Chapter 22
"We Weren't Taught This Way": Overcoming Barriers When Transitioning to New Forms of Pedagogy in Educating Initial Science Teachers for Sustainability

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In this chapter we describe an attempt to introduce a form of contextualized problem-based learning (PBL) to cohorts of students training to become science specialists in primary (or elementary) schools in the UK. We consider why we initially introduced PBL and then how and why we made further adjustments to specifically address some problems in relating to science and sustainability. It is a story of change that includes some successes and some intriguing failures. The adjective 'intriguing' is used here to emphasize the fact that in science education we often promote the idea that negative data are as interesting as positive data. In education however, we often seem reticent to discuss developments and practices that did not seem to work. One of the authors has previously observed this in other published works relating to Education for Sustainability where the desire to produce positive results seems to have limited the critical and robust nature of the research (Cook & Cutting, 2009).

Change is nearly always as difficult, time consuming and as problematic as it is rewarding, however, if we want to influence the nature and direction of science in a way that will promote issues of sustainability as key aims, then changing the way we teach and the way we teach teachers is a necessary first step. Identifying that we need change is perhaps the easy part. More difficult is the identification of the nature of pedagogic changes required and their implementation. This story concerns a journey of change that we went on and the reasons, problems, and genuine surprises that were presented to us along the way. It will hopefully present at least a partial map for others to follow.

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Talking About a Revolution

> One of the real challenges is to innovate fundamentally in education. Innovation is hard because it means doing something that people don't find very easy, for the most part. It means challenging what we take for granted, things that we think are obvious. The great problem for reform or transformation is the tyranny of common sense; things that people think, "Well, it can't be done any other way because that's the way it's done". (Robinson, 2010)

In Ken Robinson's talk he argues that there is little point in trying to improve education for it is a model that is fundamentally broken and that we need little less than a revolution in the way we approach education. Perhaps nowhere more than within the field of Education for Sustainability (EfS) is this ever-increasing call for such a revolution in teaching methods more keenly heard, particularly if we are to produce a generation capable and hopeful of meeting the problems that are presented to us in the twenty-first century (Orr, 2004). However, in some ways for those of us involved in teacher education, particularly in EfS, calling for a revolution is an irresistible sentiment (Apple, 2000; DeLeon, 2006; Freire, 1970; Giroux, 1988, 2001). The intellectual predication and the academic predilection may be appealing, however, the difficulty lies in the expediency and reality of its implementation.

If this revolution takes place, one aspect that will be necessarily integral to it will be the education of a new generation of teachers (Cook, Cutting, & Summers, 2010). For the implementation of a new and appropriate praxis of pedagogy, education graduates will themselves need to be freethinking, adaptable, and independent learners who are empowered to direct their own learning and practice. However, commonly perceived expository approaches, often associated with science teaching in particular, appear to be at odds with the innovative, student-centred methodologies that EfS appears to require.

Interestingly, when pedagogical approaches that call for critical and creative thinking, participation and participatory learning, and the promotion of systemic thinking (Tilbury & Wortman, 2004) are interrogated, it is difficult to see why they should be uniquely associated with EfS. The new methods and outcomes called for in good and effective sustainability education are simply those required for good and effective education (Cook & Cutting, 2009; Cook et al., 2010). Of course, here good science teaching is no exception. Certainly previous *content versus skills* debates have identified issues to overcome that were perhaps peculiar to science (Fensham, Gunstone, & White, 2013; Magnussun, Krajcik, & Borko, 1999), yet changes in pedagogy to facilitate creative, participatory learning are undoubtedly still required. In particular Carillo, Lee, and Rickey (2005), describing the situation in the US that is certainly not unique to that country, suggested that science teachers are too reliant on lectures and *follow-the-recipe* laboratory experiments and that they necessarily need to "increase the use of activities that incorporate student inquiry" (p. 61). Hofstein and Lunetta (2004) also suggested that the science practical sessions used in laboratory activities encouraged students to simply follow recipes and that by doing so removed any sense of the purpose of the investigation nor the ability to see the interconnectivity of the work. Rocard et al. (2007)

recognized that while most of the science education community agrees that pedagogical practices based on inquiry-based methods are more effective, the reality of classroom practice is that in most European countries, actual science teaching does not follow this approach. From an English perspective, Abrahams and Reiss (2012) reported that the prevalence of *recipe* style tasks appears to reflect a combination of the relatively short nature of most practical lessons (about an hour) and the fact that the use of open-ended tasks presents teachers with greater pedagogical challenges (Hofstein & Lunetta, 2004) than do traditional recipe style tasks. Such traditional methods describe a deductive approach to science.

