Chapter 13
Pedagogical Practices and Science Learning with a Focus on Educating for Sustainability for Pre-service Primary and Middle Years Educators

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13.1 Background

The pedagogical practices we discuss here are associated with an undergraduate primary (Years 3–5) and middle school (Years 6–9) Bachelor of Education programme (LBPM) offered at the Mawson Lakes campus of the University of South Australia. Graduates are qualified to teach in primary school, junior secondary school and middle schools (Years 6–9). The programme includes four components: educational studies major, curriculum studies, practicum and general studies. The discussion in this paper is concerned with four mathematics/science curriculum study courses which we have designed and managed.

The LBPM programme, which has been offered for the last 5 years, aims to prepare educators who are professionally competent and primarily concerned with learners' well-being and who are committed to social justice, futures thinking, sustainability, education for community living and sound pedagogical reasoning that is enquiry based (University of South Australia 2010). This aim has been informed by a range of interconnected literature and is based on the understanding that globally and locally we are undergoing rapid changes and that past practices are unlikely to meet the needs of immediate- and longer-term futures (Beare and Slaughter 1993; Fensham 2003; Smith 2002; Sterling 2001).

This chapter begins by providing a brief overview of the literature that has informed our approach to teaching and learning science. This in essence provides our theoretical framework. Having outlined the structure of the curriculum courses and key pedagogical practices, we describe four examples of how educating for sustainability is put into practice. To determine the impact our approach has on

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pre-service teachers' emerging views about teaching science and mathematics, we analyse course evaluation data from three courses. The concluding remarks provide some insights for future directions.

13.2 Literature That Has Informed the Development of Our Practice

Research literature has informed the development of the programme aim and our pedagogical approach to science and mathematics education. Whilst there is a wide range of possible topics which are relevant to contemporary science education, our professional interests and experience have led us to the following areas: connecting science education to life worlds (Fensham 2003; Goodrum 2006; Harlen 2010; Hodson 2003; Tytler 2007), educating for sustainability (Jones et al. 2010; Jucker 2002; Steele 2010; Sterling 2001; Capra 1996, 2002; Lowe 2009), futures thinking, (Beare and Slaughter 1993; Gough 1990; Gidley 2002; Hicks 2002; Page 1996; Orr 2010), place-based education (Gruenewald 2003; Loeb 2001; Louv 2008; Smith 2002) and transdisciplinary education (Balsiger 2004; Lawrence and Despres 2004).

13.2.1 Science Education Literature

The science education literature provides a rich source of ideas on how science can be taught in ways that relate to student lives and interests. Goodrum (2006), Goodrum et al. (2001), Rennie (2006) and Tytler (2007) have all pointed out the failure of many teachers of science to provide relevant and engaging science experiences for their students. It is emphasised in the literature that science courses must be situated, engaging and relevant, that is, connect to student life worlds and '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' (Fensham 2003, p. 8). This is further supported by Hodson (2003) who suggests the science curriculum be orientated towards socio-political action. In the curriculum and general study courses, the focus is to shift students' perceptions of science learning as being primarily about knowledge acquisition delivered using a transmissive style of pedagogy, an approach that Fensham (2003) suggests leads to a combination of low interest and too high a cognitive demand towards that which also focuses on political action. The first two principles for science education as outlined by Harlen (2010, pp. 6–8) resonate with the directions of the science curriculum courses, the first one stating 'Throughout the years of compulsory schooling, schools should, through their science education programmes, aim systematically to develop and sustain learners' curiosity about the world, enjoyment of scientific activity and understanding of how natural phenomena can be explained' and the second principle stating 'The main purpose of science education should be to enable every individual to take an informed part in decisions, and to take appropriate actions, that affect their own wellbeing and the wellbeing of society and the environment'.

13.2.2 Education for Sustainability

Educating for sustainability (EfS) seeks to provide knowledge and understanding of the physical, biological and human world; the skills of critical argument; and the capacity and motivation to work towards harmony and sustainability through practical action. This approach involves students making decisions about ethical, social, cultural, environmental, gender, economic and health issues and acting upon them. Education for sustainability embodies the theory and practice of social, economic and ecological sustainability, and, in turn, ecologically sustainable development depends on sustainable education and learning (Sterling 2001). So, an important aspect of our practice is to encourage students to make a positive difference in their world and to live more sustainably as empathetic companions of all the Earth's creatures and structures (Suzuki and McConnell 1997). We have drawn on the work of Jucker (2002), Sterling (2001) and local and national reports (ARIES 2009; DECS 2007; DEWHA 2010; Gough and Sharpley 2005; Steele 2010) in the area of education for sustainability and other sustainability advocates such as Capra (1996, 2002) and Lowe (2009 n.d.). Education for sustainability strongly informs the sequence of the science and mathematics courses and is the basis of many of the workshops. Four practical examples will be described in the next section.

