Reforming Education: The pursuit of learning through authentic inquiry in mathematics, science and technology

James J Watters and Carmel M Diezmann
Queensland University of Technology

j.watters@qut.edu.au; c.diezmann@qut.edu.au

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Abstract

Contemporary learning theories acknowledge that learning has to occur in context where students engage actively in negotiating meaning around new experiences. Learning theorists argue that the most important source from which we gain understanding is first-hand experience in a social context. However, traditional schooling is dominated by models of teaching, which assume learning occurs through transmission of information. Students are forced to learn from secondary experience, in which information is selected, modified, packaged and presented to them by "expert" teachers. Second-hand transmissive models dominate schooling. The outcome for the sciences is a decline in interest and participation by students especially the most talented. Reform processes need to achieve a better balance between first-hand and second-hand experience, because without opportunities to learn directly students are less likely to develop autonomy and think and feel for themselves.

The research we report in this paper draws upon a number of our studies in which students are engaged in original inquiry problems. We report here on two studies that exemplify the application and outcomes for learning science in the middle years of schooling. Study 1 is a structured inquiry in which the teacher leads students through a series of learning experiences supporting their learning of content and developing capability to undertake inquiry. In Study 2, an open-ended inquiry is examined. Emerging from this analysis are seven principles that provide broad conditions for successful implementation of inquiry approaches.

Across the world, governments are recognising the important role that science, mathematics and technology are playing to achieve healthy, safe and peaceful society. In Australia, the development of scientific, mathematical and technological literacy is a national priority for the education system. A number of major reports have implicated the quality of teaching, the relevance of the curriculum and teacher training as areas of major concern (Breakspere, 2003; Goodrum, Hackling & Rennie, 2001; Glenn, 2000; Miles, 2000; NSB, 1999). In essence, classroom teachers and policy makers are being encouraged to accommodate global perspectives, contemporary issues in the sciences and acknowledge the myriad of social-emotional problems confronting modern youth and provide more meaningful learning contexts.

However, the teaching situation in many classrooms is problematic (Goodrum, Hackling & Rennie, 2001). Despite almost two decades of research on constructivism as a referent for teaching, particularly of science and mathematics, teaching is still dominated by a didactic mode of instruction in which students and teachers view knowledge as a commodity to be acquired largely through memorisation. The features that characterise real world science – argument, collaboration, uncertainty, intrinsic motivation, hypothesis testing – are rarely seen in classrooms (Latour & Woolgar, 1986; Roth, 1996). Contemporary learning theories acknowledge that learning has to occur in context where students engage actively in negotiating meaning around new experiences. Learning theorists argue that the most important source from which we gain understanding is first-hand experience in a social context. However, traditional schooling is dominated by models of teaching, which assume learning occurs through transmission of information. Students are forced to learn from secondary experience, in which information is selected, modified, packaged and presented to them by "expert" teachers. The adoption of these models are further reinforced by community attitudes that tend to see education in mathematics, science and technology as being training for specialised careers in technical fields, rather than part of the essential general preparation to be an informed citizen in the twenty-first century. Reforming classroom practices to achieve a better balance between first-hand and second-hand experience requires teachers to assume new supportive roles in the classroom and develop the appropriate pedagogical knowledge to support new forms of learning.

Inquiry or problem-based learning is advocated as one way that students can engage in learning through the exploration of multi-disciplinary complex scenarios. Students are collaboratively engaged in problem *identification* and *solution* built around problems or tasks that are personally meaningful. They might explore a situation requiring the use of multiple sources of information, require interdisciplinary knowledge, and involve both practical empirical investigation and development of theory. The strengths of inquiry-based learning is that it: (a) is constructivistic as it draws upon prior knowledge, often in a social environment (Savery & Duffy, 1995); (b) enhances deep learning by engaging the student in challenging problems (Henningsen & Stein, 1997); (c) promotes links among subject matter disciplines (Thagard, 1991; Lee & Brophy, 1996); (d) presents a "panoramic" or holistic view of the subject and discipline (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991); (e) enhances transfer of concepts and strategies to new problems and situations (Light & Butterworth, 1992); (f) fosters self-reflection, co-operation, metacognition (Gijselaers, 1996; Norman & Schmidt, 1992); (f) simulates the cognitive demands of the discipline (Honebein, Duffy, & Fishman, 1993); and (g) enhances motivation (Lee & Brophy, 1996).

Examples of inquiry learning

In this paper we draw upon a number of our studies in which students engage in original inquiry problems. It is argued that students build their understanding and investigative skills through active inquiry, connecting their previous knowledge with new ideas and evidence. We specifically report on examples from the in middle years of school.

