

2011

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Recommended Citation

Etherington, Matthew B. (2011) "Investigative Primary Science: A Problem-based Learning Approach," *Australian Journal of Teacher Education*: Vol. 36: Iss. 9, Article 4.

Available at: <http://ro.ecu.edu.au/ajte/vol36/iss9/4>

This Journal Article is posted at Research Online.

<http://ro.ecu.edu.au/ajte/vol36/iss9/4>

Investigative Primary Science: A Problem-based Learning Approach

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Abstract: This study reports on the success of using a problem-based learning approach (PBL) as a pedagogical mode of learning open inquiry science within a traditional four-year undergraduate elementary teacher education program. In 2010, a problem-based learning approach to teaching primary science replaced the traditional content driven syllabus. During the 13 week semester, a cohort of 150 elementary pre-service teachers embarked on a Design and Make project to solve an individually chosen real world problem. Over one week, the pre-service teachers used a problem based mode of learning in conjunction with an open scientific inquiry to showcase individual working models (prototypes) in a public science museum to schools, interested stakeholders and the general public. The PBL mode of teaching science was well suited to the recommended New South Wales Science and Technology K-6 Syllabus Design and Make learning process. The PBL course had a positive impact on the pre-service teachers' motivation to teach science ideas within a real world context. This article reports on the PBL science program and offers recommendations to future instructors of undergraduate science education who may include PBL as a part of their science curriculum.

Introduction

Problem-based learning (PBL) deserves a more prominent place in undergraduate elementary science education for pre-service teachers because the process empowers students and educators to assume responsibility for directing learning, defining and analyzing problems and constructing solutions. Having students work on solutions to problems encountered by stakeholders provides all parties involved in the process with a framework for extending learning opportunities. Problem-based learning guides learners to useful facts and concepts that would not otherwise have been encountered. Finally, problem-based learning helps cultivate strategic learners and problem solvers who can work with the local community as innovators and embracers of productive, progressive education.

This article reports on the first attempt of an undergraduate teacher education program to incorporate a problem-based learning (PBL) mode of teaching at an Australian university. A necessary condition of implementing a PBL mode of learning in science is to have course instructors work together to facilitate rich classroom discussion that maintains rigorous critical inquiry and analysis. This is different to the traditional way of learning science, which often resembles *cookbook* procedures (Hackling, 2005), where students passively follow an established line of inquiry that does not promote nor require problem-solving cognitive skills (Ronis, 2008;

Zoller, 1993). In order to do this well, Evensen and Hmelo recommends that instructors of PBL courses must become learners as well as cognitive coaches (2000).

The problem-based learning process was integrated into EDUC 3726, a compulsory third year 300 level course for undergraduate primary school teachers. The course comprises a total of 39 class hours over 13 weeks, and is available for approximately 150 undergraduates in the second half of every academic year.

Each class had to begin with a Socratic dialogue using *what if* questions and draw on the pre-service teachers' prior knowledge of science ideas to highlight what they knew, what they needed to know and how they might find the missing information. This three step approach to using PBL within a science course was integral to providing a simple, clear and easy to remember structure for the pre-service teachers that would be referred to in every class and at every stage throughout the entire program. The three step method helped students utilize the open-inquiry approach to science that is especially advantageous at the undergraduate level, as it helps learners apply their knowledge and understandings to real-world situations (Ketpichainarong, Paijpan, & Ruenwongsa, 2010). The modest three step approach is shown in Figure 1:

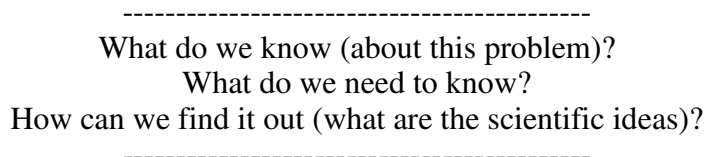


Figure 1: The PBL Approach to Open-inquiry in Science

Description of PBL and Scientific Inquiry

Problem-based learning is a student-centered method of teaching that involves learning through solving unclear but genuine problems. It is a constructivist, student-focused approach that promotes reflection, skills in communication and collaboration, and it requires reflection from multiple perspectives (Yelland, Cope, & Kalantzis, 2008). Students are confronted with real-life scenarios or a problem that requires a solution. The problem is often ill defined and *messy*, so there is no clear path or procedure to follow. Students analyze the problem and the context and apply deductive and inductive processes to understand the problem and find a possible solution or solutions. They use *a priori* and *post priori* knowledge to reason intellectually and are active learners in collaboration with others in small groups (Carroll, Clark, Kane, Sutherland, & Preston, 2009). Learners are required to utilize, wherever possible, the expertise of specialists and community members. The teacher's role is that of facilitator or architect.

The scientific method of inquiry is also a process of investigation. It is not necessarily a linear process, but it is a process. It can start with an observation and a question, after talking with others or after a personal experience. Figure 2 and Figure 3 shows the similarities and differences of the PBL mode of learning with the scientific method of inquiry, as it was used in this study.