13.2.3 Futures Thinking

Futures in education is considered by many educators (Beare and Slaughter 1993; Gough 1990; Gidley 2002; Hicks 2002; Page 1996) as being a neglected but essential dimension of education, essential primarily because 'visions and views of desirable futures always come before their realisation. Yet today positive visions are in very short supply' (Beare and Slaughter 1993, p. 105). The literature states that students should develop the skills and foresight to manage and instigate change within educational settings. It is argued that because learning is a life-long process and education is an integral component of constantly changing environments, images of futures affect powerfully what people believe and how they respond in the present. Bell (1998, p. 22) suggests that 'one of the most important futurist purposes is the study of images of the future', and Henderson (2002) states that 'visioning exercises are necessary, pragmatic and can yield practical results' (Henderson n.d). It follows that learning settings have a special responsibility to ensure that all members of a learning community are prepared for and proactive about their future (Lloyd 2005, 2007, 2010; Lloyd and Wallace 2004, 2006; Lloyd et al. 2010).

Whilst the science education literature does not explicitly point to futures education, the education for sustainability literature does (e.g. Ferreira et al. 2009; Tilbury and Cooke 2005; UNESCO 2005). Ehrlich and Ehrlich (in Orr 2010, p. 82) say that science has already shown the way towards a sustainable future by elucidating the problems and outlining many solutions. The challenge for education (school and community) is to figure out how to frame solutions in ways that will motivate people to respond; a facility integral futures thinking is designed to do so (Slaughter 2004). Developing of foresight is a task we have taken on in our courses, and students are given opportunities to reflect upon and develop positive images of possible futures.

13.2.4 Place-Based Education

Authentic education, as Sterling (2001) argues, has always been rooted in place and tradition. A necessary component of teacher education courses is that community living occurs in a diversity of settings and which ‘connects education to locality’ (Jucker 2002, p. 294). This place-based learning takes hands-on experiential learning, extending it beyond the classroom curriculum, and encourages students to be co-managers of their learning (Smith 2002; Woodhouse and Knapp 2000). Ideally, the result becomes a constructivist’s idea of what education can best be: students responsible for their own learning and learning that takes place by ‘doing’ in authentic situations. Students do their learning by studying the place(s) they live, learn and play – places they are familiar with, perhaps taken for granted, and usually not closely scrutinised and studied. They are places they take responsibility for ethically and actively.

The primary value of place-based education is the way that it serves to strengthen children’s connections to others and to the regions in which they live. The importance of connecting students to the natural world (Louv 2008; Sobel 2008) is a key aspect of place-based education. It serves both individuals and communities, helping individuals to experience what they value and hold for others and allowing communities to benefit from the commitment and contributions of their members (Woodhouse and Knapp 2000). In the fourth year, elective course students complete a placement in an urban ecological setting and work in a voluntary capacity, undertaking such tasks as revegetation and removing non-indigenous plants (Borgelt et al. 2009).

13.2.5 Transdisciplinary Education

Whilst the School of Education and the schools that it serves maintain a quite rigid silo curriculum structure made up of subjects or learning areas, we have, within the confines of imposed structures, started to explore interdisciplinary and transdisciplinary views of curriculum, teaching and learning. An interdisciplinary approach brings to the study of place a number of ways of knowing (science, mathematics, sociology, history, etc.). A transdisciplinary approach is about problem-solving where the understanding of relevant disciplines and local knowledge are used to resolve the issue or problem.

Often, science learning will contribute to the study of issues or topics that require an interdisciplinary or transdisciplinary approach. We are using interdisciplinarity to indicate that many disciplines are used in the study of a problem or theme (Wallace et al. 2005), and transdisciplinarity to refer to an approach that uses many disciplines *and* the grounded, local knowledge and needs of those in a particular social setting to approach a problem (Balsiger 2004; Després et al. 2004). Balsiger (2004, p. 407) states that transdisciplinarity is a scientific approach to understanding the world with a strong orientation towards societal problems.

