A pedagogical approach in compulsory science curriculum subjects for pre-service primary teachers that works

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Abstract

This paper describes a pedagogical approach adopted in the compulsory curriculum subjects Science and Technology 1 and 2 of a Bachelor of Education (Primary) degree. The approach uses Australia's foremost science, astronomy, as the vehicle to confront students with their lack of scientific knowledge, and to engage them in a process that they later use to develop and implement effective science experiences in other science content areas in the primary school. The approach is built on the construction of a learning environment where collaborative learning is mandatory within a problem-based learning (PBL) environment in the first subject and a project-based learning context in the second subject. These learning environments are designed to equip students with the skills and dispositions to engage with science education in the schools where they will teach.

The teaching team work collaboratively in the design and delivery of the subjects both of which are informed by current research in the field. An action-research methodology employing, in part, a pre/post-test design is used to assess students' developing content knowledge, scientific conceptions, complexity of their reasoning and their science teaching self-efficacy. In addition, ongoing feedback and evaluation procedures are built into the subjects both of which allow the tutors to make continual improvements to the design and delivery of the subjects. Engaging in real science during tutorials has both challenged students' alternative scientific conceptions and required them to reconceptualise their current understandings of scientific concepts. In doing so, they are enacting the processes essential in teaching the scientific concepts to primary-age students while concurrently developing their Pedagogical Content Knowledge (PCK). Evidence shows that the 2005, 2006, 2007 and 2008 cohorts of pre-service teachers are engaged and motivated by these approaches. This paper describes the learning environments, the collaborative learning framework and the assessment strategies employed and presents evidence of the impact of the learning design.

Keywords: cooperative learning, pedagogical content knowledge, primary pre-service teacher science education, science teaching self-efficacy.

Science education is confronted by a major problem: too few pupils elect to study science beyond the compulsory years of school. Research, nationally and internationally, has identified many factors that contribute to the rising shortfall of good quality candidates continuing to university to study the sciences. National research shows that very little science is taught in the primary school (e.g., Angus et al., 2004; Goodrum, Hackling & Rennie, 2000). In part, the problem is related to the fact that few primary teachers have taken any science subjects beyond the compulsory years of schooling and are afraid to teach it largely because of their perceived lack of expertise in the area. Thus, the teaching rationale that underpins the science curriculum subjects at CSU is informed by extensive research not only in science education but also in cooperative learning approaches and Problem-Based Learning (PBL) that involves a major investigative component.

The pedagogical approaches we implement are theoretically underpinned by social constructivism, problem- and project-based learning, and cooperative learning (e.g., Vygotsky, 1977; Johnson et al., 2007; Slavin, 1996). We frame the subjects within problem/project-based authentic learning environments where collaborative learning is mandatory and designed to equip students with the skills and dispositions to engage with science and technology in the schools where they will teach. In the two subjects, conditions are constructed within the educational design where students *want* to learn the content and *how* to teach it and the tutors' job is to help them do this.

Within this educational design, a variety of sources of data collected from students on a regular and systematic basis allow the teaching-team to reflect on students' experiences and to make adjustments to the delivery of tutorials. This action-research oriented approach presents the team with many opportunities to reflect critically on the conduct of students' learning experiences. In doing so, the team engages in both reflection in action and reflection on action (e.g., Hatton & Smith, 1995). The first of these actions take place within tutorials as the teaching team delivers the planned content and manages the learning experience of the students. The latter action takes place after a tutorial has been completed when the team has access to student formative feedback and reflection on action can happen. This team-teaching and reflecting approach will be described in greater detail below.

The team-teaching approach in the delivery of the subjects involves a minimum of two tutors being present in each tutorial. This approach not only allows the critical reflection to occur but also enables the team to explicitly demonstrate, through modelled practice, collaborative approaches to problem-solving and analytical and critical thinking skills that our students can then apply both within their cooperative learning groups and, later, in the context of the primary classroom and schools in which they will teach. Evidence collected demonstrates that the team-teaching approach is an important motivator for our students, e.g., *I liked having a variety of tutors in [the] classroom as they all gave their opinions which helped out in the planning process* (RL, 2006).