Osborne and Dillon (2008) reported that the pedagogy most strongly associated with science teaching in Europe is one which is:

> … dominated by a conduit metaphor where knowledge is seen as a commodity to be transmitted. For instance, teachers will speak of trying to 'get across' ideas or that students 'didn't get it.' In this mode, little of the writing in school science transcends the copying of information from the board to the notebook. (p. 9)

With such an indictment of the design and delivery of science courses, it is perhaps a testament to the innate interest of the subject matter that science has survived in our schools at all. Yet, in higher education institutions, students progressing on to science education and initial teacher education courses for science teachers have presumably not been put off, nor have they lost their enthusiasm. But what awaits them? Often the answer is the promotion of more of the traditional expository-style practical that is widely utilized at all academic levels for teaching science, despite the fact that its recipe-style nature has been recognized as "an ineffective means of building concepts" (Johnstone & Al-Shuaili, 2001, p. 46). More recently, Abrahams and Reiss (2012) reported that research findings into the effectiveness of practical work in enhancing the development of conceptual understanding in science remains ambiguous.

Decline and Fall: Wider Concerns Over Expositional Approaches and Why They Prevail in Science Teaching

The methods currently in use in the teaching of science have been clearly at odds with the types of progressive pedagogical approaches that are being called for in EfS. This is of genuine concern to those who perceive a primary role for science and science teaching in this area. However, such concerns are also exacerbated by a noticeable decline in the popularity of science at the point at which it ceases to be a compulsory part of a taught curriculum. Such a trend has been recognized in many high-income countries including Australia (Lyons & Quinn, 2010), the UK (Millar, 2010), and even in some so-called emergent economies such as China (Tzung-Jin, Feng, Ching-Sing, & Chin-Chung, 2013). Lyons (2006) suggested that a limited range of pedagogical strategies for teaching science is the primary reason why students are disengaged. However, teaching methodologies per se may not be solely responsible for this decline, for as George (2006) suggested, students' interest in science may be influenced by a number of factors, not least their personal attitude towards it, and this itself appears to vary with age. Peer group attitude, gender, and social background all appear to be influential, as do geographical influences both at national (UCU (University and College Union), 2006) and international scales (OECD, 2006; Schreiner & Sjøberg, 2004). While these socio-economic factors are perhaps not in the remit of teachers alone, it does appear that overall attitudes to science are influenced by its delivery in schools and colleges (OECD, 2006). Indeed, no less an authority than the UK Parliamentary Standing Committee on Science and Technology described current General Certificate in Secondary Education (GCSE) courses (the national 16+ qualifications in the UK) as, "overloaded with factual content, containing little contemporary science and [having] stultifying assessment arrangements" (House of Commons, 2002, p. 5).

The committee's report continues,

> … school science can be so boring it puts young people off science for life. GCSE science students have to cram in so many facts that they have no time to explore interesting ideas, and slog through practical exercises that are completely pointless. This is a disaster: we need to encourage a new generation of young scientists. House of Commons (2002, p. 5)

Over a decade later we have seen little change in the new National Curriculum for England (Department for Education, 2013).

The curious thing about science teaching however, is that active learning is present and of course, commonplace. Expository approaches may be identified as *student-centred*, in the sense that the student has responsibility for carrying out the experiment and the determination of results. However, such work is confined by a pre-determined methodology and normally a margin of acceptable error within which the results should fall. It certainly is hands-on, if not minds-on (Abrahams & Reiss, 2012). This type of teaching methodology will be familiar to many who have studied science over the last decade and beyond. Such an approach may produce competent graduates who have an undoubted knowledge base and are confident in prescribed laboratory procedures but it reduces the opportunity for invention, creativity and (important in the context of sustainability) the idea of interconnectivity and ethical approaches relating to the human and physical environment.

In such cases this knowledge-based content can be seen as being *owned* by the lecturer and being passed on at his, or her, behest. Of course for nervous students who may be going into teach for the first time, such approaches are perhaps reassuring through their familiarity. How initial teacher education students were taught can be an influence on their own, at least antecedent, approaches to teaching (Oleson & Hora, 2012). Furthermore, newly qualified teachers often revert back to the way they were taught in schools rather than the more innovative and research-based approaches adopted in initial teacher education courses during their first few years due to workload. Petty (2006) points out that while other areas of professional practice are increasingly evidence-based, in teaching we seemingly ignore the evidence and carry on delivering ineffective teaching methods. In this way the legacy of teaching science may be perpetuated to each new cohort and, therefore, to each new generation. The task of those involved in teaching initial or in-service teacher education courses is not only to break this potential cycle, but also to consider different, more effective, pedagogies in science that not only promote an understanding of science, but also promote the concepts of sustainability to the point where they are not seen as discrete.

Alternative Approaches and the Rise of Problem Based Learning

Having established the motivations for the general need for change in science teaching, the nature of the new pedagogical approaches would appear to need to be based on not only encouraging invention, creativity (and thereby engagement), but also the promotion of effective learning. In other words, they need to promote changes in attitudes and action through a greater contextualization of learning. Osborne and Dillon (2008) recommend such alternative approaches to teaching science as one way to provide a better education in science. They argue that there needs to be 'More attempts at innovative curricula and ways of organizing the teaching of science that address the issue of low student motivation' (p. 8) and 'Developing and extending the ways in which science is taught' to improve student engagement' (p. 9).