The pressure to adopt transdisciplinary practices comes from the need to solve complex socio-scientific problems, where one discipline on its own cannot provide an answer (Bruce et al. 2004; Horlick-Jones and Sime 2004), and this is certainly an issue for education as a social process and for curriculum delivery in the learning setting.

Transdisciplinary thinking ensures that we look for and value the self, the social and the cultural in science learning and directs the selection of topics and their construction. We illustrate transdisciplinary learning later using a topic called *A place in time.*

Whilst we have not been able to take on all aspects of the literature we mention above, and to the degree that the authors suggest, we have been able to introduce our students to these ways of thinking and acting in the science/mathematics educational context. Our aim is to provide our students with ways of thinking about curriculum and pedagogy that will prepare them for future developments in school curriculum and pedagogical practices. Current thinking in the area of EfS certainly points to each of these areas as important for twenty-first-century education. We now provide an overview of the curriculum structure and examples to illustrate how the discussed literature has been incorporated into our courses.

13.3 Structure of the Curriculum

Over the last decade, a team of science and mathematics primary/middle educators have worked collaboratively to develop a cohesive suite of courses, some compulsory and others optional (Chartres et al. 2003; Lloyd and Paige 2008; Paige et al. 2005, 2008). The four compulsory curriculum courses involve a semester in each year of the programme. All courses are characterised by participation in interactive workshops rather than the traditional lecture tutorial model. The cohesive four-course sequence has two key themes: first, to develop pre-service teachers' science and mathematics conceptual understanding through different vehicles with a leaning towards educating towards ecological sustainability and, second, planning for learning which is where students plan and implement increasingly more complex tasks with students in their practicum placements.

The optional courses involve an elective general study sub-major in science, which we do not have space to elaborate upon here. A second optional course is taken in the fourth year where students select a learning area specialisation based on their general study option which leads to their final practicum placement. In our context, the students select a learning area specialisation in science and mathematics in either primary or middle school settings. Each year, we have between 8 and 16 students. This small number correlates with research done on the lack of background and confidence in science and mathematics that students bring with them to this programme (Paige et al. 2008).

Details of the science and mathematics vehicles which are covered at each year level in the compulsory courses and the optional science and mathematics learning area specialisation course are reported in the second column in Table 13.1. The third column identifies the key pedagogical foci for each course. The workshops provide an opportunity to explicitly model practices such as the different stages of the Interactive Teaching Sequence (Faire and Cosgrove 1993) and the 5 Es (Australian Academy of Science 2007). The fourth column describes the increased complexity of the science and mathematics tasks they plan, implement and evaluate in their school placements. It is the combination of the interactive workshops and connections with planning for learning in authentic places which develop the students' confidence to teach science and mathematics.

The structure of these science and mathematics courses has several features and subsequent benefits. First, each of the courses builds on the previous course so that over the 4 years students build their confidence to teach science and mathematics. They are not one-off, stand-alone courses but a sequence of coherent courses with each increasing in complexity as seen by Table 13.1.

In the first course, students are exploring the ideas of property and attribute through a series of practical workshops where natural objects such as rocks, feathers and shells are sorted and classified using both a science and mathematics way of knowing. They plan and present a prior knowledge experience with three children. In the second course, the students experience different vehicles, surface area and angle in mathematics and electrical circuits and soils in science, and plan three lessons to teach to their practicum class. In the third course, the content focuses on fractions and acid and bases and planning units of work to teach in their third practicum. The fourth-course students participate in a transdisciplinary workshop sequence which becomes the basis of a round-table assessment.

Second, the sequence provides an opportunity for the same staff to see the students more than once and hence develop relationships. Whilst there has been a reduction in staff, we have managed to maintain the cohesion through the dedication and commitment of both tenured and sessional staff. Staff work in combinations of curriculum courses, general study and practicum courses which support students to develop as generalist teachers in 3–7 classrooms and specialists in 8–9 classrooms.

Third, a major part of the integration is linked to the pedagogy. The way mathematics is learned is similar to the way science is learned. Our practice has been informed by a constructivist approach to teaching and learning, and building on the ideas through each of the courses ensures a high level of understanding for those students who engage (Skamp 2008; Van de Walle et al. 2010). Hence our commitment to interactive workshops rather than a lecture/tutorial model more common in universities.