The Approach within Science and Technology 1

The educational design framework for the first subject is the construct called "pedagogical content knowledge": knowledge of, and beliefs about, the content; knowledge of students' alternative conceptions; knowledge of the curriculum; and, knowledge of appropriate instructional strategies (Grossman, 1990). The PBL environment is constructed in such a way that each of the four components is explicitly addressed through the assessment items they are required submit.

We create a problem-based learning (PBL) environment at the outset by administering an astronomy diagnostic test (CAER, 2004) to students at the first meeting of the subject. Marking it in class enables students to identify their prior knowledge related to aspects of the syllabus (BoS, 1993) and gives them immediate feedback concerning both their lack of content knowledge and the scientific misconceptions they hold. They form collaborative groups and share reactions to their results with their peers. Confronted by their results, they clearly understand that there is a problem and articulate it on the first formative feedback occasion: *[T]o teach science, knowledge is* *needed… more knowledge than what I have* (Anon, 2005); *If I don't know the content then how will I know how to teach it?* (e.g., LD, 2006); and, *[T]he test helped me to understand just how much I need to learn* (Anon, 2007). We analyse how they feel from the stream-of-consciousness words used by them in their feedback: *anxious, embarrassed, confronting, daunting, shocking*. These reveal the extent to which they are shocked and stressed yet, at the same time, influenced and motivated by the revelation that they know little. This is illustrated by further words interspersing the ones above: *eager to learn more; enjoyable; learning opportunity; motivating; exciting*.

We further develop their motivation through exposing them to the extensive research literature on misconceptions possessed by pupils and teachers. In this exercise and consistent with collaborative learning principles, the task of reading and analysing the literature is too great for any one individual to execute in the time available. Thus, we employ a variety of effective cooperative learning strategies including jigsaw, roundtable, think-pair-share, and numbered-heads-together to demonstrate that scientific misconceptions are endemic. Feedback from students demonstrates that this has a deep impact on their motivation. Many state that they will have to address their *own* misconceptions so that they do not pass these on to their pupils, e.g., *I learnt lots of new things from the research papers and saw the collaborative approaches as a valuable teaching tool; I have developed an enthusiasm for teaching science, especially in the area of alternative conceptions* (AS, 2007). Moreover, they are highly motivated to do something about "their problem" through making sure that they do not possess misconceptions about the material they will teach.

These highly personal and confronting experiences provide a scaffold for the groups to construct a learning program to meet their content-knowledge deficits and give them a real purpose for the learning of science content. The groups incorporate relevant projects in their program from an extensive compendium (McKinnon, 2005, 2007). We have deliberately removed any hints on how to teach the projects so that they can experiment with various instructional approaches that engage both them and their peers and later, after reflection, the pupils in their classes. The emergent knowledge about the instructional approaches became evident when one student said *[B]ut I wouldn't teach it this way*. When asked why, the group responded in ways that reflected a developing understanding of the issues pointing out the need to break the task into *manageable chunks* over a series of lessons in order to *scaffold the learning of their future pupils.*

In implementing the projects, they employ a Jigsaw II strategy (Slavin, 1996) where, for an investigation, one student assumes the role of "teacher", and thus becomes more expert on the topic in order to teach it, while others in the group act as "learners". These roles are swapped for other investigations. This requires everyone to be involved and working in their different roles during the tutorials: students as teachers, students as learners, and the tutorial team as facilitators and mentors. The tutorial sessions that follow are almost chaotic, but nonetheless are characterised by continuously high levels of task engagement. Formative feedback illustrates the extent to which they are engaged: *I loved the Jigsaw activities – everyone brought something different;* and, *We had a cooperative day where we got together and did it.* As they engage with the content, there are many, many "ah ha" occasions when students come to understand such phenomena as the phases of the Moon or the seasons. In the process, they construct highly personal mental models, e.g., one student explained 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 her group, as the abstract idea for the cause of the seasons was made concrete.

