Title: Innovative primary science classroom practice through pre-service teacher immersion in a problem-based, collaborative learning experience: Approaches to teaching that influence, motivate and inspire students to learn.

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Abstract: This paper describes a pedagogical approach adopted in a compulsory science curriculum subject within a Bachelor of Education (Primary) degree that tackles the complex integrated skills required by pre-service teachers to address the many problems identified in various national and international research reports. A problem based learning approach is employed where students demonstrate their emerging content knowledge, collaborative skills and pedagogical content knowledge within a criterion-referenced assessment framework. Their development as teachers of science and technology is presented in a vertically integrated set of assessment tasks. The teaching team work collaboratively in the design and delivery of the subject both of which are informed by current research in the field. An action-research methodology employing, in part, a quasi-experimental pre/post-test design is used to assess students' developing content knowledge, scientific conceptions and complexity of their reasoning. In addition, ongoing feedback and evaluation procedures are built into the subject through the use of one-minute Harvard Papers which allow teaching staff to make continual improvements and to cater for the individual needs of students. Students' formative and summative feedback reveals high levels of satisfaction with the approach. Student results demonstrate highly significant increases in both content knowledge and complexity of cognitive reasoning and which are accompanied by significant reductions in their alternative scientific conception sI n 2006, the authors were successful in winning a Carrick Citation for Outstanding Contributions to Student Learning.

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Innovative primary science classroom practice through pre-service teacher immersion in a problem-based, collaborative learning experience: Approaches to teaching that influence, motivate and inspire students to learn.

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This paper describes a pedagogical approach adopted in a compulsory science curriculum subject within a Bachelor of Education (Primary) degree that tackles the complex integrated skills required by pre-service teachers to address the many problems identified in various national and international research reports. A problem-based learning approach is employed where students demonstrate their emerging content knowledge, collaborative skills and pedagogical content knowledge within a criterion-referenced assessment framework. Their development as teachers of science and technology is presented in a vertically integrated set of assessment tasks. The teaching team work collaboratively in the design and delivery of the subject both of which are informed by current research in the field. An action-research methodology employing, in part, a quasi-experimental pre/post-test design is used to assess students' developing content knowledge, scientific conceptions and complexity of their reasoning. In addition, ongoing feedback and evaluation procedures are built into the subject through the use of one-minute Harvard Papers which allow teaching staff to make continual improvements and to cater for the individual needs of students. Students' formative and summative feedback reveals high levels of satisfaction with the approach. Student results demonstrate highly significant increases in both content knowledge and complexity of cognitive reasoning and which are accompanied by significant reductions in their alternative scientific conceptions. In 2006, the authors were successful in winning a Carrick Citation for Outstanding Contributions to Student Learning.

Introduction

This paper describes a pedagogical approach adopted in a compulsory science curriculum subject within a Bachelor of Education (Primary) degree that tackles the complex integrated skills required by pre-service teachers to address the many problems identified in various national and international research reports. Inheriting the first curriculum subject, *Science and Technology I,* close to the commencement of classes in 2004, the authors (tutors) implemented the previous version of the subject with only minor changes. In other research during the period 2000-2005, the authors had identified problems in primary and secondary science education and specifically in astronomy education (e.g., Danaia, 2001; McKinnon, 2005; McKinnon, Geissinger & Danaia, 2002). In previous years, there had only been piecemeal changes made to this first curriculum studies subject. A fortuitous conjunction of lecturers, one with a career long involvement in problem-based learning and astronomy education, and two others with interests in primary science education and knowledge of the students in question allowed more substantive changes to be made.