Tan (2004) concerned with "bridging the gap between theory and [the] real world" (p. 170) considered this a necessary and integral part of developing new approaches to science teaching. The positioning of science teaching in so-called *real world* settings is not necessarily a new idea. For example, the Nuffield Science Project was introduced into UK schools in 1968, but it does have particular contemporary resonance when considering the issues and problems relating to sustainability in the twenty-first century. If teacher educators accept the need for different pedagogical approaches in science, then we have to consider the alternatives that we may present to students' education, or the further education of those teachers already in-service.

Inquiry-based science education (IBSE) is taking center stage as a potential solution to the myriad of issues facing science education in Europe. The first recommendation from Rocard et al. (2007) is a reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods, which includes problem-based learning. Such methods have proved their efficacy at both primary and secondary levels in increasing children's and students' interest and attainments levels while at the same time stimulating teacher motivation (Blanchard et al., 2010; Geier et al., 2008; Rocard et al., 2007; Williams, Woodward, Symons, & Davies, 2010). The focus on inquiry is also seen in the US, where inquiry is at the heart of the proposed framework for K-12 science education (NRC 2012). In terms of science education at tertiary level, inquiry-based methods can take many forms. One such form is problem-based learning (PBL). McParland, Nobel, and Livingston (2004) suggested PBL as effective in promoting more positive attitudes to subjects. Furthermore, McDonnell, O'Conner, and Seery (2007) proposed that their PBL mini-projects contrasted significantly with recipe-style laboratories, where students completed an experiment without ever really understanding or thinking about the experiment involved. Instead, they proposed that such PBL approaches provided students with the opportunity to apply their learning, to be creative in their practical design, to contextualize their results, and to critically engage with the scientific process.

In the last decade, PBL has become "one of the most popular curricula innovations in higher education" (Tan, 2004, p. 170) and may be instrumental in a shift in focus from the traditional, didactic method of teaching, where the lecturer is the expert, transmitting knowledge to the students with coverage of content the focus, to a properly student-centred style where students are the problem solvers, the lecturer is in a coaching or facilitating role, and the problem is the focus of the learning from which content is derived (Tan, 2004). Research into the effectiveness of PBL through a number of meta-analyses has suggested that PBL is, at worst, the equivalent of other more traditional methods (Albanese & Mitchell, 1993; Vernon & Blake, 1993; Walker & Leary, 2009) and at best compares favourably across a wide range of outcomes including understanding of principles that link concepts and application of knowledge (Gijbels, Dochy, Van den Bossche, & Segers, 2005; Walker & Leary, 2009) as well as improving students' attitudes towards their subject (Vernon & Blake, 1993). It is worth noting that PBL in teacher education was reported as being particularly effective across a number of outcomes (Walker & Leary, 2009). The precise reasons for the effectiveness of such approaches are elusive, but may relate to different learning styles. PBL encourages what Petty (2006) has described as 'deep learning' (p. 29); a constructivist approach where learning is achieved by adapting and building on prior knowledge, skills, and concepts; this allows the learner to seek meaning for themselves and not the meaning as constructed by the teacher. More recently, PBL is currently receiving much attention in physics, chemistry, and biology education (Carrió, Larramona, Baños, & Pérez, 2011; Ibáñez-Orcajo & Martínez-Aznar, 2007; Kelly & Finlayson, 2007; Sahin, 2010; Selçuk, 2010; Tarhan & Ayyıldız, 2014; Tosun & Taskesenligil, 2013; Wilson, et al., 2010; Williams et al., 2010). Additionally, Smith (2012) advocated a problem-based approach to upper secondary science to ease the transition to undergraduate level science courses. Tan (2004) argued that while using problems to learn is not new, the momentum for PBL is a result of recent developments, including:

- The increasing demand to bridge the gap between theory and practice.
- The increased information accessibility and knowledge explosion.
- The emphasis on development of real world competencies.
- The developments in learning, psychology and pedagogy support the use of PBL.

With PBL, understanding is achieved through engagement with the problem and the learning environment, which activates prior knowledge and stimulates further learning. The constructivist model of learning provides a suitable educational framework within which to situate PBL. We propose that Vygotsky’s theory of learning plays a part here too. Vygotsky suggested that learning happens best through social interactions (Mooney, 2000). In essence, an individual can achieve a certain amount of understanding, but through social interaction with others, can achieve more. This gap between actual achievement and potential achievement is referred to as the ‘Zone of Proximal Development’ (Mooney, 2000; Vygotsky, 1979). These social interactions within a group take place between peers as well as with supporting adults. Not only can learners achieve greater understanding for themselves through such interactions, but also by using familiar and new materials in a discovery or problem-solving environment. Learners engage personally with such new material and therefore construct meaning and understanding for themselves (Vygotsky, 1991). Knowledge evolves through collaboration with peers, lecturers, and the use of resources, with reflection on their learning being a key element in this process. The lecturers therefore take on the role of facilitators for the whole process (Tan, 2004).