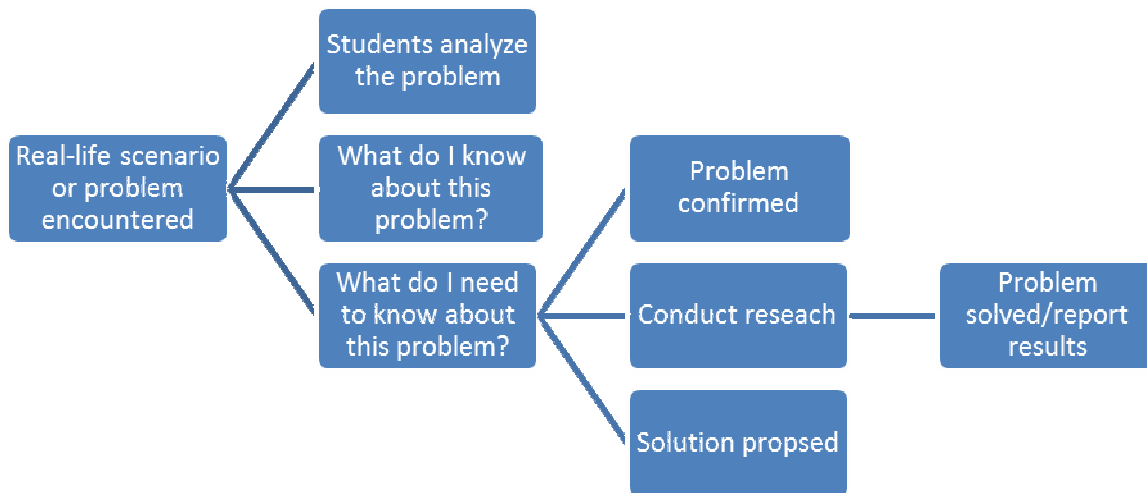


Figure 2: The PBL Mode of Research Conducted

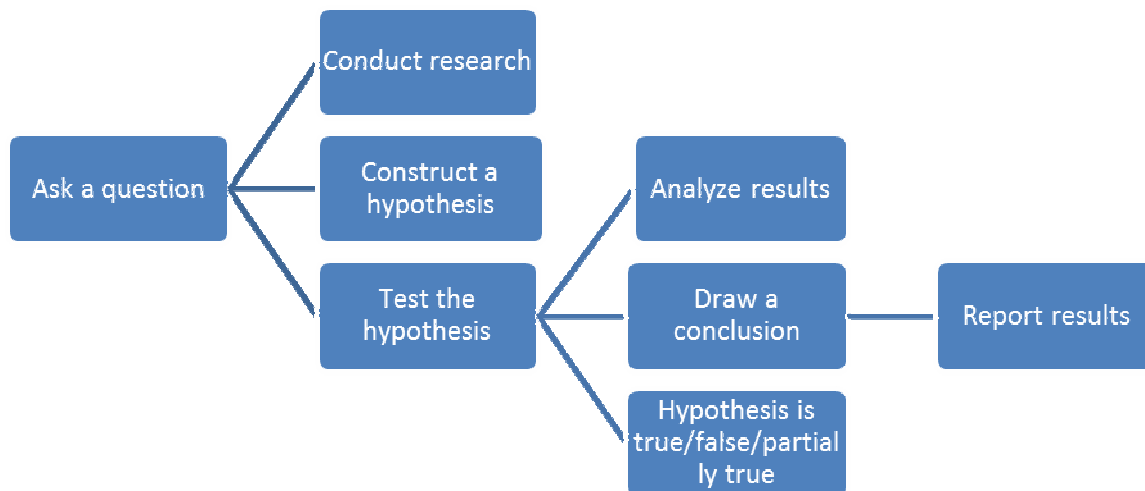


Figure 3: The Scientific Method of Inquiry

The problem-based mode of learning and the scientific method of inquiry share a similar structure of open-ended inquiry, question asking, appeal to prior knowledge, research, hypothesis testing, analysis and reporting the result(s) and/or solution(s). This means that the PBL and the scientific method of inquiry are well-matched approaches to adopt for an open-ended inquiry science program.

Literature Review

What was the rationale for designing a science course for pre-service teachers that drew heavily on the problem-based mode of learning? The course coordinator believed that the pre-service teachers in the ED 3726 course did not necessarily display the same enthusiasm for problem-solving as that expressed by their instructors and much of the learning in the science course was focused on conceptual and factual knowledge. This was particularly true in the teaching and learning content of ED 3726. It was felt that they needed to take a different approach.

Llewellyn (2005) argues that most of the science conducted in schools is of the traditional *cookbook* variety where students passively follow a procedure that resembles a ready-made recipe. As a consequence, the traditional surface approach to learning science has paid little attention to the application of scientific concepts (Selcuk, 2010). Holbrook (2005) notes that the traditional approach to teaching science is more often evident in particular branches of science, such as chemistry laboratory investigations, despite the fact that research indicates that science is unpopular and irrelevant in the eyes of students (Krajcik, Mamlok, & Hug, 2001; Osborne & Collins, 2001). The traditional teaching of science also does not promote higher order cognitive skills (Anderson, Anderson, Varanka-Martin, Romagnano, Bielenberg, Flory, Miera, & Whitworth, 1992; Hackling, 2005; Ronis, 2008; Zoller, 1993). This has led to gaps between students' and teachers' expectations of science (Sahin & Yorek, 2009; Kain, 2003; Yager & Weld, 2000). Students become passive followers of teachers' instructions and worksheets on structured practical exercises, and have found it difficult to be autonomous decision makers (Hackling, 2005). It appears that the pedagogy of science is not changing, because teachers are afraid of the classroom management involved and the facilitation of critical discussion and need guidance (Ngeow & Kong, 2001; Goodnough, 2003).

One way to implement change is to better reflect the demands of 21st century scientific investigation, and this is made possible by using a mode of open-inquiry called problem-based learning (PBL). This is a method of inquiry that requires learners to be real-life problem solvers, involved in real-world open-ended problem solving. To deal with the issues of control while using an open-ended process of scientific inquiry, the following levels of inquiry were utilized by the pre-service teachers taking this ED 3726 course. Table 1 illustrates the different levels of openness of inquiry in laboratory activities:

<u>Level</u>	<u>Problem</u>	<u>Equipment</u>	<u>Procedure</u>	<u>Answer</u>	<u>Common name</u>
0	Given	Given	Given	Given	Verification
1	Given	Given	Given	Open	Guided inquiry
2a	Given	Given	Open	Open	Open guided inquiry
2b	Given	Open	Open	Open	Open guided inquiry
3	Open	Open	Open	Open	Open inquiry

Table 1: Levels of Openness of Inquiry in Laboratory Activities (Hegarty-Hazel, 1986, as cited in Hackling, 2005)