In delivering the original version, the students seemed disinterested in science and expressed fear in teaching it. There appeared to be little that the authors could do *in situ* that influenced the students' perceptions. Our reflections on, and discussions about, the original version of the curriculum, pedagogy and assessment procedures and the subject evaluations obtained from students in both 2004, and in previous years, led us to make sweeping changes to the mode of offering of *Science and Technology I* in 2005 and 2006. The pedagogical approach implemented is informed by current research in science education and theoretically underpinned by social constructivism. Evidence shows that the 2005 and 2006 cohorts of pre-service teachers are engaged and motivated by the transformed subject. Engaging in real science during tutorials has challenged students' alternative scientific conceptions and required them to reconceptualise their current understandings of scientific concepts. In doing so, students are enacting the processes essential in teaching the scientific concepts to primary-age students and concurrently developing their pedagogical content knowledge (PCK) (Shulman, 1986; 1987; Grossman, 1990).

The authors adopted a team-teaching approach in the delivery of *Science and Technology I* that involved a minimum of two tutors teaching in each tutorial. This approach enabled the authors to explicitly demonstrate, through modelled practice, collaborative approaches to problem-solving and analytical and critical thinking skills that our pre-service teachers could then apply both within their cooperative learning groups and, later, in the context of the primary classroom and schools in which they will teach. The remainder of this paper describes: how the problem-based learning environment was constructed; the cooperative learning strategies employed; the assessment items used; some of the results related to knowledge outcomes, alternative conceptions and the cognitive complexity of students' explanations; and, the qualitative feedback together with summative evaluation data of the subject provided by the students.

Creation of the problem-based learning environment

The authors created a problem-based learning environment at the outset by administering the Astronomy Diagnostic Test (ADT) (CAER, 2004) to students at the first meeting of the subject. This enabled students to identify their prior knowledge in one content strand of the NSW Science and Technology K-6 Curriculum (Board of Studies, 1993). Marking of the ADT during the meeting gave immediate feedback to students concerning their lack of content knowledge and the alternative scientific conceptions they held. In short, the mean score of the 15 items that mapped directly to the Stage 2 Outcomes and Indicators of the NSW Science and Technology K-6 Syllabus (Board of Studies, 2001) was 2.2. Students did not know the causes of the seasons or the phases of the Moon and expressed many of the alternative conceptions reported in the literature related to these two concepts, e.g., that the Earth's distance from the Sun causes the seasons and that shadows cast by the Earth cause the phases of the Moon (e.g. Parker & Heywood, 1998; Schoon, 1995; Trundle, Atwood & Christopher, 2002).

Students were asked to record how they felt in their notebooks and, immediately afterwards, to form groups with whom they would work for the rest of the semester. The group members were then asked to share the results of the ADT and their feelings. An immediate sense of relief was engendered when each understood that despite their own bad results, everyone was in the same boat. Thus, confronted by their appalling results, students clearly understood that there was a problem. One student articulated in class that *[I]f I don't know the content then how will I know how to teach it?* (Student 369). This perception was evident in other students' feedback. This feedback took the form of a "Harvard one-minute paper" that was required to be completed by students at the end of each tutorial session. The one-minute papers comprised five sections: "What worked for me in this tutorial? What could be improved for me? Three things I learned in this tute. Three things I need to know more about. Five words to describe today's tutorial."

Students were invited to complete as many of these as they felt were appropriate. It should be noted that the student comments used in this paper have been widely chosen from both the responses to the one-minute papers and the subject evaluation forms collected at the conclusion of this subject. Furthermore, the stream of consciousness words that are included as examples below were selected on the basis that they were present in many of the student responses. The first feedback occasion generated comments such as: *[T]o teach science, knowledge is needed… more knowledge than what I have* (Student 17); and, *[T]he test helped me to understand just how much I need to learn* (Student 10). An overall impression of how they felt can be inferred from the stream of consciousness words used by them in the final section of their one-minute papers collected on the same occasion: *anxious, embarrassed, confronting, daunting, shocking, frightening, crushing*. These indicate the extent to which students were shocked and stressed. Yet, at the same time, they appeared to be motivated by the problem-posing process and which was illustrated by further words/comments interspersing the ones above: *eager to learn more; enjoyable; learning opportunity; motivating; exciting*.