Collaborative group work is a significant element of the approach. Exley and Dennick (2004) described how, during group activities, learners can be provoked into thinking deeply by questions from their peers and teachers that challenge them to take ownership of their own learning supports a constructivist learning approach.

A Successful Case Example: The Introduction of Problem-Based Learning into Initial Teacher Education for Science Specialists

By 2008, we had become increasingly dissatisfied with the expository approach that we had initially adopted for the delivery of the first year science specialist module offered as part of the Bachelor of Education Degree (an initial teacher education program for primary teachers) offered at Plymouth University, Devon, UK. Based on the arguments presented here, we decided to adopt and monitor a PBL approach to the science specialist provision. The program regularly recruits over 160 students each year onto a variety of subject pathways. The great majority enter the degree directly from school, although each year there is a small number of mature students, defined as over 21 years old in the UK, therefore most are under this age. There is a significant gender bias, common to many early years education degrees, and although since 2012 the gender gap has significantly narrowed, during the period discussed 72 % were female (Plymouth University, 2014). In relation to this project we closely followed the experiences of a cohort of students who had chosen science the science pathway through this alternative approach and compared their views with those who had progressed from the previous year that had been taught in more traditional or familiar ways. A cohort represents 20–25 students each year and the demographics of each cohort were close to the percentages cited for the whole program.

Table 22.1 The steps of PBL (as suggested by Walsh 2005)

Step	The steps of PBL
1	Identify the problem
2	Explore pre-existing knowledge
3	Generate hypotheses and possible ways to investigate these
4	Identify learning issues, in particular gaps in knowledge
5	Self-study (which would often be collaborative)
6	Re-evaluation and application of new knowledge to the problem
7	Assessment and reflection on learning

As with other inquiry or PBL approaches, there were some core elements which shifted the focus from a traditional, deductive approach to a more inductive approach. The learning was student-centred with collaborative learning a key part, the lecturers took on the role as facilitators and open-ended problems were used as a stimulus for learning. As students progressed though this module, they engaged with increasingly more complex and demanding problems. Through this engagement, it was anticipated that the students would develop their understanding of the processes of science as well as their knowledge and understanding across the sciences. Typically the structure (as shown in Table 22.1) was followed, whether the problem was solved within one class period (typically 3 h, or over a number of periods). However, the step which sometimes was missed was the self-study (step 5) part when a problem was identified and solved in one class period. In this case, students relied on their own knowledge and did not have necessarily have access to further sources of information. Additionally, this was an iterative process and if a suitable solution was not found to the problem, then the students would go back to step 3 and repeat the process. A range of problem types as defined by Jonassen (2000) were used. These included troubleshooting problems such as determining the cause of pollution in a river, along with situated case problems, such as establishing the efficacy of ancient water systems. Design problems were also included such as making a functioning electronic toy.

The precise research protocols may be found in Kelly and Cutting (2008) but the methods of data collection included, interviews and questionnaires with all students in the cohort. These were used to ascertain the whole group's experience of, and attitudes to, science prior to coming to University. A second questionnaire, once again completed by the entire cohort, was carried out at the conclusion of the program that focused on their learning experience. Throughout the module, the students were encouraged to keep a reflective diary of each session and to include critical reflections on their own learning. Small group, structured interviews were also conducted at the conclusion of the module. For brevity, the summary of the results from student feedback and end of program discussions suggested that PBL was certainly an effective mode of increasing students' confidence in scientific methodology and to some extent their knowledge and understanding of science concepts and principles. The latter needs further research, considering longitudinal data, in particular with relation to retention of knowledge and understanding and its application to other problems. However, Dochy, Segersb, Van den Bosscheb, and Gijbels (2003) reported that students in PBL gained slightly less knowledge but remembered more of what was learned. We suggest that the science PBL lecturer does not have to be an expert but does have to be competent in science methodology and in-group facilitation and our findings at this stage support this view (Kelly & Cutting, 2008).

We also identified a change in the relationship between the lecturers and students. This was not necessarily due to the change in status from *lecturer* to *facilitator*, although no doubt this may be a pertinent issue; it was rather a more subtle shift in the social relationships between them. Our approach to PBL was one that enabled and encouraged positive group relationships to develop through dialogue, discussion, and explanation. Bruner (1996) points out, in a wider sense, in science

> … we play with ideas, try to create anomalies, try to find neat puzzle forms that we can apply to intractable troubles so that they can be turned into soluble problems, figure out tricks for getting around morasses. The history of science . . . can be dramatically recounted as a set of almost heroic narratives in problem solving. (p. 126)

The recounting of such histories provides a sense of development and progression over time. It clearly demonstrates how we build on events and, whilst progression may not be linear and constant, there is an advance. It is, perhaps, this approach that PBL needs to be built around. Without a clear sense of progression and development the PBL approach runs the risk of losing cohesion. For example, one negative outcome from this program was the response from students and staff, in relation to a seeming lack of progression that, in this instance, may have been a consequence a lack of this approach. The module had been built into discreet units of work that operated over a two to three week period. Each problem was significantly different from the previous one, in terms of content, context and problem type, in order to help develop and extend the students skill and knowledge across a range of science areas. This may well have contributed to a lack of coherent progression. Therefore, certainly when designing PBL activities, it is recommended that they be positioned within a clearly structured and overarching narrative. This may have been through a sequence of issues and investigative practical sessions that perhaps concerned an identified global issue, such as the provision of fresh water. Each week the students could explore issues such as water pollution, purification, supply and irrigation, health needs related to water, for example. This approach to PBL provides a coherent framing for the activities.