In this study, the PBL mode of learning science drew on the Level 3 of openness of inquiry, as the Level 3 of openness of inquiry was most appropriate for the science course. Research suggests that when the problem, equipment, procedure and answer are open, the implementation of problem-based active learning in science education positively affects students' academic achievement, conceptual development and attitudes towards a science course (Tandogan & Orhan, 2007). It is also a brain-compatible methodology meaning that the teacher alternates between different methods of presentations, combining different intelligences and providing numerous hands-on experiences and activities (Ronis, 2008). This has a positive focus on the interplay of science, technology and society, particularly when this involves relevant, authentic and current controversial local issues, public policy-making concerns and global problems (Graber, 2002; Eilks, 2000; Eilks, Marks, & Feierabend, 2008; Marks & Eilks, 2009). It is a realistic approach to the scientific investigation of highly complex and chaotic systems (human and nature) where certain patterns lie and are open to discovery (Kellert, 1993; Wheatley, 1999; Trygstad, 1997). The Level 3 of openness of inquiry requires students to adopt active learning strategies and become more self-directed in their learning (Ngeow & Kong, 2001). It also promotes scientific proficiency and literacy, particularly when dealing with scientific concepts, the nature of science and the relationships between science and technology (Duch, 1995). This approach provides opportunities to connect theory to practice (Schwartz, Barnsford, & Sears, 2005) and deals successfully with types of reasoning and affective actions, such as Bloom's taxonomy of cognitive levels and affective levels (Liu, 2009). Level 3 of openness of inquiry encourages students to take a deep approach to learning and increases their interest, a component of attitude (Selcuk, 2010). Finally, Level 3 openness of inquiry exposes the error in seeing science education as unproblematic, universal, value free and a one-way flow of objective information from the knowledgeable to the less knowledgeable (Roberts, 2007). It is for these reasons that Level 3 openness of inquiry was assimilated into the 13 week PBL science and technology course for undergraduate pre-service teachers. In fact, there is a substantial move to increase problem solving in all school curricula. Well over 10 years ago, the National Academy of Sciences (1997, par.10) recognized the following:

The standards [K-12 curriculum] point toward a kind of teaching different from that common in many K-12 classrooms today. The teacher serves as a coach for the development of skills, such as the ability to engage in problem-solving and inquiry. The students engage in collaborative learning that includes the synthesis and integration of different types of data and analysis, and communicating the results. The benefit of learning skills as opposed to only learning knowledge—learning *how* as opposed to learning *that*—is best exemplified in sports and music. It is difficult to imagine teaching basketball or piano-playing by lecture alone, and it should be just as difficult in the case of science and mathematics.

Regrettably, there is marginal evidence of learning *how* in the traditional ED 3726 undergraduate science course presently available for teachers. Yet research on the benefits of using the open-inquiry method of learning science provides a convincing case for learning *how* (Hackling, 2005). To be highly engaged in the learning and teaching of science as a mode of learning, PBL provides a much needed alternative experience for learning to teach primary science. By solving authentic problems, learners become more accountable for their learning and are able to connect theory to practice (see Schwartz, Bamsford, & Sears, 2005). They become reflective practitioners (see Schon, 1987) who are required to dialogue in different contexts. This is important because studies of teacher education show that theoretical learning and its practical application are often disconnected from the realities of a teachers' work (Hoban, 2005). In spite of the fact that the PBL method has proved beneficial for improving students' conceptual

learning, knowledge, skills and values in science, as far as it is known, it has not been used throughout the pre-service teachers' pre-service education in science. It is for this reason that the PBL course referred to in this article was built on the current recommendations that PBL be integrated into teacher education. The instructors hope to make a contribution to the gap in the literature concerning the trials and tribulations of those who have trialed PBL within an undergraduate science course for elementary teacher education students.

Description of the PBL Science Course Project

The PBL science course was engineered by the course coordinator to be a public demonstration of scientific investigations. The pre-service teachers were required to have a working knowledge of the scientific concepts that could explain the rationale for a working prototype. The weekly, one-hour mass lectures proved to be an important venue for delivering varied examples of how to use the PBL mode of learning (see figure 2) and a scientific model (see figure 3). The two-hour tutorials provided learners with weekly on-going discussion and sharing. Most importantly, the PBL course proved to be advantageous for using scientific discourse in combination with scientific investigations.

The prescribed learning outcome for the ED 3726 science course included the following: "Students must develop the ability to conduct science investigations using prior knowledge and experiences, along with treating science investigations as problem solving." Two of the prescribed New South Wales state curricula outcomes for the elementary science course encompassed those set by the *Board of Studies, New South Wales Science and Technology K-6 Syllabus and Support Document* (1991). These outcomes are as follows: 1) "teachers are to engage their school students in the process of investigating, the process of designing and making and the use of technology" (p.23); and 2): "teachers are to engage school students in the process of designing and making which requires learners to use resources to assemble or construct products, systems or environments which may result in a model and may extend to small scale mass production" (p.23).

A third prescribed outcome is taken from the New South Wales Institute of Teachers (2010). According to the *Professional Teaching Standards: Element 3: 3.4.1*, teachers should "use high-level practical and theoretical knowledge to establish challenging learning goals to inform teaching and learning programs for all students" (p.3).

A fourth and fifth prescribed learning outcomes derive from the ED3726 Science and Technology 2 course itself. The fourth outcome requires trainee teachers to "demonstrate the capacity to work effectively with external professionals, and community-based personnel to enhance student learning opportunities in science." The fifth outcome encourages teachers to "develop strategies and resources for addressing specific needs in assessment and evaluation techniques, suitable for Science and Technology."

Taken together, these five prescribed learning outcomes provide the framework for a natural inclusion of PBL as a mode of teaching science in combination with an open scientific inquiry approach that ensures pre-service teachers are involved in ongoing scientific investigation and scientific reflection. By scientific reflection we mean analytic observations, both qualitative and quantitative, and the synthesis of findings. The outcomes drive the scientific processes that are contingent on finding a solution to a real-life authentic problem using scientific principles.

The idea of using PBL as a mode of learning in a third-year undergraduate science course for elementary teachers came about because PBL requires learners to be involved in authentic

practices. Students must diagnose a problem in the same situation as an expert would, such as by interviewing and offering solutions to key players. The course coordinator wanted the pre-service teachers to address real-world issues and then make their discoveries and results public to key players in the local community. This was a first for teacher education at the university. The PBL approach for solving real-world problems was advantageous for science education in particular and teacher education in general. Opening university *doors* to the critique of school teachers, school children, the public and professional stakeholders made the course content more accountable and transparent. We believe this is a breakthrough for moving from the traditional content-driven course curriculum to a more transparent, pragmatic curriculum that is open to public scrutiny.