By the end of the first tutorial, students had completed most of the process tasks needed to deliver the first assessable item for the subject: an essay of 600 words that expressed their personal feelings about their results, the feelings of the group members and what they needed to know in order to teach the content in valid ways. This latter task required the students to begin to navigate through the syllabus document. Feedback was supplied to the students within one week of completion of the essay.

Next, students had to analyse a selection of research literature on alternative scientific conceptions held both by primary pupils and their teachers. The approach to considering the extensive alternative-conception literature involved the students employing a variety of cooperative learning strategies including roundtable (Osborn, 1963), jigsaw (Aronson et al. 1978), think-pair-share (Lyman, 1981), and numbered-heads-together (Kagan, 1992). That is to say, each student chose one research paper from a selection provided by the tutors that addressed either the alternative conceptions held by primary pupils, or primary teachers, with directions that they needed to find a second paper on a similar topic using the Library Databases. During the following week, students had to think, and answer six questions, about the research they had found and prepare a brief summary to share with a partner from their table group (think-pair-share) who had chosen papers on the same topic (students or teachers). In the subsequent tutorial, the pairs shared their findings with their table group (roundtable) before sharing their learning with other newly formed groups so that all students had access to all other research papers (numbered-heads-together constructing the "jigsaw" of knowledge). This latter step was required because no two table groups had the same set of research papers. This is a key feature of cooperative learning where the members of a group are reliant on each other to construct the entire picture (Slavin, 1991). Feedback from the students demonstrated that this process had a deep impact on their thinking. Specifically, students indicated that they had to address their own alternative conceptions so that they would not pass these on to their students. Comments made by them included: *[T]here are many misconceptions among students, adults and teachers* (Student 34)*; Misconceptions need to be addressed* (Student 5); *[M]isconceptions are easily passed on* (Student 56)*;* and summatively*, I learnt lots of new things from the research papers and saw the collaborative approaches as a valuable teaching tool* (Student 70).

A formal academic essay of 1000 words, properly referenced assessed their understanding of the literature on alternative conceptions. Again, feedback was supplied to students within one week of submission of their paper.

Constructing curriculum and the learning environment

The outcomes of these processes provided a scaffold for our students, in their collaborative groups, to construct a curriculum to meet their content-knowledge deficits and gave them a real purpose and motivation for the learning that was soon to take place. Once students had understood clearly that there was a knowledge-deficit problem, resources for their learning were supplied. These took the form of an extensive compendium of astronomy related projects (McKinnon, 2005) and all of the equipment they needed to conduct them. Thus, the groups of students had to collaboratively construct a sequence of projects that would redress their knowledge deficits and in the process map these to the relevant Outcomes and Indicators of the syllabus (Board of Studies, 2001). In addition to the mandatory objectives of the subject, the students derived personal objectives on the basis of their performance in the ADT. They clearly articulated in their feedback papers that they wished to acquire the scientific content knowledge in order to be able to teach it without transmitting the alternative scientific conceptions that they previously held. Students were also required to map their projects to the Outcomes and Indicators of the other five Key Learning Areas (KLAs) of the NSW Primary curriculum. This latter process served to demonstrate for them that science and technology could simultaneously address multiple KLAs and the findings in the literature that many teachers offered for not doing science, viz., that there was not enough time and that they were too busy teaching English and mathematics (Angus et al. 2004). Quite often science in primary school is overlooked and not taught at all (CRTTE, 2003; Goodrum et al. 2000; Angus et al. 2004). The mapping exercise was undertaken by the group in a jigsaw approach and tendered for assessment together with a group-constructed rationale for the projects that they had decided to explore.

