonnes of CO₂e. (Student 2)

My simple pledge of not using my clothes dryer resulted in a reduction of 0.19 tonnes in greenhouse gas emissions and a saving of \$76.40 for the 10-week period. This represents a huge difference on an annual basis. I intend to continue with my pledge and do my small part to sustaining our environment, and think about other changes I can make to further decrease my greenhouse gas emissions. (Student 3)

This is the fourth cohort of pre-service teachers at the university to undertake an Act of Green pledge. Each year there are similar examples based on reducing water consumption through pledging to spend less time in the shower and to cease purchasing single use containers heading to landfill (plastic water bottles and cardboard coffee cups). Different examples emerge for different cohorts. For example in 2013 examples included buying fruit and vegetables at local markets rather than from supermarkets thus trying to reduce food miles, reducing water whilst brushing teeth and turning off a night light. In 2014 original Acts of Green included one student who decided not to flush after urination, another who pledged to 'wash my dog twice a week rather than every night', another who participated in meat free Mondays, and finally one who purchased necessities rather than wants and reduced the time watching television. The pre-service teacher who has taken a pledge not to flush after urination based his concern on the 'availability of fresh water not only for future generations but also mine'. The pre-service teacher who pledged to participate in "meat free Mondays" chose the action because she believed that the way in which we consume, and in particular red meat, is unsustainable and ethically cruel (eg factory farms).

3.2. Giving of time and energy: volunteering

Students volunteered for a Place-based Education experience in urban ecological setting for between 3-10 days. Assessment involved a digital narrative presenting to class about how the resource can be helpful for a beginning teacher. Settings where voluntary work was undertaken included National Parks where they removed non-indigenous plants, Kitchen Gardens, where they worked with groups of children to cook food from ingredients sourced from the garden. Trees for Life where they attended workshops about propagating trees from seeds, and a Nature Education Centre, where they cleaned out animal cages. The pre-service teachers also contributed in an educational sense through developing websites, and pamphlets.

Other outcomes included (a) Fund raising for Cans for Cancer, (b) Writing protest letters in support of particular causes and issues, and (c) Guerrilla Gardening, where students turned up on campus to plant trees at an entrance to the School of Education building. Such outcomes often had long lasting benefits for themselves and others.

These practices continue to evolve, with each cohort bringing their own expertise and interest to the program. However, the overarching aim is for all graduate teachers have an appreciation for a curriculum that is constructed and has a focus on educating for sustainability and social justice. It is important that they understand the environmental and social issues that currently face the human race and that they are mindful of their

ecological footprint. Equally, it is important that they gain an understanding of their local choices and appreciate that their actions can have a profound effect on the life-chances of those people in impoverished circumstances and whom they are unlikely ever to meet.

In aiding the students to consider, and evaluate such issues, and in exploring ways to embed such issues into their teaching, there was always a mindful attempt to position specific instances on a continuum from local to global, and to include within the analysis the contributions that could be made by individual action within a wider critique of socio-political and global-economic issues. Whilst the majority of pre-service teachers complete the task and make comment about how it has assisted them to think about how else they can reduce their ecological footprint, there is also a deliberation of wider/deeper notions that confronts the differential consequences of policies related to recycling containers as opposed to recycling cars off the road and onto public transport.

4. Evaluation of success. Collecting data

Two methods of data collection were employed to evaluate the success of the learning experiences in the case study; (i) a debriefing analysis following the formal 'round table' assessments presented by pairs of pre-service teachers, and (ii) collection of direct student evaluation data by means of an online survey.

4.1. Evaluation of the round table assessments

The Round Table assessment was one of four formal assignments employed to assess the science and mathematics courses. This particular assessment was conceived as a synoptic assignment which drew together the various themes that had been explored throughout the semester long courses. In this 'round-table' assessment, pairs of students undertook a 30 minutes presentation outlining their learning from the Place in Time task. Specifically they were asked to consider:

- What each of the three (science, mathematics and sustainability) lenses identified.
- An example of informed student action that was taken to preserve and/or develop the area as an environmental teaching resource for mathematics and science.
- How experiences like A Place in Time could assist young people to attach to place.
- Specific examples of thinking mathematically and thinking scientifically.
- Suggestions about how such an investigation would support developing students' numeracy in the primary/middle years.

Following the assessment presentations, which occurred over four full days, the academic staff involved in the assessments carried out a series of debriefing meetings where they moderated their assessment scores and evaluated the demonstrable learning outcomes exhibited by the students. It was the nature of these assessment deliberations which informed the evaluation process.