Table 13.1 Overview of compulsory and optional science and mathematics courses

Content vehicles	Key pedagogical foci	Planning for learning Links to practicum
Studies in science and mathematics education 1 (1st year)		
Sorting and classifying	Understanding the disciplines of science and mathematics	Plan and implement a prior knowledge learning experience of a science and mathematics concept with three students and plan next lesson
Vertebrates and invertebrates	Introducing the Interactive Teaching Sequence/5 Es	
Pattern	Interdisciplinary approach	
Number	Key concepts, thinking and working	
Forces and movement		
Studies in science and mathematics education 2 (2nd year)		
Measurement (area)	Developing student's questions	Plan, implement and evaluate sequence of three lessons in both science and mathematics to teach in second practicum
Electrical circuits and energy use	Exploratory experiences and investigations to build on prior knowledge	
Spatial sense (properties of 2D figures)	Integration	
Soil science	Lesson-planning sequence	
Mathematics (3rd year)		
Chance	Unit planning	Plan, implement and evaluate a unit of work in science and mathematics in third practicum
Rational number		
Acids and bases		
Numeracy: issues in mathematics and science education (4th year)		
Dimensions of numeracy	Transdisciplinary workshop sequence *A place in time*	Round-table assessment
Mental computation	Sustainability	
Data handling		
Professional pathway (optional 4th year)		
Educating for sustainability	Transdisciplinary planning	Digital narrative
History and philosophy of science and mathematics	Planning for learning models: 5 Es, interactive teaching, critical praxis	Year planner in science and mathematics
	Place-based experience	

Interactive workshops provide an opportunity to model effective practice and develop deep learning. Workshops authentically link theory with practice, for example, interacting with manipulative material, engaging with online learning tools and spending time in the outdoors.

Fourth, links to practicum placements in their second, third and fourth year allow students to develop their confidence and competence to plan, teach and evaluate science and mathematics experiences in increasing complexity, from a prior knowledge activity with a small group of students in their first year to a transdisciplinary unit over a 5-week block in their fourth practicum. Four examples of how ecological sustainability leading to possible action is woven through the courses are the focus of the next section.

13.4 Putting Educating for Sustainability into Practice

Each of the four following examples provides an insight into how education for sustainability is translated into practice in the science and mathematics courses. The first two examples use an interdisciplinary approach using mathematical and scientific ways of knowing and primarily focus on science and mathematics conceptual learning; the second two examples use a transdisciplinary approach to solving problems which require mathematics and science understandings, in these cases, connecting students to community and place.

The first example occurs in the second year course where a series of three workshops focus on electrical circuits and energy use. In the first workshop, the students explore their prior knowledge of electrical circuits through annotated diagrams of torches and are provided with opportunities to develop their understandings of circuitry, currents, voltage, conductivity and electrical energy measurement. In the second workshop, the students are involved in investigating their own questions around parallel and series circuits, current and voltage. Students are exposed to a range of models for recording their investigations including those presented by Primary Connections (Australian Academy of Science 2007). In the third workshop, students are asked to bring in the wattage reading from an appliance that they commonly use such as a hair straightener and a microwave as well as a recent electricity bill. Students measure the amount of electrical energy they use for their appliance and then work out, using indirect measurement, their greenhouse emissions for that appliance for the billing period. This is a good example of how the sustainability focus is evident but the science and mathematics is still central and how a sustainability focus can be introduced into a science/mathematics unit.

The second example is a two-workshop sequence which focuses on exploring mathematics for citizenship through data handling. In the first workshop, the students explore ideas of mean, median and mode through collecting data about themselves, for example, their height and neck circumference, and representing it in a range of ways including using software packages such as *TinkerPlots*. In the second workshop, the students are asked to collect and bring data about their personal water consumption. For example, the amount of water to wash, amount of water flushed via toilet and amount of water consumed in washing/cleaning clothes, cars, home, dishes and personal items. The students use stem and leaf and box and whisker graphs to represent and compare aspects of the data. The workshop draws two conclusions: ways students can reduce their personal water use and ways that different countries use water, using data from the *New Internationalist* magazine and Anita Roddick's *Body Shop* website.