Students' reactions to the learning and teaching are formalised in a Reflection and Feedback instrument developed by us to focus their attention on the various components of PCK. Feedback obtained during these sessions reveals students' changed feelings: *active, inspired, informative, collaborative, beneficial, enjoyable, productive, powerful, intense, engaging, interactive,* *supportive, interesting, and thought-provoking*. Other, more informal, evidence bears this out: in 2007, a third-year student wandered up to one of us in Week 4 of the semester and asked, "*How is this year's mob progressing*" In response to a non-committal answer, the student offered "*They seem to be getting it. I overheard some of them having coffee this morning talking about what you are doing with them.*" (RK, 2007).

In short, although we had expected changes in students' engagement, we are continually and pleasantly surprised by the extent to which task-orientated discussion happens within groups to the exclusion of all other problematic conversations, e.g., their social lives. In 2007, the *Chancellor of the University* visited one tutorial class and talked with the students as they undertook their investigations. He was intrigued by the extremely high level of engagement. Impressed by the professional manner in which the investigations were being conducted he asked "*Is it always like this?*" the answer to which was given by one student as "*Yes, isn't it exciting?*" (NM, 2007).

Assessment in Science and Technology I

The construct of PCK progressively and cumulatively mediates students' interactions with the assignment items focussing their attention on each of its components and the role it plays in effective science and technology education. Assignment 1 is a short essay designed to have students reflect on the fact that they do not possess the necessary content knowledge to teach science in a valid fashion. One major outcome of this assignment is that they clearly understand that their lack of knowledge is a problem. Assignment 2 is designed to alert students to the fact that pupils come to school with many misconceptions and that teachers also possess many of these. The assignment takes the form of an academic essay scaffolded using a number of collaborative approaches to cover many research papers. Thus, they now understand the importance of the second component of PCK, i.e., knowledge of students' conceptions and how these can affect intended learning outcomes. Assignment 3, tendered by the group, addresses the "curriculum" component of PCK. The task is only achievable by employing a jigsaw approach to map the group's projects to the outcomes of not only the Science and Technology syllabus but also those of the other five subjects of the primary curriculum. Assignment 4 requires the students to write a series of mini-essays. These address reflection about instructional strategies and cooperative learning approaches in relation to their developing PCK. The experiential base on which these mini-essays is based are the teaching experiments they implemented with their group to teach the scientific content. The final assessable item is a content knowledge test that covers the key concepts related to the science they will be required to teach. They have to demonstrate mastery of the concepts and give scientific explanations for their answers.

The nature of the tasks together with the scaffolding implemented by us during the tutorial sessions underpins the necessity for them to be pro-active in analysing the relevant materials to execute the assignments with the net consequence of students becoming independent learners. The large effect sizes presented in Table 1 below indicate the extent to which they have been successful in improving their content knowledge, their ability to explain scientific phenomena and in reducing their scientific misconceptions and are testimony to the effectiveness of the educational design. Students understand the educational design and appreciate the scaffolded nature of the assessment tasks: *Structure in this subject was great and content purposeful, collaborative structure worked and assessments were helpful! Overall well done!* (KB, 2006).

The Approach within Science and Technology II

The first subject serves as the platform on which this second one is built. Students have acquired significant skills in problem-based learning, collaborative learning strategies and can apply these to address their lack of scientific knowledge. We create a project-based authentic learning context at the first meeting of a class where students assume the role of being teachers in a primary school and the tutors their newly appointed Executive. The Principal invites the "staff" to get into their "sub-group teaching teams" (Kindergarten, Years 1 &2, 3&4, 5&6) and presents a "scenario" constructed from national and international reports where the new executive “have examined previous programs and found them wanting” in terms of the Board of Studies requirements.