This project is particularly concerned with the role of the teacher in facilitating inquiry-based learning. Teachers need to implement new and different ways of teaching to develop classrooms as communities of learners (Brown, 1997; Mousley, 1993; Renshaw, 1998; Taber, 1998; Varelas, Luster & Wenzel, 1999) in which learning through inquiry is a significant approach. Teachers need to provide structural guidance and inform students of the purpose of inquiry (Watson & Wood-Robertson, 2000), to re-evaluate their beliefs about what constitutes mathematics and science, and to develop the confidence to implement such inquiries. Such approaches to teaching may represent radical change from existing practices (Moscovici, 2000; Watters & Ginns, 1997, 2000).

Although advocated for the best part of the last century (Dewey, 1910; Schwab, 1966), the adoption of inquiry approaches by teachers has been problematic. While teachers can adopt effective pedagogical practices to implement such inquiry-based learning, such change is complex (Diezmann & Watters, 1998; Watters, Diezmann, & McRobbie, 1997; Watters et al, 2000). One reason is that teaching practices are culturally dependent and resistant to change (Stigler & Hiebert, 1999). Before exploring the specific examples a brief overview mathematical and scientific investigations is given.

(1) Mathematical investigations

Mathematical investigations have three key implications for teaching. First, they are extended problem explorations, which provide students with opportunities to engage in deep learning through the identification of a problem, collection of data, exploration of multiple strategies, communication of solutions, and reflection on the outcomes of the investigation. Second, due to their open-ended nature, teachers can capitalise on the use of investigations to provide opportunities for students with a range of mathematical abilities and interests. Additionally, teachers need to cater for the diversity of students by creating authentic opportunities for collaborative teamwork because individuals can contribute their specialised knowledge or skills to the task. For example, one student may undertake and record complex calculations within an investigation, whilst another student may complement the symbolic representations of these calculations with text and pictures. Third, investigations provide a context for students to apply their mathematical skills and to learn new skills. Hence teachers can determine whether students not only know how to do a procedure, such as addition, but can apply it. For example, in one investigation students erroneously calculated the number of sweets in a sealed container by adding the height of the container and its mass. Thus the teacher needed to realise that although the students could add, their result was meaningless in this context.

(2) Scientific inquiry

Several approaches to inquiry based learning in science can be identified. These include structured, guided and open inquiry (Colburn, 2000). In both structured and guided inquiry the teacher plays a significant role in both identifying and planning the problem. However, open inquiries foster opportunities for students to experience uncertainties, ambiguities and the social nature of scientific work and knowledge. Here, the teacher plays a very different role. In this study, the constraints, affordances and concerns that guide the role of the teacher are addressed. The study highlighted the importance of three main issues. First, the formation of a community of learners was developed which facilitated the higher ability children and also contributed to enhanced performances of lower ability children. Second, an open-ended inquiry approach afforded opportunities for high ability children to grapple with more sophisticated ideas and processes. Third, classroom discourse was structured to encourage the development of “scientific talk” for the children.

Through these complex investigations students develop in context a range of key scientific and mathematical processes and skills such as problem finding, problem posing, constructing hypotheses, explaining, justifying, predicting, and representing, together with quantifying, coordinating, and organising data. Students become mathematically literate by generating and interpreting information that is represented in multiple forms such as diagrams, charts, tables, and graphs. They become scientifically literate by engaging in hypothesis testing and evaluation of evidence and they become technologically literate through the use of tools relevant to information or data gathering. These processes and associated understandings are essential for effective participation in a knowledge-based society. They become technologically literate through the use of calculators, the internet, and various word processing, spreadsheeting and presentation technologies.

The aim of this paper is to describe a set of principles or conditions which we find necessary in the establishment of successful investigations. Indeed, seven principles emerge from an analysis of both structured and open-ended inquiry:

1. Establishing context
2. Adopting a design focus
3. Employing a constructivist epistemology
4. Connectedness
5. Conceptual change teaching
6. Differentiated instruction
7. Scaffolding through discourse patterns

Study 1: Structured inquiry

The following is an example of a structured inquiry in which students in a Year 7 (12 year olds) learnt about energy transformations over a period of approximately 20 weeks. The theme was developed over two phases. In the first phase, in term 3, the students were introduced to the concept of energy through a number of activities related to change in energy such as rolling objects down ramps, and measuring the behaviour of dropping balls. These activities were undertaken in the school playground. In phase 2 in term 4, students explored energy transformations in machines by constructing windmills and Ferris wheels using Lego Dacta in the classroom. Three-four students worked together in teams.