At the conclusion of the year interviews were held with all students on the module and the majority confirmed that, retrospectively, they could see how such an approach had helped them. This was particularly true in relation to their project work and their own confidence as researchers. They felt that the module provided them with a range of opportunities to express themselves in discussion; often realizing that they knew more than they had initially thought. One intriguing and common comment suggested that the approach promoted academic equity within the group. With each member having different skills and backgrounds to bring to the problems no one individual dominated. In turn this promoted stronger group cohesion that they felt would be maintained throughout their second year. Indeed, they generally felt well prepared to progress into their second year and most could clearly identify the relevance of the approach, although, interestingly, they saw less application in the problems they were asked to solve. However, despite this, the students in this cohort reported that they felt that they had become more confident in science methods and approaches.

Another interesting finding from the adoption of this approach was the importance of the group work element. This seems to have been a key component to the success of the new design, with 86 % of the students agreeing that cooperatively working in groups enabled them to learn in a positive and supportive environment. Despite occasional references to negative issues (such as disagreement within the group as to how to proceed and other issues associated with group work generally), by the conclusion of the program many of these issues had been resolved. Indeed the cooperative and supportive nature of such learning was highlighted by the students as a very positive outcome.

Overall, this approach is one that has presented challenges for both lecturers and students, not only in terms of abandoning traditional teaching methods, but also in the functional relationship between students and lecturers within a learning environment. This new approach has undoubtedly promoted the confidence and skills of both lecturers and students to think in scientific ways. By grounding science in problems, it has enhanced the idea of science as a method for finding solutions. Working through problems, which are often multi-faceted, fosters a sense of the possible and by placing the students in that process allows them to apply their own intuitive sense of appropriate and inappropriate methods. Such approaches may well have the potential to produce an inventive, imaginative, and ethically sound generation of science graduates, equipped to meet the salient problems of the future.

At the conclusion of the year we had successfully introduced PBL into our first year delivery and had found that the students had engaged with the problems, had developed confidence in science, had been innovative in their own experimental designs, and had the opportunity to discuss and defend their results. They had worked successfully, and with equity, in supportive groups, had developed positive relationships with us and subsequently felt much more prepared for the second year. It had been a successful year as we further reflected and evaluated our approach. Even so, we decided to make some changes the following year with the new first year students.

A Far Less Successful Case Example: EfS and PBL, Too Much, Too Soon

Encouraged by the success of PBL with our science specialist primary initial teacher education students, we decided to maintain the approach with the new first years. We made the requisite changes relative to the coherence delivery and once again offered the program using a PBL format. However, in the second year that we used this approach it became apparent that the problems the students were asked to address had become known to the lecturers and so the program lost something of its originality and dynamism. We had seen the responses of the previous year’s cohort and were now in a position where they could make suggestions and provide guidance, beyond that of the *informed friend* of the previous year. Consequently, there was a subtle return to a more formal relationship between the lecturers and students; once again, the lecturers knew the answers.

Student feedback was very positive at the conclusion of the module and that alone was not sufficient to elicit a change in delivery. However, the decision was made to review the subject matter of the problems we were presenting to the students. In this instance, given that the call for innovative, creative, and participative learning in EfS (Tilbury & Wortman, 2004) were the very same criteria that we wanted science teachers to both possess and promote, the decision was taken to provide a coherence to the delivery of PBL by providing a context entirely within the area of science of sustainable living (Cutting & Kelly, 2010).

The following provides a brief overview of the planned program for the third year of the PBL approach. There were twelve sessions, with laboratory and class-based sessions of three hours duration. Field trips were generally half or full days. When engaging in the problems given, students did not necessarily follow the typical steps (as described in Table 22.1) and certainly not in the typical order. Additionally, the self-study was more of an experiential nature as they engaged with people and places on a range of field trips. This was to allow for more of a collaborative approach to be taken. As with the previous program, collaborative group work was a key element.

Week 1. Introduction to the module. Familiarization with sessions and assessment. Ice breakers and induction.

Week 2. Learning though growing: This section looked at teaching ecology. The students were given a design based problem around teaching selected basic ecological principles in outdoor settings. In this week, the students visited the Forest Garden Project at the Dartington Estate, Devon, UK. http://www.agroforestry.co.uk/trustinf.html

Forest gardening is a form of environmentally harmonious gardening whereby the structure of the woodland in terms of ground flora, shrub layer, and canopy are mirrored by the crops that are grown amongst the existing flora.