The desired outcomes of the *NSW Board of Studies, K-6 Science and Technology Syllabus* (1991) include the process of investigating, the process of designing and making and the use of technology. This requires learners to use resources to assemble or construct products, systems or environments. The syllabus suggests that a model may result in and could extend to small scale mass production.

The pre-service teachers were instructed to design innovations that could be made from inexpensive materials and be presented as a working demonstration. The invention was to display exhibit reliability and attempt to solve an ill-structured problem using scientific principles. The prototypes were individually designed and constructed by the pre-service teachers with the knowledge and understanding that they were to *go public* with their invention at a science fair and at the local science museum. The pre-service teachers understood that their inventions could include everything from domestic appliances to products for the workplace, from leisure and rural- to urban-based ideas. The pre-service teachers were informed that they were to be fully informed about the scientific principles and procedures that gave support to their inventions. They should be more than just prepared to answer challenging questions from interested stakeholders.

One of the outcomes of the *NSW Board of Studies, K-6 Science and Technology Syllabus* requires that teachers investigate small-scale mass production. However, the pre-service teachers were also exposed to information that was not a necessary part of the science curriculum. For example, in the first class, the pre-service teachers and instructors discovered information relating to a patent that can be granted to an inventor if an invention is "new" (i.e., how the invention works is not already public knowledge). This means that if a demonstration of the invention is given in public before steps are taken to register the patent, the inventor would not be able to obtain a valid patent. This led to a series of further inquiries encouraged by the pre-service teachers themselves. The pre-service teachers investigated the mechanism for protecting an inventor's intellectual property, and David—the pre-service teacher who designed alphanumeric recognition letters to solve literacy and numeracy problems for children—began the process of applying for a patent before presenting his working prototype in public at the museum.

The Application of PBL

Science investigations and PBL use similar methods and skills for problem solving. Drawing on the suggestions by Wetzel (2008), we decided to revise our former program by using some of the strategies used for conducting science investigations. To engage directly with science ideas, the weekly PBL tutorials focused on teaching the following science skills and drew heavily on the following Wetzel recommendations:

- Ask Questions—Have students reflect on prior knowledge and experiences to develop their questions as they analyze the problem at hand.
- Propose Hypothesis—Develop a hypothesis based on the results of answers to questions and prior knowledge and experiences.
- Isolate and Control Variables—Design a fair test. Work with one independent and one dependent variable at a time to avoid confusion and erroneous data. Make sure students identify variables that do not change throughout the investigation. Control variables.
- Keep Records—Accurately record answers to questions for comparison with collected data.
- Reason by Analogy—Compare with findings from similar investigations.
- Model—Use diagrams, concept maps, graphs, pictures, physical models and other means to explain an investigation's findings.

Science is about doing, so the PBL approach to teaching science requires students and teachers to be inquisitive and autonomous learners. This works well with students, as young people are naturally active, curious and exploring. As Goodrum, Hackling and Rennie (2001) maintain, primary students enjoy science when it is student-centered, active and focused on investigation. The instructors of this course believed that to make learning science truly student-centered, relating it to real-life problems and possible solutions, they needed to design a science course that would prepare these future teachers to think critically, identify and use appropriate resources and be creativity. It was precisely because problem-based learning could be all these things that we decided to adopt it as the main method of teaching and learning science.

The Assessment Rubric

Although PBL addresses messy, ill-structured problems, the assessment was designed to identify a student's areas of achievement and weakness. For clarity and structure, it was important to provide the students with a generic scoring rubric adapted to meet the different learning aspects of PBL. The purpose of the scoring rubric was to act as both a self-assessment and peer-assessment so that the pre-service teachers could monitor and evaluate their performance and self-regulate both their own learning and that of their colleagues. This was a working, 13-week course prototype solving a real-world problem and presenting the solution to a public audience. This was also to be assessment *as* learning, because it occurred during and at the end of each unit of work. To make this most effective, we used the five point PBL rubric recommended by Ronis (2008) for the assessment. This allowed for both self-and peer-assessment as well as instructor assessment at the end of the unit of work as a summative assessment. The rubric is shown in Table 2:

Criteria	Novice = 1	Basic = 2	Proficient = 3	Advanced = 4
1. Research quality	Numerous inaccuracies, with little or any detail.	Inconsistent accuracy, but some level of detail.	Accurate and competent, with relevant detail.	Highly accurate and sophisticated, with explicit detail.
2. Strategies used	At least one acceptable strategy attempted.	At least one acceptable strategy correctly applied.	Several high-quality strategies applied.	Numerous complex and sophisticated strategies applied.
3. Organization of research	Confusing and clumsy organization.	Simple but acceptable organization.	Reflective organization demonstrates solid planning.	Intuitive organization displays complex and perceptive thinking.
4. Communication	Ineffective and vague.	Superficial quality. May lead to some confusion.	Competent and effective communication.	Precise and nuanced communication shows high level of sophistication.
5. Comprehension	Little, if any, understanding demonstrated.	Limited, superficial understanding demonstrated.	Demonstrations of accurate and thoughtful understanding.	Numerous demonstrations of profound and perceptive understandings.

Table 2: Problem-Based Learning Evaluation Rubric

Source: Ronis, D. L. (2008). *Problem-based learning for math and science: Integrating inquiry and the Internet*. California: Corwin Press.

The scoring rubric provided a measure for both the course instructors and the pre-service teachers. The pre-service teachers used the rubric for on-going self-assessment during the 13 week course and the identical rubric was used by the instructors at the end of the course as a summative assessment. The peer assessment occurred during class time, with every pre-service teacher giving a brief 10 minute individual presentation two weeks before the first public presentation. Each class member scored the presenters based on the five point criteria. The identical rubric was used by the instructors at the completion of the course, with each presenter giving one final presentation to the class. This meant that all the pre-service teachers gave a total of three presentations during the 13 week course. The assessment included a culmination of three scores gained from three assessments: one self-assessment, one peer-assessment and one instructor-assessment.