Several issues emerged in this example which highlight the pedagogical approaches adopted to support learning:

- Establishing the context
- Strong focus on designing experiments and fair testing.
- Teacher beliefs concerning student learning were consistent with constructivist philosophies
- Student ideas related to the inquiry were linked to student experiences
- Understanding developed sequentially through conceptual change strategies
- Acknowledgment that inquiry approaches need to be differentiated for different students

Establishing the context: The teaching of science in primary schools is an endemic problem with an extensive literature base highlighting the many issues that impact on effective teaching. Not least among the constraints to teaching science is teacher confidence and conceptual knowledge. The regular teacher in this class has a strong interest and passion for science. As a typical primary teacher she is responsible for all key learning areas and hence science is only part of her repertoire of skills. Her colleagues held her in high regard as a competent teacher in science and her sense of self-efficacy was high on formal measurements. The class, like many primary classes, have not had expensive exposure to science in preceding years. Developing the skills to engage in collaboration, to ask questions and to assume some independence were priorities for this teacher prior to the implementation of the inquiry program.

Design focus: The teacher's approach in these investigations was to provide a hypothetical scenario and suggested that students could generate questions to investigate. In commencing each topic she would provide some prototype questions and then challenge the students: "What other things could you investigate?" Through discussion she attempted to draw out an understanding of what features were important and not important in the scenario. She also emphasised that students were responsible for phrasing their own questions about the scenario. She sought to develop students' understanding of the notion of a fair test as a core element in scientific inquiry. She deemed it essential that students understood that inquiry required confidence that they were testing only one factor in a situation. She provided guidance in structuring their initial experiments in Phase 1 so that they conceptualised experimentation as a process of controls and variable. Her expectation was that they would see the design of fair tests as paramount in inquiry.

For example, in exploring the energy changes in dropping balls she introduced the lesson by proposing to the students the following challenge: "I want you to compare what happens if you drop different balls from the same height. What sort of energy change is there?" Students attempted to respond but the teacher stated: "I am not going to answer, these are rhetorical questions, I am just putting them out there and you are going to find the answers."

She clarified the problem again and stated that she had collected the necessary gear into a box. She posed several questions about the nature of the balls: what sort of balls would I have chosen and gets the students to discuss among themselves before responding. The purpose was to elicit ideas about how to design the experiment and what variables might be considered. The discussion continued to emphasise the need to design a fair-test. Students were encouraged to develop think about the fact that the balls would be different size and different shape which has the potential to negate a fair-test. Although the teacher outlined a possible protocol, she encouraged the students to develop their own strategies. They were not provided with any worksheets or specific guidelines and consequently several approaches were developed (Figure 1).

Figure 1, Designing and conducting an investigation

Observations of students confirmed persistent engagement. Students acknowledged their freedom to choose different investigations. This flexibility featured throughout the program. For example, in a later task in Phase 2, two students negotiated to explore the properties of a water wheel using water from a tap to drive it instead of the windmill as most others were building,

> Me and Huan did get to build the water wheel because everybody in the class was building windmills. It was our suggestion because we would like to try something different

Students' knowledge of investigation developed during the semester. They understood the purpose of investigations could describe the notion of working scientifically as involving identifying and controlling variables and enjoyed and felt successful meeting the challenge.

> What I think an investigation is doing a series of trials to learn about something - prove an idea. (Sue)

> I think we learned how to design our own experiment and get used to the things you have to have in the experiment, like the variables and (inaudible). I think we also learnt how to come up with our own questions because once you did one you had more questions, and you wanted to find out how to make that into an experiment or investigation. (Rachael)

> Maybe at the beginning you think it looks really hard but after you do it its not too bad. (Tom)

Constructivist beliefs: In fostering an inquiry approach, the teacher adopted the following strategy:

> I actually talked about what they (the pupils) may have done previously, or previous experiments.

She then drew upon what students wrote in their log books to give her some direction for teaching or to be aware of how ideas were being developed before proceeding. She made sure that the events in the investigations were linked to the pupils' experiences, either in the investigations that she had done or in the discussions that followed. She frequently stated that the primary goal of instruction was to develop a deep, rich understanding of processes of science, which are "best acquired through student inquiry."

The teacher's approach to the implementation of an investigation was expressed in the philosophy,

> Teaching is a cycle which begins with the detection of pupils' ideas, continues with the teachers providing help to the pupils to understand scientific ideas, which are different from and better than existing ideas.