The third example occurs in the fourth year numeracy: issues in science and mathematics course, focusing on a transdisciplinary topic, *A place in time*. Building on science and mathematics concepts covered in previous years, pairs of students select a significant tree on campus, and using three different lenses, (science, mathematics and sustainability) they connect to a place on campus. Using the mathematics of measurement, they explore the attributes of distance, surface area and capacity. For example, they develop strategies to estimate the heights of the tree, the number of leaves and the area of the tree's shadow throughout the day. They also describe its location using distance and direction and construct a map so others can locate it. Using a science lens, they investigate the properties of soil such as colour, pH levels and porosity. They identify the physical structures of the tree and its functions, the animals living in or near it and why they live there. They also collect data about aspects of weather (e.g. temperature, humidity and cloud cover) at different times of the day. Next, using a sustainability lens, students construct a futures scenario of their place in 50 years time and use Van Matre (1990) sensory activities to add to their sense of place. There is a requirement that they talk about undertaking a possible action, for example, planting sedges to attract butterflies to the campus. A summative assessment involves students presenting their findings at a round table (Australian National Schools Network 2002). This example involves students thinking and working mathematically, scientifically and sustainably outside the classroom. Engaging with students' local environment to develop a sense of place and connection are two of the teaching pedagogical practices embedded in this topic (Paige et al. 2008).

The fourth example occurs in the professional pathway which is held in the semester before their final practicum. Ecological sustainability is a key focus. The course consists of two components. The first component focuses on planning and programming where students plan a unit of work in science and a unit of work in mathematics and present this as a professional development experience to their peers together with a transdisciplinary unit of work for a nominated level of schooling. The second component focuses on a place-based experience which is assessed through the presentation of a digital narrative. In the place-based experience, students spend time in an urban ecological setting, undertaking such tasks as removing non-indigenous plants from national parks and collecting data about water quality in local rivers. This voluntary work over the semester results in pre-service teachers adding to their knowledge of ecological science, developing a sense of belonging with a community, connecting to a new place and developing an appreciation for the needs of future generations.

The four examples provide an outline of how ecological sustainability is woven through the courses spread over the 4 years. The science and mathematics is still central but it is covered within a context that is relevant for student life worlds. It is expected that these experiences will provide the pre-service educators with the confidence to implement meaningful and rigorous science and mathematics during their practicum, in the first instance, but later as beginning teachers. The next section explores feedback from students who have undertaken these courses.

13.5 Evaluation of Student Data

What impact does participating in the courses have on developing pre-service teachers' confidence to teach science? At the end of each semester, students are invited to complete an online course evaluation. In this study, we focus on feedback from three of the five courses, the first and second year compulsory courses we use the course evaluations as the main source of data. The third course included is the optional fourth year course which has low numbers and therefore provides an opportunity for in-depth focus group discussions and explains the difference in evaluation data. These three courses are well established and have been refined over several years. The other two courses are still undergoing development and modification.

13.5.1 Science and Mathematics Education 1 (1st Year Course)

Examining the 2008 data for the first year course provides some useful insights. Of the 143 students who took part, 58 (41%) completed the survey. For the question, 'Overall I was satisfied with the quality of this course', 71% either agreed or strongly agreed. Only 9% replied in the negative. Two other questions relevant here were asked: (1) What are the strengths of the course? (2) What ways has this course supported you to develop confidence to teach science and mathematics?

Comments about the strength of the course have been organised around the themes of pedagogy, building content knowledge, learning theory, resources and assessment. The proportion of responses from the pre-service teachers has been recorded as a percentage after each theme.

Pedagogy (34%)

Recurring themes about pedagogy include the hands-on approach to learning, modelling good practice, having the opportunity to put ideas into practice and resources. A sample of responses that refer to pedagogy are listed next:

> The 'hands-on' approach to learning, for example, the structured play time, was very helpful.
>
> Being active in manipulating materials and 'getting your hands dirty' to better understand concepts.
>
> How the tutor models the constructivist strategies we are required to learn.
>
> Use engagement activities, proved very successful!
>
> The many different techniques of constructivist teaching and how the teacher exhibited them.
>
> Having an opportunity to put some things into practice by conducting the prior knowledge activities with learners.
>
> It explored how to construct a learning experience which will help with future teaching.

Resources (22%)

A second key theme to emerge from the survey was about the importance of resources. Two typical responses that reflect pre-service views include:

> The course has highlighted some good resources to assist in teaching science and maths.
>
> Provided endless ideas of how to approach lessons and activities for the students to participate in.