4.2. Online survey

The second method comprised an online survey. This was a voluntary participation survey which gathered data on three discrete themes; (i) the quality of teaching and learning experiences, (ii) challenges arises from the nature of the content, and (iii) preparedness for teaching. Each theme contained two or three free-response questions. In addressing the aims of this paper, through gaining insight into the students' understanding of the nature and role of SSIs, and probing their understanding of the benefits of adopting transdisciplinary approaches, only the responses to theme (ii) will be considered.

Theme two questions were:

- ✓ Question 1: Considerations of socio scientific issues and connecting to the life worlds of students have been two foci of the learning experiences. Please comment on which issues most impacted your learning and how you might incorporate these in your teaching?
- ✓ Question 2: What have been the challenges and benefits of learning about teaching science and mathematics in a transdisciplinary way?

5. Results

5.1. Data from the 'round table' assessments

From scrutiny of the roundtable assignments, followed by the assessment debriefing, three broad themes were formed which summarised key aspects of the pre-service teachers' learning. Within each of the themes the demonstrated strengths and areas for development were identified.

Theme 1: Understanding of the nature and role of SSIs in teaching science and mathematics

Strengths

- They understood the idea of social action, and how they can connect the notions of social action to the concept of SSIs;
- They understood the advantages and challenges that issues based planning presents
- They appreciated that in order to solve problems you are required to work collegiately and adopt different ways of knowing.

Areas for development

- They showed less knowledge or skill at being able to transfer the potential of the rich tasks to an age appropriate to primary learning.
- They were too idealistic to work in the pragmatics of real classroom spaces
- The balance of the science, mathematics and sustainability emphasis were inappropriately in the planning. They tended to focus on one dominant context

Theme 2 Understanding the notion of socially just pedagogies

Strengths

- They understood that it requires a relevant curriculum to connect to the life worlds of students.
- They appropriately asked questions about ‘whose interests are being served?’ when adopting a critical numeracy lens.
- They demonstrated the concept of living the idea through their assignment by working as a team and valuing each other’s views and opinions.

Areas for development

- It was far too demanding for some students who adopted surface approaches only
- The indigenous perspectives were either very strong or very weak
- The collection and adaptation of resources was particularly challenging for some.

Theme 3 Understanding the benefits of a transdisciplinary approach

Strengths

- They understood the power of the three lenses even if they didn’t always get the balance right.
- They demonstrated ‘connected learning’, i.e. employing rich tasks has a greater chance of engagement.

Areas for development

- They tried to be too ambitious and too sophisticated in the time available.
- The good thinkers ‘got it’ but procedural thinkers didn’t.
- Some were more mechanistic and lacked the development of higher order thinking.

The strengths outweighed the areas of development and provided opportunities for reflection on the impact that utilizing SSIs has on the pre-service teachers’ learning experience.

Responses to the online question: Eliciting student views of the experience

What was the impact on their thinking and learning?

Earlier, we wrote that a key outcome of the learning experience is the students’ personal participation, which arises from engagement with the transdisciplinary study. The few selected examples below illustrate some of the explicit actions carried out by the students. These actions illustrate critical moments and events in the students’ professional journeys, and in some instances show quite profound changes in patterns of thought or a re-prioritising of their personal commitments. For many of the students, these actions were not trivial, but an affirmation of their seriousness to principles, beliefs and values. Students’ evaluations, which uses their words (student voice) have been used to reflect the impact of the experience on their choices and their decision making. The italics below were added by the authors.

The fabrics and fibres stuff, it was about more than what fibres are. By introducing clothing and how it is made and the social issues that come with that it helps to connect the issues (such as sweatshops) and gives children insight into the world. I really enjoyed the tree assignment. Relating Science AND Mathematics to a tree was just a very creative idea and is a great resource for us when we go out and begin teaching for ourselves. (Student 1)

Poverty was a major issue that we covered in maths through looking at numbers and graphs. It is not something I would have thought of before and is definitely something I will incorporate into my teaching in the future. (Student 2)

Socio-scientific issues (SSI) are scientific topics that are controversial and engage students in dialogue, debate and discussion. One SSI that impacted on my learning was the discussions we had about the ethics and cost of clothing and who receives what percentage of the sale. By engaging in discussions and research surrounding this, and the ethics of the clothing industry, along with exploring the durability of certain fabrics and materials, my own beliefs and spending patterns were challenged. An essential aspect of the implementation of SSI is that the teacher does not promote any particular belief; rather, the teacher's role is to promote evidence-based critical thinking and argumentation. Thus as a teacher I would incorporate an SSI using the 5E's approach and provide students with the opportunities to engage in critical, analytical debates, discussion and research that would empower them and allow them to develop their scientific literacy skills. (Student 3).

These issues were really important and through the 2 courses I found that connecting students to the environment to be a very important aspect along with using manipulative and engaging resources. (Student 4).

The activity based around the tree. It has helped me to understand our environment and our impact. (Student 5).