She believed in replacing the old ideas with the new more scientifically appropriate. However, in achieving this cycle she recognised the need for close supervision and scaffolding. For in describing her implementation of an investigation she stated,

> I actually give them something to do and watch how they tend to go about it. Just to see what their ideas about investigation are.

Connectedness: An important aspect of these lessons included a recognition of how new ideas are inter-related to other experiences and ideas. These links were made in conversations with the students but also were built into the program in a comprehensive way so that key ideas developed in science were able to be related to ideas in other areas of the curriculum. This was noted by students, who argued,

> I think the main thing that we learnt about kind of connected with our social (science) stuff because in SOSE (Studies of society and the environment) we learnt about development and how we used energy in 2000BC and how we use it in 2000AD, and that kind of connected into our investigation. I think...because we also did a bit of looking at previous inventions and then we could compare them to what we built and made and investigated, and we could see the changes (inaudible) and maybe how people don't really change.

Conceptual change: Listening and responding to individual ideas enabled her to challenge existing ideas and provide alternative explanations by drawing on the pupils own ideas. Her belief was that experimentation or hands-on activities did not challenge students understanding and that thinking had to become public in order for ideas to be challenged with alternative more powerful explanations. She described her approach,

> So we look for the anomalies and the discrepancies in the data, and have a bit of a talk about why that might be; and they contribute various reasons. I often say to them Okay, this isn't fitting with what we thought was going to happen. What might have happened? So they do it rather than me. I just say You have a buzz about that and come up with your ideas and reasons about what might have caused this. And we get a variety of things depending on what you're doing: like the direction of the wind; or

> the way you held this; or someone might have had it on a slope. You get a whole range of different ideas and have a look at them.

Students also acknowledged that learning was a process of building on knowledge in active ways,

> I think once you've done it and learnt how to do it with science; you have a way about doing it – a procedure. If you find that and you remember that it will work. (Rachael)

Differentiated approaches: The teachers' approach provided her with direction. She could moderate her teaching to meet the needs and capability of individual pupils. The approach also provided her with better insights into the pupils' capabilities by giving her a sense of what response she could expect from individuals. In conducting inquiry she was sensitive to the capabilities and motivation of individual students. She considered it important that all students could benefit from investigations and that the students should feel free to express ideas. For example, she noted,

> You get an idea of the kids who are willing to have a go and the kids who don't. Lots just do their task and sit with folded arms and wait for the next direction. So usually I try to - with some scaffolding, not just an open thing - give them something to do and then listen to their conversations and try and pick up their experiences. And just to get them to talk. My kids spend quite a bit of time talking and discussing with each other or whole class discussion. It's anathema to me if they've got to put their hand up in the air to speak. That's not what adults do, so in my class-room I try to get over that.

Achieving these goals required perseverance, time and patience. It required her to reconceptualise of the purpose of schooling an issue she had long grappled with,

> My expectations of what inquiry might look like have not changed much at all. I know what I should expect to see in the classroom if students are learning by inquiry and I believe it is achievable but it is something that requires time. It requires change on the part of the student's expectations of what school is about and also what they expect to happen. To develop greater independence in their learning requires time and an incremental movement towards the desired goal of student initiated open inquiry.

Scaffolding: The teacher emphasised the need to listen to students and observe their actions carefully. For her learning was a dialogical process (Stables, 2003). Lemke (1990) describes the relationships as communities of practice in which students and teacher engage in sense making. She attempted to extract explanations, to engage students in debating the ideas and then as appropriate provide necessary information to resolve questions .

She stated, "you have a bit of a discussion about those while dripping in some other information that I have." She described her approach, in which scaffolding involved explicit explanation as well as the use of demonstrations to help students,

> And a lot of kids when they're stuck, they saw it as the air here and it was just bouncing on the air and they didn't get the idea that it was a stream of air going around and so we had this idea that it was bouncing. So that was a misconception so I thought Okay, the Bernoulli also applies to liquids. So very quickly I went and got a ping pong ball and mixed up some green paint and I painted liquid and Okay, its going down, not up and the principles the same. So it moved over the ping pong ball and it was all green, it wasn't just green on the bottom. It wasn't just hitting---and they thought Okay, it works the same way. So I did that quite a bit. And just having a range

of little experiments that they're not doing or little demonstrations that they're not going to do that you can do to illustrate your point.