Each of the groups' curricula was unique because each group had specific content-knowledge requirements to be met and alternative conceptions to be redressed in order for them to be able to teach the contents of the NSW Science and Technology K-6 curriculum (Board of Studies, 1993; 2001) in valid ways. Any hints on how to teach the content had been carefully removed from the projects in the compendium by the author, so that the students could begin to construct for themselves the PCK necessary to teach the material, first to their peers in the group and, later after reflection, to pupils in their classes. Here, PCK refers to: knowledge of, and beliefs about, purpose; knowledge of students' conceptions; knowledge of the curriculum; and, knowledge of appropriate instructional strategies (Grossman, 1990).

At this early stage, the students had already begun to address the first three components of PCK. In order to scaffold students' understanding of the fourth component, a set of papers was supplied to them. These were analysed in a Jigsaw strategy where each student chose only one paper. During the following week, they returned to class and presented the key instructional approaches appropriate to science education to their group members. Again, no individual student possessed the entire "picture". Rather, each was reliant on the others within the group to construct the larger picture through the jigsaw strategy. In addition, they understood that they would have the opportunity to implement these instructional approaches as they taught each other the scientific concepts contained within the projects of the compendium in a Jigsaw II fashion (Slavin, 1990). That is to say, one student assumed the role of "teacher", and thus became more expert on the topic in question in order to teach it, and the others in the group acted as "learners". These roles were swapped for other investigations so that each student could better understand the perspectives of being both teacher and learner. Consistent with collaborative learning principles, the task of acquiring the content knowledge contained within the projects was too great for any one individual to execute on their own in the time available.

The content of the compendium was aimed at reducing or removing the alternative scientific conceptions held by the students while increasing their scientific content knowledge. For example, a common alternative conception held by 95% of students on the pre-test was that the Earth's distance from the Sun caused the seasons. Importantly, students had to discover for themselves (in their group and through close questioning by their tutors and each other) that it was the altitude of the Sun and the amount of time that it shone on the planet's surface that was responsible for the temperature variation between summer and winter. Their growing understanding of the various instructional strategies and sophistication in their use became evident in one face-to-face interaction with a group when one student said *[B]ut I wouldn't teach it this way*. When asked why, the group responded in ways that reflected an early stage of understanding of the pedagogical issues. They made comments about the need to break the task into *manageable chunks* over a series of shorter lessons in order to *scaffold the learning of their future primary students*.

The approach motivated individuals to engage with the content both as learners and as teachers and facilitated the following: face-to-face promotive interaction; positive interdependence; individual accountability and personal responsibility; interpersonal and collaborative skills; and the development of critical reflection of both their own, and their group's, performance (Johnson & Johnson, 1984; Johnson, Johnson, & Holubec, 1993; Slavin, 1990). Individualised programs tailored to the group's needs required everyone in their different roles to be involved and working at different levels during the tutorials: students as teachers, students as learners, and the members of the tutorial team as facilitators and mentors.

A more structured method has been adopted to elicit feedback by directing the students' attention to the many roles involved in the teaching-learning process using a "structural reflection and feedback" paper. At the end of each lesson, the "teacher" is required to reflect on a number of issues related to the preparation and delivery of the "lesson" involving both the content knowledge presented and the instructional approaches adopted. The "learners" are required to focus on the instructional strategies implemented and their effectiveness in helping them understand the content knowledge. When completed, the teacher and learners exchange their observations and reflections in a roundtable session with the teacher making notes about what the learners have said about the "effectiveness" of the lesson. The feedback papers are employed as an experiential record that provides them with data for the construction of their final essay.