In this authentic context, the “staff” brainstorms and develops units of work on a particular topic drawn from the Syllabus that articulates from Kindergarten through Year 6. At “staff meetings” held each week, the Principal facilitates discussion as each sub-group presents their output to date and which the Deputy records on the SMART Board. Each week, they complete a meeting template, construct an action plan and delegate tasks to be completed by the following week. The numerous roles are inter-changed on a regular basis to ensure that all acquire the additional skills of effective team management. The collaborative skills developed in the first subject allow them to organise and divide the many tasks: define the scope and sequence of content; identify appropriate activities and misconceptions that pupils might possess; conduct the chosen activities to make sure that they work; include appropriate background knowledge for any teacher who might use their unit; define assessment procedures and instruments; and, communicate with each other effectively. Influenced and motivated by the process, many students bring their laptops while others hire them from the library to supplement the internet-connected computers supplied. They share their products using flash-drives, email and more informally through their many conversations and discussions not only within their own sub-group but also with the other ones.

The draft unit is submitted for formative assessment and acting on feedback, they also begin to make decisions about the activities that they will implement in local primary schools which we visit in the second half of the semester. The purpose of this work-integrated learning is to develop further students’ existing PCK together with the additional components of knowledge and beliefs about purpose and knowledge of context. In testing parts of their unit with real pupils, they observe the impact it has both on the pupils and their teachers who are required to be present. Groups employ various mechanisms to obtain feedback from their audience that is then used to fine-tune the electronic version of their curriculum document to be submitted for summative assessment. The in-school experience visit has a major impact on them: *I enjoyed the school visit as it added meaning to the learning which allowed me to engage in the subject* (SP, 2007).

Treating our students as professionals in their field is a major motivational factor that inspires them to act as teachers. Discussions centre both on the impacts that their unit will have on pupils and the coordination of various approaches to improve learning outcomes. These impact level interactions are evidence of the professional way that they are being treated, their increasing confidence as teachers, and their developing expertise in programming and evaluation: *I feel the development of the unit was a rewarding and worthwhile exercise that allowed me to develop my skills as a unit developer and teacher* (KD, 2006); *Overall, the subject layout was great-focussed on our development as science teacher* (KW, 2006). Summatively, many students comment positively on the scenario: ***I liked the school/staff set up for classes. Thank you!!*** (SN, 2006); *Make sure you keep the “school” format etc - worked very well* (ES, 2006).

An important additional motivational device introduced by us in 2006 involves the collation of all of the units-of-work and supplying them both to the students and to local schools on a CD-ROM. Many students comment on the value of the collection: *The unit development assignment was fantastic and was a very worthwhile exercise. Very valuable resource provided on CD-ROM* (CF, 2006). Thus, our students exit this second subject with a full-school science and technology teaching program covering all components of the NSW Syllabus that have been trialled and evaluated. It also contributes to the professional learning of teachers in local schools, feedback from whom is extremely positive with many teachers using the units of work with their classes.

Evidence shows that the students are highly motivated, engaged and reflectively critical about their future roles. *This subject has been the most valuable core subject I have had so far- as we get a* *useable unit of work! There is something beneficial for us at the end of the subject and it makes the work worthwhile - not just to get a mark* (MB, 2006). We attribute these outcomes to the authentic project-based learning context into which they have been placed and the work-integrated learning in schools.

Assessment in Science and Technology II

The goal of the assessment here is similar to that of the first subject but with the added goal of making them independent *and* autonomous learners capable of both specifying what they need to know and executing the learning in order to teach it successfully to pupils in an engaging fashion. There are two assessable items: a group task to construct a unit-of-work; and, the writing of an individual exegesis.

The first assignment is tendered for formative assessment half-way through the semester and we provide extensive feedback within one week. We comment on such things as language, structure, sequence, age appropriateness, pedagogies employed and the activities included. The students appreciate the rapidity with which feedback is dispatched to them: *I couldn't believe you sent out our unit of work to us in the break - I thought this was brilliant (nice idea) and helped us with all the feedback* [you] *provided* (LB, 2006). When this feedback is completed, we return it to a pre-nominated group member who has already organised the group, in a jigsaw fashion, to make changes to the electronic document. This leader coordinates the members by forwarding relevant sections with directions for the completion of their individual tasks. The completed digital curriculum document is then rapidly assembled for summative assessment.