The story of stuff (sustainability) video was an eye-opener for me . . . Also the teaching of Maths and Science embedded in life made more sense to me (A Place in Time Assignment). I think I would be looking at more real life contexts in which to incorporate Maths and Science learning and look for more creative ways of teaching them rather than simply doing numerous sums from a page in a book. (Student 6).

Having the round table as an assessment was a fantastic initiative, as was peer assessments. Will definitely use these in the future. (Student 7).

Fair trade, sustainability these could be incorporated in to mathematics, science, art, history and English. (Student 8).

The sustainability focus in all of these courses is shown throughout these courses, they show direction for a healthier attitude to sustainable living. (Student 9).

Well it's been made important to us that our students should know about sustainable living through all the courses. We have had experiences that show us how to have sustainable lesson focuses. (Student 10).

Educating for Sustainability is all about getting the knowledge into students so they can make sustainable decisions, as well as getting them engaged with sustainability issues and seeing how their choices can make a difference. My understanding has come primarily from Numeracy and the Learning Area (pathway) more than the previous courses. (Student 11).

Each of these courses has started from a basic level where we have all understood then built on these to develop our knowledge and understandings. (Student 12).

6. Discussion and conclusions: reflections on students' responses

It seemed that pre-service teachers were able to reflect on their experiences across four years and make comment about the impact of SSIs on their learning about teaching mathematics and science. The key themes around equity, social justice and sustainability were evident in the responses. The pre-service teachers identified issues that had an

impact on their thinking e.g. poverty, ethics of clothing industry and fair trade. Language associated with a SSI perspective such as evidence based critical thinking, argumentation and dialogue was also evident in the responses. Practical applications to classrooms were also commented upon with students making reference to authentic assessment such as roundtables and using the “Tree Study: A Place in Time” as examples they could see being implemented into their classrooms. It should be noted that whilst there were many thoughtful insights into their learning some students chose not to make any comment.

We were not surprised by the nature of the challenges the pre-service teachers encountered or the enormity of the task they faced. Course evaluations led us to believe that some real progress had been made in provoking students to think, not only about their classroom practice from a science and mathematics perspective, but how utilising an SSI approach could facilitate them to engage with teaching to promote socially just outcomes. This is a demanding aspiration for inexperienced teachers, but one that we think, is worth pursuing and promoting.

For the past eight years the primary/middle curriculum courses in science and mathematics have been sequential, integrated and influenced by socio-scientific issues and educating for sustainability. What this paper has tried to do is to analyse the impact that this approach has had on a cohort of pre-service teachers. Examining the outcomes from the courses, including the students’ pledges and active participation in socially just activities, as well as course evaluation data, a case can be made that students have valued this approach and seen the pedagogical practices as supportive of them to plan, and teach connected and meaningful science and mathematics in their final placement and as early career teachers. There has been lots of positive support for the approach. One indicator is that five years ago there were 10 students enrolled in the mathematics and science elective pathway and this year we had 36. Each year there is an increase and we are sure it is because of students’ conversations with previous students about how engaging the course is. We are not aware that there has been any resistance and would have thought we would notice the lack of participation but silence and lack of response to the question from some of the students could be read that way.

None of what is described above is easy to implement but as primary/middle teachers entering a profession that is undergoing significant changes the approach provides what we believe is crucial preparation for teachers. Resourcefulness, deep knowledge, critical perspectives, and openness to new ideas are all features needed of these graduating teachers. Being exposed to, experiencing and constructing transdisciplinary units of work and support from tertiary educators ensure that the “hard” thinking is done. Combining different ways of knowing (scientific, mathematical and sustainability) in order to explore a socio-scientific issue more holistically has been undertaken as part of the authentic assessment. As an early career teacher a transdisciplinary approach can be difficult to undertake but exposure to these themes during an undergraduate degree can show what is possible.

We have taken risks and pushed the boundaries in conceiving, planning and implementing these courses. They might not be unique but they are distinctive and they take seriously the nexus of science, and mathematics education with issues of social justice. We believe that the pathway we have chosen, which is to emphasise the importance of SSIs both in science and mathematics, and to utilise its role as a foundation stone for implementing a transdisciplinary approach to be a worthwhile and

potentially enabling strategy. This is something we aim to continue to promote, although in this current more educationally conservative climate this could be difficult.

In the near future there are plans at this university for a new conception of our undergraduate primary/middle program and it is likely that there will be an injunction to separate the study of science and mathematics. Given the richness and diversity of the work that has been undertaken, we feel that this is a retrograde step, and it is something that we will be actively working to retain. Given this possibility, it was important for us to document the impact that this coherent sequence of courses has had on many cohorts of our students. Fighting the fight to continue this innovative practice has not yet been completely lost, so hopefully we will be able to report some new and exciting developments in a few years hence.

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