PBL Pilot Prototype Results

A curriculum requirement for the Bachelor of Education degree is successful completion of the undergraduate course ED 3726 Science and Technology 2. There were 150 third-year pre-service teachers enrolled in ED 3726 when we embarked on this PBL pilot. We familiarized the students with the revised 13 week science and technology strand Design and Make. The Design and Make strand is one of the core learning processes found in the *Board of Studies, Science and Technology K-6 Syllabus* (1991). This learning process requires teachers to “identify [student] needs and propose practical means by which these needs can be addressed” (p. 36).

The pre-service teachers were instructed that this science course would require them to individually solve a real-world, ill-structured problem using a mode of learning called Problem-based learning (PBL). This mode of learning science would include an emphasis on the process of “design and make,” with each individual ultimately constructing a working prototype to resolve a personal, local or global problem. The PBL prototype would advance over 13 weeks and, by way of the scientific method of open-inquiry (see Figure 1), result in a public showcasing of the pre-service teachers’ scientific prototype inventions at two public venues.

First, the university would provide a platform to host a science fair where all 150 pre-service teachers would showcase and give demonstrations of their inventions to three visiting primary schools and be open to the public and interested stakeholders. The presentations would be repeated one week later at a local science museum, where public and professional stakeholders would once again be invited to observe and question the quality of the research and inventions. The pre-service teachers were arranged in groups of 25 and given a day from Monday to Thursday to showcase their prototypes. The museum wanted this event to blend in with its established science displays, so the event was open to visiting school children, teachers, professional stakeholders and the general visiting public.

The museum took the initiative and invited a variety of former scientists, high school and elementary school teachers, engineers, architects and medical practitioners to the PBL presentations. However, the attendance of these groups was already guaranteed because all the stakeholders were represented by existing employees at the museum. Many of the pre-service teachers had conveyed to their course instructors that particular questions asked and comments given by the visiting school students and other inquirers at the science fair the previous week had been extremely useful for revisiting science concepts related to their inventions. The university science fair had also been a positive experience for the pre-service teachers because the questions and comments given by the school children and their teachers had given a greater sense of the pre-service teachers’ knowledge and grounded their inventions in relation to scientific principles. Because the science fair had been heralded as a problem-based method of learning and teaching science weeks prior to the event, the questioners were more appreciative of what the pre-service teachers had achieved. Most of the questions were thus geared to the process of PBL in relation to the prototype, which had manifested because of the open-ended inquiry into a particular problem.

The Science Fair

As a lead up to the science museum exhibition, the university hosted a one-day science fair on the grounds of the university campus. This experience proved to be significant for both the course instructors and the pre-service teachers. For the course instructors, attendees' observations at the science fair and verbal and written comments solicited from school children and teachers provided valuable information about the PBL process. For the pre-service teachers, the fair provided a valuable self-assessment of their scientific knowledge and an opportunity to communicate that knowledge to others.

On the day of the fair, every school and teacher was issued with a scoring rubric that was used for a self/peer formative assessment and instructor summative assessment (see Table 2). The course coordinator invited a number of local schools to the fair, and a total of four schools and approximately 300 visiting school students attended the fair. Besides having the scoring rubric, at the request of their teachers the school students came prepared with a list of additional scientific questions for the pre-service teachers to answer about their models. The visiting schools had been sent a list of the 150 inventions, together with an explanation of each. To prepare for the science fair and to make it an educational experience, the schools were given four weeks to organize and formulate questions in their science classes. This way, the science fair visit was integrated into their science curriculum.

The pre-service teachers recalled their experience of the day in a debriefing session in their classes the week after the fair. Many of them reported that the school children had asked them to verify their results and explain the science that grounded their prototypes. This question/answer format of the science fair became one of the most challenging and positive aspects for the pre-service teachers. As a consequence, many of the pre-service teachers were required to re-invent their models and, in particular, gain additional scientific knowledge about their prototype. In one pre-service teacher's journal, she recorded how she hadn't fully understood the scientific procedures that lay behind her invention: "I was asked to give the scientific procedures behind (*sic*) my invention.—I didn't really know what was meant by *principle*.—I was then asked to give an example of a comparison I had made with a similar invention. I knew I was being asked to explain the fair tests that I had conducted prior to my invention, but I couldn't because I hadn't done that."

In preparation for the science museum presentation the following week, the pre-service teachers continued to conduct research and persist in developing a greater depth of understanding to support the science ideas and principles that had inspired them to construct their particular models. Because of their experience with the visiting school students at the science fair, many of the pre-service teachers revised their research methods, referring back to the PBL and scientific mode of inquiry (see Figure 2 and 3) and many chose to represent their procedures and data on graphs displayed on posters.

At the Science Museum

As part of the PBL pilot group—staggered over four weekdays, from 10:00 a.m. to 2:30 p.m.—150 elementary pre-service teachers individually prepared data display poster boards and arranged demonstrations of their working prototypes to show at the local science museum. Each pre-service teacher prepared to present a variety of facts, processes, scientific ideas and the stages of construction.

The prototypes were designed by the pre-service teachers, both in class and at home, over the duration of the 13 week science course. The event had gained media interest, receiving coverage in local newspapers, on local radio and via a web link located on the main website of the museum. Because of the interdisciplinary nature of the PBL mode of learning, it was expected that a variety of interested stakeholders would attend. Among others, the museum had confirmed that during the daily presentations they had invited architects, designers, engineers, scientists and the media. These were *real* stakeholders who could offer specialized feedback to the pre-service teachers regarding science concepts, research quality, originality, design qualities and even on manufacturing potential and the critical *need* factors.