The remaining three themes include content knowledge, learning theory and assessment and are encapsulated in the following responses.

Content knowledge (19%)

Providing a good basic understanding of some key mathematical and science concepts
The relevance of content to what we will be teaching in schools

Learning theory (9%)

How it makes you understand how children learn maths and science concepts
Learnt how to become a constructivist teacher

Assessment (8%)

The assignments were practical tasks which we will eventually use in our teaching careers.
I believed a strength was the assignments where we were able to interact with students and were able to get an understanding of their learning and enjoyment.

Overwhelmingly, this group of students found this course of value for its hands-on approach, the modelling of constructivist practices and the opportunity to put theory into practice during their practicum placement. A few students found the workshop approach unhelpful, preferring a lecture style approach, and a few students said they needed extra help to understand the assignment tasks. Interestingly, there were no comments on aspects of sustainability modelled in the workshops.

13.5.2 Science and Mathematics Education 2 (2nd Year Course)

For this course, comments about ways the course has supported students to teach science and mathematics have been organised around three themes that emerged during the analysis of their course evaluation: confidence, inspiration and engagement. The percentage of responses that reflect each theme is recorded after the heading. Examples of answers to the question 'What ways has this course supported you to develop confidence to teach science and mathematics?' include:

Confidence (28%)

It has made me realise it's not that hard after all.
The assignments on creating lesson plans and understanding prior knowledge has given me a confidence boost.
Made me realise how exciting science and maths can be when it is taught in such an engaging, manipulative, active and relevant way.
This course gave me the confidence to teach mathematics and science in my practicum; my mentor noted on my report, my passion, for my science teaching.

Inspiration (21%)

The enthusiastic teachers and useful information.

How we cover what is needed by you as the teacher as well gives us clear knowledge of what is expected of us in the future.
I thought science and mathematics would be two boring subjects to teach; however, the course has shown me fun ways to approach these subjects.

Engagement (16%)

The ways in which we learnt, new things they were always interesting.
High-demand subject.
One of the main elements that this course taught was to always find out the 'before views' of the students before proceeding with a lesson plan.
To go the extra length to actively participate in workshop discussions.

Examining the 2008 data for the second compulsory course also provides some useful insights. These students seem to be more confident in providing critical comments. Of the 115 students who took the second course, 35 (30%) completed the survey. For the question 'Overall I was satisfied with the quality of this course', 80% either agreed or strongly agreed. Only three students (8%) replied in the negative. This course is connected with students' second practicum experience in which they are required to plan and teach units of work. What students found of particular value with this second course was the way it prepared them for teaching in their practicum placement. Particular aspects they refer to include planning for learning, knowing the importance of and how to elicit students' prior knowledge. One student commented with respect to this aspect, 'Not having a sound background or confidence in either learning areas I surprised myself and my ability to teach in these areas'.

13.5.3 Professional Pathway in Mathematics and/or Science

In their fourth year, students choose a specialisation pathway which is connected to their final practicum. In 2010, 15 of the 16 science/mathematics pathway students completed a questionnaire on the value of the course. Most students mentioned the importance of maths/science learning for living an informed life. For example, one student said that mathematics and science 'are important subjects, maths and science are in everyday life, and if you want to develop successful citizens maths and science will (help) do this'. Students also described how this final course in their preparation for teaching had 'built up … confidence to teach effectively'. But what was most pleasing was that many identified the joy and pleasure that can come from studying these subjects provided they are taught in an interactive and engaging way; 'There are so many ways to teach these learning areas in an engaging and rewarding way; What is important is to engage students with experiences that are relevant to their lives'. They saw the value of 'place-based experiences in connecting to the community' and the 'photo stories provided an idea on what groups/organisations can be incorporated into student learning'. Students indicated that they had 'Built confidence as an educator with diverse and specific teaching strategies/skills that can be used across the curriculum' and the course had 'strengthened … skills in planning units and made me more specific in what I'd want to teach and how students learn best'.

When reflecting back over the 4 years about their understanding and practices of sustainability, one student responded:

> The overall impact of the courses has changed my world view and impacted on many of the decisions I make about my personal life. I think that I will be able to share this with my future students and this is an area that I feel is very important and perhaps where I can make one of my biggest contributions for future societies. I hope that my future students will learn to question and inquire scientifically and use the thinking and working skills from the mathematical and scientific concepts that they learn in my classrooms to help them decide on their future and also make a difference to future generations. It has been a fantastic learning journey!