Figure 2, Scaffolding

The students also recognised their dependence on the teacher for support as Rachael explained,

> You can get easily confused in science, and if you need something to help you, its not like you can go straight to the bookshelf and get a book out and read about it. So, normally, if you're confused you can rely on the teacher and you expect her to know or help you. … I think once you've done it and learnt how to do it (inaudible) with science; you have a way about doing it -- a procedure. If you find that and you remember that it will work. (Rachael)

Summary

In concluding a discussion of structured inquiry, we note the dilemma faced by the teacher. Her philosophy, beliefs and practice were in alignment. Investigations are important but also important is the need to establish a core understanding. The approaches used by this teacher were highly effective in achieving this balance. The notion of explicit teaching as complementary to investigations epitomises the teacher guided approach. Her ideas were stated,

> Explicit teaching, and by explicit teaching I do not mean the stand and deliver type lesson, is essential at this level. The explicit teaching occurs during the investigations and the discussions that follow those investigations. Investigations are an essential part of this phase even though the question and the investigation is teacher generated. It is through this approach that students do ask the questions which lead to discussion and further investigation.

She was strongly of the belief that Inquiry teaching and learning can be represented as a continuum from inquiry with an in-class focus, closed inquiry leading eventually to open inquiry.

Study 2: Open inquiry

This example draws upon a study conducted in term three of a large parochial boys school located in a major city. Over a period of 15 weeks (90 - 135 minutes per week) students in a Year 8 class of 32 boys, aged 12 to 13 years, were introduced to a program of inquiry science in which they explored a common problem. The junior high school Year 8 class was identified on the basis of ease of access and cooperation provided by the school. Year 8, the first year of high school, was selected because of the flexibility of the content of the school program. The regular classroom teacher willingly agreed to the conduct of the study and the parents provided consent for their sons' participation.

The methodology adopted in this study was that of a teaching experiment. One of the authors was the teacher who with the cooperation of the regular classroom teacher took over the class for a full term of 15 weeks. A teaching experience that involves the implementation of a new way of teaching conducted with careful monitoring in order to capture the dynamics of the teaching learning process allows the practitioner to draw inferences based on his own experiences and applies it in context. It is a manifestation of action research in that the initiatives are carefully analysed in collaboration with critical friends who have observed the teaching or videos and responded to events. Thus the regular teacher was a constant observer of the class and a critical friend. She provided substantial feedback on the program. Other data sources included videotapes of the lessons, work artefacts from the students, interviews with students, and quantitative surveys of attitudes.

The first task of the study was to establish a classroom environment that was representative of a community of learners engaged in a common task of knowledge construction (Lemke, 1990). The focus of the intervention was emulating authentic practice, implementing cognitive apprenticeship and facilitating situated learning by: (a), the establishment of a co-operative and collaborative classroom with participants engaged in exploration of each others reasoning and viewpoints so that a shared understanding and commitment to goals evolved for all participants; (b), skilling of the students in the heuristics of problem solving and scientific reasoning (Galotti, 1989; Kuhn, 1993); (c), development of autonomy (Collins, et al., 1989), and, the development of motivational states oriented towards learning goals rather than performance goals (Dweck & Leggett, 1988).

The investigation

The concept of an open-ended, independent investigation (or project) was introduced by referring to a futuristic newspaper item, dated 28 February 2035, that suggested travel to Mars was now much easier and migration to the planet would be an attractive possibility, considering the large population on Earth. The newspaper item included an advertisement inviting interested groups to tender for the construction of a biosphere as part of the infrastructure to support the establishment of a colony on Mars. A concurrent and related problem, referred to in the same advertisement, was the need to study a variety of animals and plants and identify those that would be necessary as part of a viable colony on Mars. The latter problem was included to have some identifiable component of the open-ended, independent project that was in accord with the content of the schools Grade 8 science curriculum for that term. Each group brainstormed and recorded on paper initial ideas for both problems. These initial ideas were then subject to peer review by passing them from group to group for written comment and suggestions on a round robin basis.

In reporting on the issues emerging during this open inquiry, the words of the regular teacher and students are used.

Establishing a context: In implementing this program of open, unstructured inquiry, students were experiencing a very different model of science teaching. Normal science classes as experienced in the previous three terms were universally described in ways that depicted a fairly traditional classroom. Students were seated in rows, a textbook formed the core of the program, and formal testing impacted strongly on the teaching. The reflections of one focus group in the interview sessions graphically described the environment and were representative of comments provided by other focus groups:

J We normally sit in front of the teacher
D And she writes stuff on the board
A ... and we write it down
C a lot
A the teacher talks
D Normal science, you just sat there and you fall asleep.
C And you'd just watch the Suncorp clock tick by.
D And then it goes backwards and you're going ahhhhhhh!
E 2.06, and then it goes 2.05 ... and you think No.