Four Pre-service Teachers Share their Experience

David: Science Idea—Key Stimuli and Two Dimensional Patterns

One education student, David, used the PBL/science prototype project as an opportunity to solve a common literacy and numeracy problem among some students and adults: deciphering between letters and numbers that look similar (alphanumeric recognition). As David continued to research and share his research weekly with his peers in class, we were exposed to deep and rich discussions of scientific phenomena, such as spoken and written language, visual perception and object recognition; two dimensional patterns relating to behaviour in humans under the control of key stimuli; and the effect of size and angle of patterns in regards to object recognition:

I did some intense research and found that alphanumeric recognition is a problem throughout our community. I took it upon myself to design a child-friendly and tactile model of letters and numbers that have a similar shape, allowing the children to physically recognize, through using the model, how the shapes of these letters and numbers can be similar. Students get to physically move wooden models around to create different letters, such as a d and p, and visually learn the difference. I think my invention is a great learning model for primary school students and is a really fun way to teach them alphanumeric recognition. The principle of stimuli, angle, size and certain patterns became very evident in my research leading to the final invention.

Cathy: Science Idea—Movement and Force

Many other innovations included a consistent investigation of scientific ideas. For example, Cathy, who designed an aqua net to reduce childhood drowning, investigated the theory of movement and force to design an aqua net to save lives:

I looked at Newton's concept of movement and found that reaction force, for example, if you stand on a trampoline, it stretches. I took this principle and considered how to make a net that would not suffer from the reaction force of a child who falls into an open pool. A force occurs in an action-reaction. So I needed to use material to design a net that would push back up on you in the event of a person falling into a pool. In the event of a child drowning in a pool, the child falls onto the aqua net and is pushed back upwards against gravity. The net would be the contact force and be made from traversed synthetic plastic rope. As a result, the child is supported at the surface of the water. This will provide a safety barrier and the child will be able use the net to crawl safely to the side.

This experience provided Cathy with tactile experiences of forces acting on a floating object (the aqua net). She was exposed to important concepts such as the *up thrust of water*, the

weight force down and action-reaction. The opportunity and experience to identify forces and the direction in which they acted were real-life principles and ideas that she discovered and shared weekly with her peers in class and, eventually, with interested audiences at two public venues.

Joanne: Science Idea—Substance and Physical Change

Joanne's design addressed the idea of physical change and how the visual demands of colour can result in visual errors of pattern and motion. Using the idea of a reflective tennis ball, Joanne studied the ideas of substance, properties and cause and effect. The substance was the tennis ball and the property was the colour. Joanne trialed a number of different colours of paint over one week at the same time every evening as a fair test to determine the effect of colour, pattern and motion on a tennis ball.

More and more people are playing tennis in the evenings. I designed a ball that can be seen clearly at night. After many failed attempts at applying a fluid substance that is used in glow sticks, I found a glow-in-the-dark, oil-based paint that could be applied to a tennis ball. The oil paint is long glowing and actually is good for the environment because it recharges its glowing ability through exposure to light. This was helpful because this new substance—the paint—from a scientific perspective, has an identity that is independent of the object—the ball. I found that the type of substance one uses is important because substances can change into new substances when they chemically react with other substances. I found that this would be important for choosing a type of paint that is used, for example, by the fishing and safety industry for notifications, warnings and providing information.

John: Science Idea—Movement, Force and Kinetic Energy

John's idea for a prototype drew on the idea of movement, force and kinetic energy. This idea evolved into the form of a wheelchair see-saw for disabled children. He explains the process:

I designed and built a wheelchair accessible see-saw for children. I found that hollow things tend to roll further because they have less weight and there is less friction, and things with less weight seem to go further. Considering the principles of kinetic energy, I designed a wheelchair that was very lightweight and a see-saw that used potential energy stored in a steel spring at both ends, which acts to raise one end of the see-saw into the air. Energy is being transferred from one location to another. I used a combination of wood and steel to build the see-saw. You simply roll the wheelchair over the see-saw and attach the steel framed lock that extends around the sitting post.

Conclusions

This study reports on the experience of implementing a PBL approach to the teaching and learning of science for third year primary pre-service teachers. The pre-service teachers used a Level 3, problem-based learning methodology to design and build a working prototype to solve a chosen real life problem. The problem-based learning approach was successful in terms of fulfilling the ED 3726 course; *NSW Board of Studies, Science and Technology K-6*; and the *NSW*

Institute of Teachers learning outcomes. These outcomes all required that teachers use theoretical and practical knowledge, work with external professionals and the community and develop strategies to assess and evaluate a variety of resources.

The NSW Institute of Teachers requires all graduating teachers to use high-level practical and theoretical knowledge to establish challenging learning goals to inform teaching and learning programs for students (NSW Institute for Teachers, 2010). The Institute also requires graduating teachers to demonstrate the capacity to work effectively with external professionals and community-based personnel. This is to enhance learning opportunities in science and the development of strategies and resources for addressing specific needs in assessment and evaluation techniques (ED3726 Science and Technology Syllabus, 2010). The course coordinator and course instructors believed that these were all achievable goals with the inclusion of a PBL mode of teaching science. When combined with the scientific method of inquiry, the open-inquiry PBL approach ensured that pre-service teachers were involved in ongoing, authentic scientific reflection.

Experience with science ideas alone is insufficient for a person to develop as scientifically literate (Skamp, 2004). It is when these learners considered how scientists might approach questions and problems that they began to research and gather significant evidence for their inventions that would be acceptable to others. There were two research questions that the instructors raised in every class meeting that we believe helped give the pre-service teachers greater focus: 1) What will I have to think about doing to collect data to help me solve my problem? and 2) What will I have to think about doing to make sure my data is believable to myself and others (see Skamp, 2004, p. 51)? When the pre-service teachers were given the opportunity to showcase their inventions to a real audience of interested stakeholders they eagerly took the role of open-inquirer. They began to perceive themselves as having authority to talk about certain science ideas and possessed intellectual ownership of their innovations, much as a researcher gains expertise in a chosen area.

At the conclusion of the 13 week semester, the PBL approach to teaching science was deemed significant by the pre-service teachers, course instructors, museum co-coordinator and those who attended the presentations. However, what was most central to the course was the self-evaluation completed by the course instructors and, most importantly, the pre-service teachers at the commencement of the course and again at the completion of the 13 weeks. The debriefing evoked a positive response by the pre-service teachers and course instructors. The point here is not that a positive response is an objective measurement for success or even progress, rather what it showed is a notable improvement with the pre-service teachers' attitudes towards science. Science became *alive*, as one pre-service teacher noted. The higher value they now placed on teaching science was compatible with the positive recommendations of Selcuk (2010) for instructors to consider combining a PBL mode of learning with the teaching of science. In addition, a higher value placed on science parallels Bloom's taxonomy of the interplay of the cognitive and the affective domains of learning (see Liu, 2009). The increased motivation to be a reflective and competent teacher of science is a possibility worth pursuing.