The second assignment is an exegesis that requires students to reflect critically on their experiences during the two subjects. The vehicles for analysis of their experiences are critical reflection, PCK acquisition and the curriculum design and execution processes. At this stage, there is little need for feedback, though it is provided in a summative analytic rubric. They understand where they are situated as learners and as teachers within the discipline area. In short, they conclude that they are at the centre of these processes and are: developing their PCK; using PCK to develop curriculum; and, continuously engaging in critical reflection about their development as both teachers and learners.

Action Research in Action

Progressive action-research cycles have occurred and are based on our deep reflection of not only the extent to which our intentions have been translated into practice but also the extent to which students' reactions to the educational design produce the outcomes we intend. Specifically, the action-research cycles happen at two levels within both subjects.

At the first level, the actions on reflection that happen on a weekly basis allow the teaching team to make adjustments to the conduct of tutorials and lectures. The formative feedback, elicited from students at the end of each tutorial and through the Reflection and Feedback instrument obtained at regular intervals during the semester, provides the data upon which the teaching team reflect. The reflections provide opportunities to make the adjustments necessary to ensure that no student is left behind and that they understand the underlying reasons for the educational design that they are experiencing.

At the second level, these formative feedback data coupled with the summative evaluations made by the students at the end of the semester allow the teaching team to reflect critically on the components of the educational design and their interaction. For example, the 2005 assessment framework in the first subject was transformed from a portfolio design to one in which multiple smaller tasks were constructed as a scaffold to help students deal with the apparent complexity of the PCK construct. For the second subject, in 2005 students had to construct two units of work. Based on their summative feedback, we reduced this to one unit of work and had them implement components of it in local primary schools in 2006. In addition, we introduced the project-based learning environment described above and included the formal sharing of their units of work through the production of a CD-ROM.

At the end of 2006, and somewhat surprised by the reduction of the effect size of students' content knowledge and ability to explain scientific phenomena reported in Table 1 below, our reflections led us to consider the impact the subject designs were having on students' efficacy beliefs about teaching science. A Science Teaching Efficacy Belief Instrument was implemented at the beginning of both subjects in 2007. The results are highly positive and have led to further minor changes in both subjects.

Thus, the action-research framework allows the teaching team to fine tune the educational design of both subjects. The results presented below illustrate the extent to which these processes have been successful in constructing a pedagogical approach that works.

Results

The outcomes of the approach in the subjects are presented in Table 1. Effects sizes describing students' acquisition of content knowledge, reduction in alternative scientific conceptions, ability to explain scientific phenomena for the first subject and science-teaching efficacy beliefs for both are outstanding. To achieve a change of 0.7 sigma is notable where an effect size of 0.7-0.8 in educational research is normally described as "strong" (Burns, 2000). To achieve changes of 1, 2, 5 and 6 sigma are testimony to the robustness of the educational design, the scholarly and critical way in which we interrogate its implementation and the ways in which we act on the feedback from students. These effect sizes are under-estimates of the true effect-sizes given that the post-test is more difficult and requires students to represent different scientific phenomena in a variety of ways.

Table 1: Knowledge, Misconceptions, Complexity of Scientific Explanation, Efficacy

Effect sizes (Cohen's d):	**2005** S&T-I	**2006** S&T-I	**2007** S&T-I	**2007** S&TII	**2008** S&T-I
Increase in Content Knowledge	2.133	1.076	5.950	Not collected	5.75
Reduction in Misconceptions	0.734	0.958	1.964	Not collected	2.50
Increase in Complexity of Explanations	1.286	0.784	5.080	Not collected	5.15
Increase in General Science Teaching Efficacy	Not collected	Not collected	0.734	0.345	0.904
Increase in Personal Science Teaching Efficacy	Not collected	Not collected	0.134	0.694	0.729

The products of the second subject are confident and competent students (Appleton, 2003) motivated to teach science and technology equipped with resources created by them. Summative comments illustrate the impact that the two subjects have had on students: *I really enjoyed both [*subjects*]- both covered different aspects and motivated me to become a better teacher* (CF, 2007); *I love the structure of these courses. I find them useful in developing our skills to be teachers* (EF, 2007). Local schools are impressed with the outcomes in terms of resources and student attributes. This has led to many invitations by schools for our students to be involved in facilitating in-class science and technology experiences for pupils and to attend regional science days to present their work.