This description of the typical science classroom environment by the students is in accord with the observations of the researcher-as-teacher made earlier in the year. The standard layout of the junior science laboratory with its fixed benches was noted as a factor that had to be taken into account when planning and implementing the various learning experiences.

The responses of students in one group summarized the feelings of most students about the learning environment established for the project. They believed the learning environment provided a context for students to develop autonomous learning capabilities. Fred described the changes in the learning environment, which demonstrated that the students were actively engaged in understanding, "In our normal classes, like, the students as ourselves, we take a back seat, but now in these new classes, the teacher takes a back seat and really we with Tyrone completing the sentence get to expand our thoughts." Tyrone continued: "This way we are actually making experiments doing experiments as well as getting information from the library and places like that."

Nigel, another member of this group added: "in like our normal science lessons, we just used to walk in, sit down, copy out the whole lesson and it was really boring, and I don't think, because you're so bored. Were just copying it down and you're not learning anything." He continued: "We are the ones ourselves who take a back seat when its us should be learning, not the teachers. But in this one were like working as a group, as a team, as a community." Nigel concluded,

> We actually did something instead of writing stuff off the board, and following experiments, we got to do our own when we learn, we learn about stuff that is interesting.

The nature of the problem, the individuality of tasks, and the level of intrinsic motivation all contributed to an authentic science experience. Students acknowledged that they were working like scientists because they worked in groups, solving their own problems by doing it themselves.

Creating a design focus: The teacher expressed some initial concerns with students having the liberty to design experiments but saw value for students finding out by themselves,

> That is one of the things I see with science. I see it as a very important part to solve puzzles and to explain things but you often have some thing you have to try and find out reasons for.

However, she acknowledged some constraints and reported that open inquiry was viewed as a problem by some support staff,

> The library too, staff were not sure. They were used to having a structured situation where they were told ‘yes the kids would go to this booked marked site on the Internet or they could go to this CD or this topic’ so it was very different for them too. I think they didn’t mind that.

As the program developed she saw problems related to perceptions of the students that they were falling behind. For some there was a sense of slow pace of learning. For example, student feedback to her prompted these responses,

> After the first couple of weeks into the last term some kids were anxious that they did feel they were getting very far and they were missing work that other classes was doing.
>
> I think some of them they lost a bit of enthusiasm because I felt they did not see things progressing as quickly as they would like. They had ideas that they wanted to put into place and it didn’t seem to happen and I think, I am not being critical of anybody here, because it think that only having three periods a week and they would start to get an idea and it would be a couple of days before the next thinking happened and that made it difficult.

These sentiments reflected the highly traditional nature of teaching in the school. Year 8 is often about establishing a common understanding of basic science content given that students attending the school come from many feeder schools. The pressure is on both students and teachers to cover the content. Given there were seven classes running in parallel with this project class, students were well aware of where each class was in covering the content.

Constructivist beliefs: The approaches adopted were influenced by assumptions that students learn best when actively engaged in negotiating meaning in a social context with effective support from a knowledgeable teacher. Key assumptions about learning through sharing of ideas and social discourse in some instances needed to acknowledge students reluctance to share ideas in this context. For example, the teacher described the experiences of one student, who felt constrained by the requirement to work cooperatively,

> He had a concern that by sharing the ideas that other would grab onto his ideas rather than thinking of other ideas. (He would have been happy) if he had been able not to have had to share ideas. Andrew was concerned but he would have concerned more productivity, time was concerned about the lack of structure and not knowing where he had to go and this is how it has to be done etc.

However, she noted that sharing ideas was valuable but opportunities were constrained by school structures,

> Well I guess they got an opportunity that they would not normally have to toss ideas back and forwards and gain from other peoples ideas in a situation where they would not normally get the opportunity we would not normally take the time. … Well I think that’s a valuable part of learning the only problem I see is that with the constraints we have imposed on us it is something very often that is a luxury that we don’t have the opportunity unless kids work in groups outside the school time to work on things like some projects.

Nevertheless, students acknowledged that they were learning to learn through this inquiry approach. They acknowledge that learning involved a commitment and required them to take responsibility for their learning. One student emphasised the importance of work and highlighted the emphasis on deep learning. Learning was seen as about learning to think and learning to learn

> In the first two terms it was more of a case of learn the science exam material and now it more like learning for our own knowledge and what we re taught we remember & we are interested.