Observations of students by tutors and visitors revealed that the classroom was a dynamic, task-orientated environment. As they engaged with the content, there were many, many "ah ha" occasions when students came to understand such phenomena as the phases of the Moon or the seasons, and in the process constructed mental models that were highly personal. For example, one student developed a model to explain the apparent movement of the Sun in the sky during the course of the year, based on the peeling of an orange. The sharing and explanation of this idiosyncratic mental model excited both the originator and the members of her group as the abstract idea for the cause of the seasons was made concrete. Extracts from the feedback papers obtained during these sessions reveals students' feelings when they were engaged in their activities: *active, inspired, informative, collaborative, beneficial, enjoyable, productive, powerful, intense, engaging, interactive, supportive, frustrating, tiring, interesting, critical reflection, thought-provoking.* A range of comments about the collaborative approaches and group work illustrate the extent to which the students were involved, motivated and task orientated: *I loved the Jigsaw activities – everyone brought something different* (Student 42)*; Cooperative learning is great and useful* (Student 74)*; Staying on Task [sic] by moving through each component* (Student 26)*;* and*, We had a cooperative day where we got together and did it* (Student 21)*.* In short, although the tutors had expected changes in students' engagement, they were pleasantly surprised by the extent to which task-orientated discussion happened within groups to the exclusion of all other problematic conversations, e.g., their social lives.

Student formative feedback and the roles of the tutors

Consideration of the one-minute papers employed early in the semester allowed deeper reflections by the tutorial team members and enabled them to develop strategies that could be implemented in the following week's tutorial. These, for example, allowed the identification of learning barriers and conceptual problems. Analysis of one paper led the authors to think that one student did not understand the connection between actually doing the project activities and their future teaching of science and technology. The student wrote: *Why don't we just spend more time constructing units of work?* The strategy adopted at the start of the following tutorial involved one tutor, in an ethical way, asking the whole class to consider the connection between these two components, i.e., doing the projects and their future as teachers of science and technology. Students, in their groups, discussed for a few minutes the connection and presented their thoughts to the whole class. There was a high degree of commonality amongst the thoughts: that in the process of doing the activities they were developing their PCK on how to implement activity-based science. In the previous class, the student had been sitting disengaged from the activity of the group. Following the intervention, the student became highly involved, smiled often, and was pro-active both in that tutorial and for the rest of the semester.

The roles of the tutors (i.e., the authors) were thus many and diverse. Tutors stimulated students' thinking and developed their analytical and critical thinking skills by asking higher order questions. They encouraged students to extend their knowledge and learning by conducting research both for their own benefit and to inform their future teaching of science in problem-based learning environments. Comments extracted from the one-minute feedback papers highlight the various roles adopted by the tutors' and made explicit by their behaviour in class. The comments include: *Great tute [tutor]! I normally find Sci & Tech so boring but you are making it really easy to understand things so it is much more enjoyable* (Student 3)*; I think it is very good that the tutors are so helpful in assisting us to complete the activities each week* (Student 62)*; The activity today 'The Seasons' was difficult and hard to understand. However, with teacher guidance and explanation the activity and its findings became clearer* (Student 44)*; Nice to have some 1:1 with the tutors (just for some different perspectives)* (Student 61). The approach led students to understand in a very concrete way how social constructivist learning takes place and which was explicitly modelled by the tutors in their many discussions both with each other and with them.

Assessment of student learning

A criterion-referenced assessment framework is employed with a set of clearly specified performance outcomes on a number of criteria for each of the four assessment tasks. The criteria are provided to students at the outset in a marking rubric that provides a clear structural guide for both the student and the assessor and increases the reliability of the assessment process. Formal assessment of the students' efforts is grounded in team discussions about what constitutes acceptable performance. Extensive feedback is provided to students so that they could meet the outcomes of the criterion-referenced framework. Performance that is deemed to be at less than the standard is discussed with the student within one week of submission of an assignment and the remedial steps necessary are specified. In one respect the feedback provided to the student is both formative and summative. It is formative in the sense that if the student wishes to address the feedback provided, they are encouraged to resubmit the attempt in order to achieve the necessary minimum performance level against each of the criteria. Failure to do so, as the students came to understand, would result in failure of the subject. It is summative in the sense that should the student not wish to address the issues identified in the feedback and they have achieved at the necessary performance level then no further submission is necessary.