Week 3. A review of the previous field visit followed by a student debate/presentation on the wider problems of learning outside the classroom.

Week 4. Here the students were asked to evaluate two approaches to farming, in a situated case problem. Soil and Soil Science: Prior to 2013 this was a major part of the National Curriculum for Science in England and once again, this was delivered outside on a field trip to a permaculture project, the Landmatters Co-operative, near Totnes, Devon. Here the wider principles of permaculture were introduced. The second half of the day was a visit to a more mainstream ‘organic’ farm that operates extensive, free range grazing and whose soils are independently verified by the UK Soil Association (the organization charged with awarding the *organic* kitemark to farm produce) as pesticide and inorganic fertilizer residue free. Soil samples were collected from both.

Week 5. Soil Science (practical). The soils that were collected the previous week and those sampled from an intensive farm were analyzed for nutrient status as well as texture and structure. The students presented their results in the context of a discussion concerning the evidence for and against different farming techniques. Did the analyses of the soils suggest one form was more effective in terms of soil husbandry? The students were encouraged to be critical of the data presented.

Week 6. Living more sustainably: In recent decades a number of low environmental impact communities have been established within the British countryside (Cook, 2008; Cook & Cutting, 2014). They are singular examples of people in the industrialized world attempting to live very near *One World* standard of resource use (Pickerill & Maxey, 2009; WWF, 2006). This means that they have the level of resource demand that could be sustained by the entire planetary population, and that they are consequently the nearest examples we have in the U.K. of *sustainable living*. They involve groups of people who are living in self-built dwellings unconnected to water mains, drainage, sewerage, gas, or electricity. These increasingly popular *sustainable community* initiatives are populated by young people who often, by their own admission, have no specific skills relating to sustainable living and are therefore, themselves, simply learning through experience. The problems they face include building energy efficiency into structures and shelters, sustainable food production and storage, soil husbandry, power production (in terms of heat and electricity) as well as water supply and waste treatment and discharge. All of these problems are significant in relation to minimizing the environmental impact of these communities and have yet to be resolved in some sites. Investigating potential solutions and improvements would necessarily involve the practical application of science and the potential of these communities for exploring real-world issues in relation to sustainable living was seen as providing both an original means of contextualising PBL in science and an extensive range of problems that students may choose to address.

Week 7. Feedback session on low impact living. The students were asked to stage short group presentations on the specific problems relating to low impact living that they had chosen to concentrate on and how they might use their understanding of science to address such issues. This problem would be best described as a diagnosis-solution problem.

Week 8. Reading week: This was set aside for assessment development and student based work.

Weeks 9 and 10: The final two sessions involved visits to two local ecosystems, both in the nearby Dartmoor National Park, Devon, UK. One was to an internationally famous wetland area that is threatened by climate change and has seen significant drying causing ecological change (Fox Tor Mire). The second was to a woodland area, of international significance, being regarded as the last area of the original post-glacial ‘wildwood’ that once covered the whole of England; a site that is also seeing significant and accelerating ecological change, almost certainly driven by climate change (Wistman's Wood). The problems, best described as diagnosis-solution problems, centred on the promotion of resilience and future management.

Week 11: Assessment presentation: We decided to align the assessment to their professional practice and gave them a project whereby they had been provided with £5000 to *green* the school that they were attached to by professional practice, akin to a situated case problem. This plan was to be presented to the group.

The presentations were the penultimate week of the module. The last session had been set aside for tutorials.

This new cohort were not subject to the same research protocols as previous groups. The research programme had concluded and the only formal feedback that we received was through generic standard module feedback forms which are distributed at the conclusion of all modules as part of the University-wide quality assurance cycle. This cycle requires students to provide feedback on programmes at module level and they are asked to comment their learning experiences. The module leader is then obliged to respond through a written report.

The module had been a genuine attempt to provide an authentic context for issues of sustainability for future science teachers. It had presented a series of problem based learning sessions that had nearly all been in outdoor settings, providing first hand learning experiences, based around very real issues relating to sustainability. As the initial research showing the effectiveness of PBL approaches had been completed, we felt assured that we had provided an original and potentially effective learning experience for the students and that the cohort seemed to be engaging effectively with the approach. However, the students disagreed.

As an experienced team we had become quite assured and indeed, reassured, over the years as feedback on our teaching in these modules had been usually very highly rated. However, in this instance the student returns uniquely recorded dismissive responses. In fact the scores were the lowest we had ever been given. To receive such poor responses then was as difficult as it was challenging, particularly as we had no indication that anything was wrong. In fact, we had the erroneous impression the program had been generally well received. It was only at the very end, when the students were asked to reflect on their learning that these views emerged.