Another student Nick, emphasised the changing roles of teacher and student with a recognition of the importance of developing a community of learners,

> In like our normal science lessons, we just used to walk in, sit down, copy out the whole lesson and it was really boring, and I don t think, because you re so bored, we re just copying it down and you re not learning anything. He continued: we are the ones ourselves who take a back seat when it s us should be learning, not the teachers. But in this one we re like working as a group, as a team, as a community.

The task involved students drawing upon knowledge of a wide range of areas from astronomy to biology. In most instances, students needed to research this information for themselves, which was time consuming. Some expected that the teachers would provide the information so that they could move on more quickly.

Connectedness: A number of students reported in their log books that they had visited public libraries and worked at weekends with their team mates on the tasks. Being able to share ideas and listen to peers was acknowledged as a valuable process to support learning. Furthermore, most groups also recognized that learning to work in groups was an important life skill and that this strategy was a worthwhile and successful element of the intervention. Of the eight groups only two, conceded that their group work was not very effective in achieving their goals. The tasks were seen to be meaningful for life long skills in that they had learnt the process of learning through the development of information literacy and group skills,

> We have learnt how to research ourselves, where to go, what sources to find, which sources are best. Maybe, if we have an upcoming assignment in the next couple of years we will know where to go.

> Group skills will be valued for the rest of our lives" and "It's a big bad world in the business world, you've got to work as a group sometimes and it gives you skills, maybe at debating. You've got to work as a group.

Conceptual change: In the independent open ended approach students took on the role of exploring ideas and information outside the classroom.

Students were provided with open access to the library as well as organized library periods to undertake research. In contrast to normal library periods, library staff were briefed that students would not be provided with a set list of resources as customary but would have to search multiple sources of information, including encyclopædias, texts, Internet and teacher-prepared notes.

The task was pursued with some alacrity. Most students demonstrated that they were able to construct detailed reports on the characteristics of selected animals as evident in the posters, and logbook and protocol book entries. Indeed, in the focus interviews some students displayed a considerable depth of content information even to the extent of remembering the Latin names of genera. They were confident that they had learned substantial content and understood it better. It was more interesting and therefore they were motivated and found it easier to remember,

> At the start of the term, none of us knew anything about invertebrates or anything like that, and now at the end of the term we've learnt heaps of stuff. If we had learnt about invertebrates in the format of first and second term, I would not know it as well.

Differentiated approaches: Differentiation involves modifying the instructional program to suit the learning needs of individuals. It may involve changes to the content, assessment, environment or processes. In this open inquiry students were encouraged to negotiate the learning task. Some pursued complex investigations involving the simulation of Martian atmosphere to monitor the behaviour of plants and insects. Others undertook a library research project on the characteristics of different plants and animals to ascertain which would be useful on Mars. Some explored the construction materials needed to build a Martian base and constructed out of modelling clay a prototype base. The lessons were differentiated because student had choice. Nevertheless, there were some concerns as revealed by the teacher in response to a discussion on motivation,

> I think some of them they lost a bit of enthusiasm because I felt they did not see things progressing as quickly as they would have liked. They had ideas that they wanted to put into place and it didn't seem to happen. And well I think (there were problems for) some of the lower ability. For example, I don t think that Nick got started at all, and then some of the higher ability like possible Tim, who really wanted more structure and really did not know where to go and he felt frustrated by um not seeing the goal. I think he is used to seeing how much is going to be done in every lesson and what is going to be covered and things have to move quickly and (he) found that difficult as well Tim mentioned that to me and Andrew, in the group where he did most of the work felt that he wasn't achieving because he did not have the group to bounce ideas off. Some of the others really enjoyed the fact that they could bounce ideas and could discuss and talk with one another with peers of similar abilities.

In summarising her perceptions the teacher stated,

> I do think that overall that group probably wasn't ready for doing that. I think there are kids there that certainly had the ability to benefit and I think that unfortunately in a group of thirty although there were enough kids who weren't ready or weren't prepared to cooperate that spoilt that situation of learning for others. It certainly I would not say it wouldn't be valuable particular if you could take half the group and a cooperative group rather than a few who were not prepared to do anything or not be cooperative.

These issues reflect in part the lack of experience that the students had with inquiry approaches and the lack of self reliance in their learning. The school operated a traditional program with high expectations for success held by parents and teachers with heavy reliance on formal testing.