Conclusion

The support mechanisms for students' development as teachers continue. In 2008, we designed and implemented a Cooperative Learning Evaluation instrument to identify emerging difficulties with groups' interactions. Once problems are identified, we act as counsellors to address the issues with the group but take care not to single out individuals. We get the group to read the relevant literature, supplied to them in the digital materials, on how to function more effectively and discuss with them how they might deal with the problem. We monitor how the group progresses and model for them effective forms of communication and positive verbal reinforcement.

In these ways, through the deep interrogation of our teaching and of the educational design of the subjects, we create conditions where students can experience success. This "success" influences positively their overall experience of higher education and their attitude towards the teaching of science and technology. Extracts from the summative evaluations not only illustrate the extent to which students' perspectives had been transformed, they also they illustrate the extent to which we provide support and respect them as individuals.

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)*(MR, 2006)*;*

I am no longer afraid to have a go and teach science in the classroom. This subject had a much nicer environment compared to […] *I felt that my efforts were rewarded at university and especially in this subject* (CT, 2006);

I thoroughly enjoyed the challenge and look forward to the next science subject. I think that the results speak for themselves as I witnessed first hand the vast improvement in my knowledge. The course has not only taught us scientific skills but also universal skills that are appropriate for use in all areas of our teaching across the board. Congratulations and thank you for the experience (signed GN, 2008).

References

Angus, M., Olney, H., Ainley, J., Caldwell, B., Burke., G., Selleck, R., & Spinks, J. (2004) *The sufficiency of resources for Australian primary schools*. Canberra: Department of Education, Science and Training.

Appleton, K. (2003). How Do Beginning Primary School Teachers Cope with Science? Toward an Understanding of Science Teaching. *Research in Science Education, 33*(1), 1-25.

Board of Studies (1993). *Science and Technology K-6: Syllabus and Support Document.* Sydney, Australia: Board of Studies.

Burns, R. B. (2000). *Introduction to Research Methods*. London: Sage.

CAER (2004). *Astronomy Diagnostic Test* (Southern Hemisphere Edition modified). The Collaboration for Astronomy Education Research, School of Physics, University of Sydney; School of Teacher Education Charles Sturt University.

Goodrum D., Hackling M. & Rennie L. (2000), *The Status and Quality of Teaching and Learning of Science in Australian Schools*. DEST, Commonwealth of Australia: Canberra

Grossman, P. L. (1990). *The making of a teacher***:** *Teacher knowledge and teacher education*. New York: Teachers College Press.

Hatton, N., & Smith, D. (1995). Reflection in teacher education: Towards definition and implementation. *Teaching and Teacher Education, 11*(1), 33-49.

Johnson, D. W. & Johnson, R. (1989). *Cooperation and competition: Theory and research*. Edina, MN: Interaction Book Company.

Johnson, D. W., & Johnson, R. (1998). Cooperative learning and social interdependence theory. In R. Tindale, L. Heath, J. Edwards, E. Posavac, F. Bryant, Y. Suzrez-Balcazar, E. Henderson-King, & J. Myers (eds.), *Theory and research on small groups* (pp. 9-36). New York: Plenum. Social Psychological Applications to Social Issues, Vol 4.

Johnson, D.W., Johnson, R.T & Smith, K. (2007). The State of Cooperative Learning in Postsecondary and Professional Settings. *Educational Psychology Review*, *19*(1), 15-29.

McKinnon, D. H. (2007*). The sky at night and other practical astronomy projects for teacher education students (3rd ed.).* Bathurst: CSU.

McKinnon, D.H., Geissinger, H. & Danaia, L. (2002). Helping them understand: Astronomy for Grades 5 and 6. *Information Technology in Childhood Education Annual, January*, 263-275.

Slavin, R. (1996). Research on Cooperative Learning and Achievement: What We Know, What We Need to Know. *Contemporary Educational Psychology, 21* (1), 43-69.

Vygotsky, L. S. (1977). The development of higher psychological functions. *Soviet Psychology*, 16, 60-73.