The Board of Studies Science and Technology K-6 Syllabus (1991) requires teachers to "identify needs and propose practical means by which these needs can be addressed" (p. 36). Because the course aimed to involve pre-service teachers with identifying needs and solving meaningful problems, their perceptions of science as theory to practice were challenged. In one sense, they were confronted with a personal challenge in a quest for necessary knowledge and the application of that knowledge for possible solutions, and this goal in itself required so much more than collecting facts to be memorized. It required an application of acquired information to become competent problem-solvers as well as self-directed learners. They had to sort out useful

information from useless, so all the best research strategies needed to be applied. This proved to be one of the ultimate challenges of the course, mainly because the pre-service teachers already measured themselves as competent researchers. They were familiar with the Internet and technology in general. However, it was in the taxonomy of quality information from the less reputable that proved to be one of the greatest challenges for the pre-service teachers.

The results suggest that schools of education should adopt a similar problem-based learning methodology to support a scientific method of inquiry and to increase the motivation and confidence of pre-service teachers. If prospective teachers are to develop effective thinking skills in science it behooves teacher education to include curriculum courses in problem-based learning.

Lessons Learned

One question that ought to be addressed by university faculty is how best to assist pre-service teachers to work with ill-structured, complex and messy problem-solving environments in science. This is important because we found that students are far more used to having precise limitations on learning and solutions. However, we suggest that this is not necessarily a problem. Students are by their very nature already curious and motivated problem solvers. They bring to the classroom a natural awareness and motivation to solve problems. However, since they primarily experience content-driven, structured learning in science, open inquiry skills are rarely, if ever, called upon or exercised. When students were first required to engage in critical thinking, we found they lacked confidence and, in some cases, became antagonistic to the unstructured PBL approach. Yet, as Trygestad (1997) points out, we should not give up, because authentic learning is often chaotic and inexact and the scientific approach requires continual evaluation in the midst of disorder.

As instructors in science, we must help pre-service teachers move away from the checklist mentality for completing work tasks to an appreciation that learning is not always in the end product but often in the process, the questions and in the unending discoveries made possible through the ongoing research. As Fleer & Robbins (2003) have observed, authentic learning is a dynamic and transformative process and not a specific end result. Because students have minimal experience with open inquiry process learning such as PBL, we recommend additional time be given for discussion and questions at the commencement of any open inquiry course. If one is to gain a sense of comfort with a PBL approach in science, time is needed to unlearn much of what has been taught at school.

Although PBL does not utilize a particular approach to learning science, we found that the PBL mode of learning (see Figure 2) and the scientific method of inquiry (see Figure 3) helped to define, frame and recognize what is required of an open-inquiry learner. PBL learners need time to *grieve* as they move from being passive learners in science to active *doers*. This means that time is needed in every class to discuss challenges and, most importantly, to analyze, synthesize, recommend and continually critique each other's work-in-progress. This was fundamental to the success of the PBL course we developed for this pilot.

Recommendations for Further Study

This study builds on the realities concerning the implementation of PBL as a collaborative process that elicits scientific experiences with meaningful problems. This study

sought to create a public *stage* for 150 pre-service teachers to showcase and promote their scientific literacy to the local community and interested stakeholders. In this way, it helped grant future teachers of science with the opportunity to become significant stakeholders in solving real-life problems (see Kracjik et al., 2001; Osborne & Collins, 2001). Thus, individual accountability for scientific learning is increased and pre-service teachers become more self-directed in their learning (Yager & Weld, 2000). The pre-service teachers are increasingly confident in exhibiting their scientific literacy to the general public, and these results are consistent with research done by Graber (2002); Eilks (2000); Eilks, Marks and Feierabend (2008); Marks and Eilks (2009); and Selcuk (2010).

This study is innovative, as it activates the process of PBL as a legitimate mode of learning and teaching science within the context of a public science museum. It is hoped that, because of this study, sufficient direction and incentive will be given to future instructors of elementary PBL science courses for teachers. Therefore, this study recommends PBL as a mode of learning to tackle real-life authentic problems and as a good way to promote science.

Important to note is that many of the pre-service teachers had perceived themselves as confident teachers in the humanities, but less so in the sciences. While elementary teachers may be well prepared to instruct learners, they may not be well prepared for educating students to apply scientific knowledge (Ngeow & Kong, 2001; Goodnough, 2003). Therefore, it is recommended that course coordinators take the lead in helping to integrate the sciences with the humanities so that the relationship and possible application of the two disciplines are bridged. This supports previous recommendations for an integrated cross-disciplinary education program for teachers (see Liu, 2009). This is especially important for elementary curriculum that has already been established as cross-disciplinary. A PBL mode of learning science helps achieve this reality.

This study reports on an innovative approach for implementing PBL in a science course for elementary teacher education and discusses the lessons learned. The instructors of ED 3726 Science and Technology 2 delivered and experienced two diverse PBL science courses for primary teachers. In the first attempt, they did not define the purpose for doing PBL, the procedures that would be used, the different expectations that PBL has on the role of instructors as *cognitive coaches*, as noted by Ronis (2008), and the different realities of being active learners that PBL requires (see Ngeow & Kong, 2001). These changes of role should be discussed at the commencement of the first PBL class. Without such inclusions, attempts at integrating science with PBL may be unsuccessful. Comparable to Haberman (1991) we suggest that the greatest challenge for PBL instructors of primary science will be breaking out of the content-driven traditional mode of curricula so as to help their pre-service teachers do the same. In many classrooms, students have been trained to think that problem solving is getting the one right answer, similarly shown by Wilson et al. (1993), but as this study confirms, PBL takes time, patience and practice to understand otherwise (Kain, 2003).