In terms of the negative feedback, the onus on fieldwork was commented on the most, followed by the lack of tangible learning aids such as paper-based handouts and briefing sheets. A number complained about the lack of Powerpoint presentations placed onto the University Virtual Learning Platform, therefore, there were few resources to reflect upon. Furthermore, they could not see the 'relevance of the assessment'. As the field trips were non-assessed as a module component they could not see the relevance of them. The formal summative assessment was in two parts. The first took the form of an essay based on a negotiated title that related to aspects of science and sustainability. The second part was a presentation around how they might *green a school* based on a fictional budget of £5000. Once again, a number struggled to see the relevance of this assignment, not only to the program content, but also to their future role as teachers. They did not see *greening* as involving professional development, but rather only applying to the retrofitting of buildings or alternative power generation.

As luck would have it, there was still one more session set aside, which, given the negative student responses facilitated the arrangement of an open-group discussion that took place the following week. To provide a structure for the session the questions from the feedback sheets were used and the students were provided with the mean scores from the Likert scale responses for each question. The key aspect to emerge here was the relevance of the module to contemporary science teaching. It became apparent that the students had quite prescriptive interpretations on what constituted *science* and that their views on what they perceived as *relevant* were seemingly constrained by the content of the National Curriculum for England. At this early stage of their careers the National Curriculum and how to deliver it appeared disproportionately influential on their perceptions of teaching science in general.

It became apparent as the discussion went on, that the students had been inappropriately prepared for the student centred PBL approach that the module had adopted. During the group discussion it emerged that the group had never thought of sustainability as a mechanism for the delivery of elementary science components of the National Curriculum. Indeed, most of the students had never covered any topic relating to sustainability or sustainable living in their pre-university science courses. This is a generation of future teachers that have been educated throughout the UN Decade of Education for Sustainability, a generation that has grown up with environmental education. They appreciated the importance of sustainability and agreed that it should be part of a curriculum, even part of a science curriculum, however, there was a sense that sustainability issues would be best addressed elsewhere, perhaps outside science and that their understanding of the science of sustainability was generally poor.

There was also some concern that science for sustainability may be too complicated or too political a subject to form the basis for general science teaching and some felt that while science could play a role in the promotion of sustainability that there was a certain amount of 'environmental weariness' related to environmental issues. All students in the cohort however thought teaching science through environmental and/or sustainability issues was worthwhile and that teachers should try harder to apply science to such issues.

Furthermore, many in the group reported that their attitudes to the science of sustainability were undoubtedly affected by the use of PBL. However, although they could see the merit of using this, they were not enthusiastic about using it as an approach in their own future teaching. They continued to see the way they had been taught science as an effective method and there seemed little acknowledged commitment to promote any change.

What we, as a team, learned from this session was that after 13 years of school-based teaching methods, the students had trouble using and learning through new approaches. We felt that such approaches were liberating but the students saw them as intimidating. We thought the science of sustainability was contemporary and engaging but the students saw it as too complicated an issue and largely irrelevant to teaching science in schools.

Despite the small group sizes (in this case 20 each year over the three year period) it was illuminating that the students had independently come to feel this way. Obviously, they had spoken as the module progressed; however, they did not seem to be able to express their concerns to us. This was seen as being something related to the initial relationship between these new students with established university lecturers. The fear of expressing their concerns seemed to be a key factor that we had thought a PBL approach would help overcome.

A Transition to Transition: Preparing Teachers for the Science of Sustainability

Despite this second cohort of students only being one observed instance, our conclusions suggest that we are, as teachers, part of a transition to sustainability, but as such, we may need to manage our teaching methods through an associated transition. This instance warns against too much change too early in programs. It suggests that it may be efficacious to include a transition in teaching and learning styles if we are not to lose students to more accustomed (and even less transformative) approaches, where familiarity provides a form of academic security.

However, this attempt to design a program for potential science teachers, however negative, does provide an opportunity for critical reflection on practice. Students coming into teaching will have preconceived ideas on practice. They will have reflected on their own experiences and will almost certainly have knowledge of contemporary schools through work experience, or school visits. The problem here, of course, is that the contemporary provision is widely regarded as needing urgent reform. Over twenty years ago Milbrath (1992) wrote "We are now training our children to live in a world that cannot be sustained" (p. 188) and although much has changed in the world in twenty years, how much closer are we, in science education in particular, to a curriculum and approach to teaching that is centred on promoting sustainability? How many of our students in science-based initial teacher education courses, and indeed, how many in-service teachers, would see science as an agent of change towards a more sustainable world?

As a result, students coming into teaching will find calls for profound and fundamental change, initially at least, challenging. We certainly needed to understand this in the design of our program and to provide a more familiar framework and approach in the early stages of the first year. The transfer of the program to PBL was successful in that the subject content, rather than the approach, was at least familiar. If we had provided a series of expository lectures around sustainability and science it too might have been, if dull, at least reassuringly familiar for the students. This is not an argument for conservatism in our approach, but rather one that actually concerns the effectiveness of the implementation of more progressive, even radical approaches to teaching science. However, the imposition of fundamentally different pedagogical approaches requires staged implementation.