Each of the assessment tasks described above have both an individual and a collaborative component. For example, students are required to collaborate in order to develop perspectives generated by their consideration of the research literature and of their experiences as teachers or learners as they engage with the activities in their group-constructed curriculum. Apart from the third assessment task, students are required to present their distillations in an individual fashion to ensure academic integrity.

The final assessment task is a content knowledge test worth 30% of the subject mark and on which the students must demonstrate at least 70% mastery of the concepts involved. The test serves a particular purpose, *viz*., to drive the students' engagement with the often difficult scientific concepts related to this one strand of the syllabus.

Formal subject evaluation

A formal paper-based subject evaluation is conducted at the end of each semester where, with appropriate ethical safeguards, students provide feedback on their perceptions of the subject. The success of our informed approach is illustrated by the fact that in 2004, using a 19 item questionnaire, only 7 items indicated student satisfaction; in 2005, using a 29-item questionnaire, 28 of the 29 items (excluding workload which had a mean of 3.54) indicated high levels of student satisfaction on a five-point Likert scale. Responses extracted from the subject evaluation are presented below to illustrate the challenging nature of the subject and the positive feelings that students derived from engaging with it.

> *This subject was full-on and scary but looking back through those stressful nights, I have, & many others, accomplished so much. [The tutors] were very helpful & wanted us to achieve our best – their attitude was greatly reflected on us, especially me. Thank you for your support! Thanks for your passion, greatly appreciated. (Signed)* (Student 51).

> *I believe that the collaboration and teamwork component presents opportunities and challenges – a great development for me personally and [the tutors' names] enabled this subject to be a positive and enjoyable learning experience* (Student 73).

> *I am no longer afraid to have a go and teach [sic] science in the classroom. This subject had a much nicer environment compared to [subject]. I felt that my efforts were rewarded at uni [sic] and especially in this subject* (Student 103).

> *The opportunity to re-submit assignments was extremely beneficial, and promotes us to improve. The group work taught many skills not just in science but other KLAs. Working collaboratively is a motivational tool* (Student 37) .

> *I think the collaborative project was fantastic* (Student 83).

> *I enjoyed the post-test today. I think I did really well. It was awesome* (Student 65).

Discussion

In just 11 weeks, the success of the approach, for this most difficult of primary science content areas, in terms of learning outcomes, is demonstrated by the following results. Analysis of the post-treatment Astronomy Test (MANOVA) has revealed that students' content knowledge significantly increased (effect sizes (2005, 2006) =1.997, 2.26 (*Cohen's d*)). More importantly, their alternative conceptions have reduced significantly (effect size=0.688, 0.507) and they have acquired a significantly increased ability to explain the astronomical phenomena they will be required to teach (effect size=1.333, 0.95) (McKinnon & Danaia, 2005).

In addition, the evidence from students' feedback indicates that, where they were previously afraid of teaching science, did not know the content, could not explain the reasons for certain scientific phenomena or were simply bored by the subject, they are now enthused, motivated and committed to improving their content knowledge. They know how to address their own and future pupils' alternative conceptions and are acquiring the skills on how to teach science content in interesting and engaging ways.

The first two authors have extended the study in 2007 to assess students' science teaching efficacy using STEBI-B (Enochs & Riggs, 1990). The pre-intervention results reveal that approximately half of the students entered the subject with high levels of confidence about teaching the Science and

Technology Syllabus content. For this group, the ADT results quickly disabused them of this notion and showed that that they were not competent to teach the content. The other half of the cohort did not perceive themselves to be confident about teaching the content. Indeed, the ADT results also demonstrated that they were not competent to teach it (Appleton, 1997). It would have been interesting to re-administer the STEBI-B immediately after they had marked their papers but this was not possible. The authors expect that the post-intervention analysis of the STEBI-B will support the qualitative evidence extracted from the formal subject evaluations in earlier years where there appeared to be an increase in students' perceptions of their competence and confidence to teach science and technology.

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