Secondly, although the instructor is a facilitator throughout the PBL process the instructor is always active in the process (Tan, 2004). It is vital that instructors consider themselves as actively involved *cognitive-coaches*—as learners of learners—and continually facilitate self-reflection (Evensen & Hmelo, 2000). They need to spend adequate time at the beginning of the course to ask and model pertinent *what if* questions and teach and monitor fundamentals such as effective group discussion, research strategies, resolving conflicts, revising problems and solutions and generating analytical questions.

The PBL science program did not alter the prescribed outcomes located in the *Board of Studies, Science and Technology K- 6 Syllabus and Support Document* (1991). These guidelines support the application of scientific principles and the interaction of science with community,

professional stakeholders, teachers and, of course, the students themselves. The syllabus and PBL mode of learning are conducive to the epistemological interplay of prior knowledge with the new and the public communication and application of this knowledge to interested others.

At the same time, we suggest that the PBL mode of learning science be used to integrate the scientific principles *behind* the problem solving. We found that once students were able to articulate the principles underlying the science and understood how principles apply to their solutions, they were more confident in explaining their PBL prototypes to a public audience. What we mean by principles is best encapsulated in the example of natural and human complex systems. The principle of complexity lends itself to an accurate understanding of complex systems (Trygstad, 1997) and PBL has a natural attraction to complex scientific problems, as noted earlier by Kellert (1993) and Wheatley (1999). Because there could be a multiplicity of solutions to any given problem, students should be encouraged to thoroughly investigate the underlying principles that govern systems. This simply means that course instructors make continual reference to the importance of *sequence* or *patterns* that are to be observed. Certain principles have to be mastered first before it becomes possible to learn other things, such as solutions.

We would also endorse further study of using self-assessment, peer-assessment and instructor assessment for PBL in science courses. We believe that the recommendations of Allen, Duch and Groh (1996), who proposed that peer assessment could comprise up to 10 percent of a student's final grade, are worthy for further investigation. As a PBL practitioner, Ronis (2008) suggests that instructors should employ a variety of assessment strategies in their PBL courses, such as "scoring rubrics, portfolios, student performances and presentations and journals" (p.96). For the pre-service teachers learning how to assess is enhanced because they are required to apply theory to practice; however, the challenge is for instructors to individualize a somewhat subjective culmination of assessment to comply with course curricula and prescribed learning outcomes.

The PBL/science combination was appropriate to students' personal and social needs, building upon an *a priori* and *post priori* knowledge, as suggested by Carroll et al. (2009). The pre-service teachers have an expectation that courses will give them the practical tools to teach. The PBL science course provides a theory to practice learning experience (see Schwartz et al., 2005; Kellert, 1993; & Wheatley, 1999) that can be easily transferred to the classroom and beyond. Moreover, the open-ended inquiry mode of learning science creates a space for students to expose their strengths and weaknesses in a safe environment of discovery learning. Because it was in their interest as future teachers—stakeholders in public education—a presentation of their skills and knowledge at a public museum was a realistic motivator for pre-service teachers to assist one another in producing authentic and innovative prototypes that would solve an authentic problem. Such a Level 3 openness of inquiry (see Hackling, 2005) helped the pre-service teachers to consider themselves knowledgeable *experts* in their science (Roberts, 2007).

Based on the results of this study it is recommended that future instructors of science at the tertiary level implement PBL into their science program for teacher education students. The results of this study indicate that it has potential to produce positive learning environments that are secure, supportive, structured and, most importantly, authentic. The PBL science course helped facilitate the pre-service teachers' initiatives and learning attempts in science. They took risks, drew on prior knowledge and experience, discovered new knowledge, tested ideas and worked with a variety of people, materials and equipment to "construct a small scale working model," as prescribed by the *NSW Board of Studies, K-6 Science and Technology Syllabus* (1991). The environment of learning was positive and supportive and the pre-service teachers

were collaborative in their on-going learning as they shared the PBL experience weekly in class with their peers and instructor.

Although PBL requires resolving murky ill-defined problems, the learning process needs careful organization. We recommend that instructors highlight to students the similarities of the PBL method of inquiry and the scientific method of inquiry (see Figure 2 and 3). PBL as a method of teaching and practising science is advantageous for immersing pre-service teachers in stimulating environments of problem-solving where curiosity and the desire to understand the world are nurtured and talents, interests and skills are fostered. This is precisely the kind of learning environment we encourage elementary teachers to establish in their classrooms. This course provides a workable *prototype* of how to implement open-ended scientific investigation in a science and technology curriculum for elementary pre-service teachers.

Other Recommendations for Action

We recommend a concentrated effort to modify the traditional science course curricula for undergraduate elementary teachers to increase and broaden these suggested actions to comply with the PBL mode of learning and teaching science. The following T-Chart (Table 3) shows the comparison of the initial structure of the science course with the new recommended open inquiry PBL mode of learning science.

	Initial Structure of the Science Program	New Structure of the PBL Science Program
Science	Science is compartmentalized to be a private discipline of study: structure is epistemologically vertical.	Science is a public display of research and investigation: structure is epistemologically horizontal.
Concepts	Science concepts are taught by instructor for private examination.	Science concepts are learned by students for application in public demonstration.
Syllabi	Course syllabi are structured on weekly topics of traditional science content.	Course syllabi are cross-disciplinary and structured on Socratic dialogue of <i>what if</i> questions.
Lectures	Weekly 1-hour lectures present syllabi content to learners with minimal participation.	Weekly 1-hour lectures are used to present examples of real-world, open-ended messy problems requiring active participation from learners.
Tutorials	Weekly 2-hour tutorials are content driven.	Weekly 2-hour tutorials are evaluative as every learner reports on progression using the PBL steps of investigation.
Investigations	Scientific investigations are instructor-controlled, Level 0 closed-inquiry (see Hackling, 2005).	Scientific investigations are student controlled, Level 3 open-ended inquiry (see Hackling, 2005).
Assessment	Assessments are traditional test-type, contingent on a bell curve or norm.	Assessment uses a generic scoring rubric, but is varied using a combination of self-assessment, peer-assessment and instructor-assessment.

Table 3: T-Chart of Initial Problem and Open- Inquiry PBL Program

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