Furthermore, when we look to sustainability issues in science teaching we too often encourage students to look to science to solve planetary scale problems. Usually, the magnitude of such problems and the complexity of the scientific response can seem abstract and understandingly beyond the experience of many. Applying science at the community level may have the potential to promote low-level practical science as a means of providing solutions to local sustainability problems and provide a context and role for science so that it is part of practical local solutions, rather than a perceived cause of global problems. We adopted this approach here, and yet while the students could appreciate the importance of sustainability issues at the community level and agreed that the local context was more meaningful and manageable, they did not necessarily see it as relevant to science teaching at an elementary level. If we are to engage teachers in this process, who are increasingly confined by National Curricular pressures, we must first be creative ourselves in developing and demonstrating innovative ways in which nationally prescribed learning outcomes and even content descriptors may be met through such approaches. Not to do so will, almost certainly confine EfS to the margins of the curriculum. In this context such creativity must focus not only on our approach to teaching science, for in a sense that is the easy part. The difficulty lies in providing a more progressive pedagogy within the extant and often conservative constraints of government policy and national curricular requirements.

For example, in England in 2000 the National Curriculum Handbook made 29 references to sustainability. The 2008 Primary National Curriculum made 17 references to it. In 2013, despite protestations and petitions at the time, sustainability was removed in terms of direct reference from the primary (elementary) National Curriculum for England (Cutting & Kelly, 2014). Given that one objective was to reduce the curriculum to detail the 'essential knowledge' in the prescribed subjects, the absence of 'sustainability' indicates that the Government in 2013 at least does not recognize it as essential. Even if teachers do, they will need invention and creativity to include EfS as a focus, let alone implement the more fundamental changes in education that have and are being widely called for (Cook et al., 2010; Evans, 2012; Huckle & Sterling, 1996; Orr, 2004).

Certainly PBL has been shown to be an effective tool in increasing student's confidence in scientific methods and in promoting understanding of science concepts and principles (Kelly & Cutting, 2008; Pepper, 2008). When applied, it becomes not only a teaching methodology that promotes understanding, but also one that encourages engagement with people. The students not only model the experience of science research, but also are actively involved in its application. However, what appears to be vital in its adoption in teacher education is the nature of the problems that are set, in relation not only to the skills that students will develop, but also the recognition of the transferability of those skills to professional practice and delivery. PBL may be a highly effective method of promoting good science teaching, fostering creativity, innovation and critical capacity, however, the nature of the issues and the specific skills learned require, at least in the early stages, to be made quite apparent and their relevance to teaching reinforced if students are to remain engaged.

Conclusion

As indicated in the beginning of this chapter, calling for profound changes in education is in some ways the easy part. Developing specific methodologies, along with their implementation and critical evaluation, is somewhat more problematic. In the school sector examples of the implementation of the types of learning styles and approaches that are often called for seem to be ‘special events’ rather than the norm and as soon as national examinations become paramount the temptation is to fall back on more expository methodologies. This is an important point; for are we *teaching* teachers to deliver a curriculum or are we *educating* them about learning as a process? The fact that we need to ask this question demonstrates the ascendancy of the state or other controlling factors in reducing teacher autonomy. At a time when there is a recognized need for innovation and creativity in both science and in education generally, our ability to produce innovative and imaginative teachers who have the capacity to inspire and engage children and young people in the forms of learning that the future will require appears to be hindered by the implementation of educational structures and systems that in turn discourage experimentation and innovation (Cutting & Kelly, 2014). Recently, we asked a group of science education students the question, ‘will science save the world?’ The responses we received were more ambiguous than definitive. If you are involved in teacher education in science, it is an interesting question to ask your students also. If these views are representative of trainee science teachers, the implications for science teaching in the twenty-first century may be profound.

If we are to challenge such pessimistic views of science, it is imperative that we develop a science of sustainability. Such a science would not necessarily require the methodological shift away from reductionism that some have called for (Harding, 2006) as that runs the risk of promoting some form of pseudo-science. However, Sterling (1996) identifies the characteristics of EfS as: contextual, innovative, focused, holistic and human in scale, integrative, process orientated, critical, balanced, systemic and connective, ethical, purposive, and inclusive. None of these exclude science education. Indeed, they would enhance it.

In this chapter we have reported on the relative success of promoting innovation and confidence using PBL approaches in relation to a science teacher education program and our failure, when using the same approach to issues of sustainability. We feel that this reflection on our practice has provided some important insights and invites further analysis and development. Students need a staged transition period especially when progressing directly from school that may well be conservative and expository in the first instance, before becoming more progressive, even radical. Furthermore, with an increasing onus on testing and assessment, any call for change needs to appreciate that it must include changes at a policy level, for it is policy that increasingly constrains educational innovation. The final point is something of a truism for those of us in education. Trying new things sometimes fails and when things go wrong, it can be difficult to accept, both professionally and personally. However, as scientists, we know that the process of experimentation will almost invariably involve negative results. This does not stop us experimenting, but rather helps us adapt and progress. We need to remember this as science educators, for it is only through the dynamism of experiment and change that we can hope to provide teachers and students of the future with the assuredness that will be required to face the future. Our legacy must not be the problems that they will face, but rather the provision of skills and approaches that will provide solutions.

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