13.6 Key Findings

What can be drawn from this evaluative data? What can be said about the key themes that have underpinned our coherent sequence of courses, place-based education, transdisciplinary education, futures thinking and educating for sustainability? What have we learnt about how pre-service primary/middle teachers have been influenced by these themes? Reflecting on these questions indicates that whilst we have a strong theoretical framework for our course construction, we are only in the beginning stages of ascertaining the impact on pre-service teachers' confidence to teach science. The innovative approach to teaching science curriculum involves an enormous amount of intellectual work as individuals and as a team. At the end of workshops, assignment moderation and semester's work, we are looking for ways to do things better. Feedback from students via the course evaluation instrument provides a student perspective. However, the questions are set, and whilst we can add our own, it adds to the length of the survey and reduces students responses. So, whilst we have some initial data, it highlights the need to do more comprehensive evaluation to provide deep analysis of all key themes. At this stage, we can really make comment about two key themes: educating for sustainability and the lack of it in the first two courses and place-based education in the fourth year course.

Feedback indicates that pre-service teachers are developing their confidence to teach science and mathematics. The approach modelled in interactive workshops actively engages students in constructing their conceptual understanding. Comments reflect the positive impact this has on their learning and confidence to teach in these two areas.

It appears that the first two courses are coherent, that the students can see each course builds on the previous and that the passion and inspiration of the teacher is crucial. Second, the links with practicum in their second course enables the students to practise their planning for learning within an authentic context. Students acknowledge how much they appreciate being scaffolded within the assessment framework to construct lesson plans which are transferrable into the classroom.

What is evident from the evaluation from these two courses is the lack of comments referring to the impact of the focus of educating for sustainability. It appears in the first 2 years that students are in 'survival' mode and need to start with developing conceptual understanding in each learning area and foundations in how to teach before planning within an interdisciplinary framework that has sustainability themes. However, by the fourth year, pre-service teachers enrolled in the science and mathematics pathway, though still focusing on the importance of taking the final step towards teaching independently in terms of preparation as a beginning teacher, were in a position to take on board the complexities of educating for sustainability and place-based education. Planning transdisciplinary topics for their final practicum contextualised the science around topics such as sustainable energy, water conservation and kitchen gardens. This was evident by the students being able to 'walk the talk', that is, incorporate the principles of educating for sustainability in their planning. In a different way, their experience with place-based education had been influential. Undertaking the place-based experience had contributed to their confidence to work in a voluntary capacity, developing connectivity to community. Whilst they acknowledged the impact of this on their own learning, it was not easy to implement when undertaking a 5-week final placement. Investigating this with recently graduating teachers would provide further insights.

In summary, the opportunity to reflect on the impact of the spiral curriculum over the 4 years highlights the pre-service teachers' improved confidence to plan, implement and evaluate science and mathematics; only in their fourth year were they able to make connections between pedagogy and educating for sustainability. Building on this feedback, and exploring other themes such as futures thinking and transdisciplinarity, more explicitly needs to be the basis of future research.

13.7 Concluding Comments

We have used evidence from students' course evaluations to continuously improve an approach to teaching science and mathematics which attempts to balance traditional pedagogical content knowledge with the emerging need to far more strongly connect curriculum to student life worlds and the emerging issues around sustainability. Such an approach takes science knowledge beyond the technical to include personal well-being, ethical living and the political action as suggested by Fensham (2003), Hodson (2003) and Tytler (2007). We use the content knowledge as vehicles to illustrate effective teaching practice so that students can experience what their students will experience and, as educators, reflect upon the value/effectiveness of our approach. The learning experiences are interactive, place based and situated in an explicitly identified integral space.

Our approach is evolving. The introduction of a fourth year course which uses issues as the vehicle to develop science and mathematics concepts and processes is an example of the ongoing development. The issues will be local as well as global, focussed upon ecological sustainability and transition to a low-carbon society and develop ideas of intra- and intergenerational equity. This course, along with the others in the programme, will complement the School of Education's focus on reducing its ecological footprint and developing confident, well-informed, futures-thinking 'green' teachers.

Our challenges will be with our own ability to learn and adapt in a rapidly changing and globalising world and to do so within the resource limits placed upon us by the university administration.

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