Scaffolding: In this open ended approach the teacher assumed the role of advisor and mentor. Advice was provided on where to find information, how to set up experiments, and where one might find appropriate resources. In addition understanding was constantly checked to ensure that students were proceeding productively. It was important to remain open to student ideas, to encourage curiosity and to support them to explore their ideas in practical yet systematic ways. Models of working scientifically were reinforced. For example, students were reminded of their questions, what sort of data would answer their questions and how would they obtain these data. The dialogue was designed to reinforce student independence and inquiry. This approach was acknowledged by students, for example, Greg, stated,

> The teachers teach us step-by-step and like Mr Watters, he makes sure we know everything first until we go on to the next thing.

Another student described the interaction in similar terms,

> Mr Watters always came by and said, 'Oh, do you think that'll work?' and 'tell me how it would work?. Or 'Tell me what you're gonna do' and 'if there s any problems, tell me what they are, and maybe we can get the class to solve it for you.'

This approach contrasted to the normal experiences in the class as one student stated, "Mr Watters got involved with you, Mrs Xjust told you the answer then just went on to another person."

Although students perceived the term 4 (project) environment as a lot friendlier, they acknowledged that learning still involved a commitment and required them to take responsibility for their learning. One student emphasized the importance of work and highlighted the frequently stated association between interest and effort,

> In the first two terms, it was more of a case of learn the science exam material and now it is more like learning for our own knowledge, and what were taught we remember. We are interested. Learning was seen as about learning to think and learning to learn. Although it was perceived as friendlier, laid back, it was learning to learn. We still had to put in the hard work.

Summary and Conclusions

All students can benefit from an inquiry approach to learning provided some fundamental supports are provided.

A major constraint with the open ended inquiry described above and others ( ) is the context in which it is implemented. In research situations where the class structures and traditions are perturbed students are unsettled and confused about their roles. The perceived freedom for some students is difficult to manage in a responsible way. Similarly, school structures are often unable to cope with the complexity of student needs. Libraries are often accustomed to preparing set sources of information, furniture in science classrooms do not facilitate good interactions, opportunities to leave uncompleted project material undisturbed for several days or weeks is problematic and criticism from colleagues for perceived rowdiness of students is ever present.

Hence developing the skills to engage in inquiry is paramount. Structured inquiry approaches provide an introduction to the continuum. Learning to inquire is a scaffolded process with the need for intensive and often explicit support in the beginning with a fading of intervention as students develop the skills and confidence to inquire.

The seven key principles that have emerged in comparison of structured and unstructured inquiry are important factors.

Table 1
Strategies to meet the principles of inquiry based learning

Principle	Teaching strategies	
	Structure inquiry focus	**Open inquiry focus**
Establishing context	Developing a scenario that has common elements but scope for individual exploration. Teacher initiated and planned	Teacher sets problem boundary with students negotiating inquiry
Adopting a design focus	Teacher focuses on process as an outcome	Focus moves to product
Employing a constructivist epistemology	Local social context, making meaning	Wider context, mentors
Connecting student experiences	Developing relationships, interconnecting ideas	Knowledge production, meaningful activities
Conceptual change teaching	Internal, guided by teacher	External, reflected on by the student
Differentiated instruction	Orchestrated by teacher	Orchestrated by students
Scaffolding	Of process before product	Of product before process

Through these complex investigations students develop in context a range of key scientific and mathematical processes and skills such as problem finding, problem posing, constructing hypotheses, explaining, justifying, predicting, and representing, together with quantifying, coordinating, and organising data. Students become mathematically literate by generating and interpreting information that is represented in multiple forms such as diagrams, charts, tables, and graphs. They become scientifically literate by engaging in hypothesis testing and evaluation of evidence and they become technologically literate through the use of tools relevant to information or data gathering. These processes and associated understandings are essential for effective participation in a knowledge-based society. They become technologically literate through the use of calculators, the Internet, various word processing, spread sheeting, and presentation technologies.

Implications

The implications of this research impact directly on attempts to reform the teaching of science, mathematics and technology to acknowledge contemporary learning theory and to accommodate the burgeoning and changing knowledge base necessary for competence in the sciences. However, there are significant challenges. Curriculum innovations have historically failed to influence teaching and learning practices due, in part, to teachers' scarce opportunities to learn new content and improve their practice. Inquiry approaches to learning assume that teachers are well prepared to engage in inquiry themselves a position that is challengeable given the preservice educational courses most have experienced. Teachers on the whole have had limited experiences in scientific research or opportunities to generate knowledge themselves through inquiry. This lack of experience is however compensated for by the pedagogical knowledge that effective teachers possess. However there needs to be the willingness to let go of their concerns about the quality of learning that emerges through inquiry because through inquiry students learn to become autonomous and not function as repositories of useless information.

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