Inquiry science: Issues in the implementation of a community of learners

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Abstract

This paper reports the problems of a researcher-teacher attempting to meet the challenge of inquiry learning in grade 8 science. The research was conducted in two classes the first being a class of 32 students taught over a term. During these 27 lessons, students were engaged in investigating the establishment of a space colony on Mars. The second class was taught the following year for six weeks during which students were engaged in a range of problems associated with the properties of matter. Issues concerning problems of scaffolding, group dynamics and goal direction that were identified in the first study were addressed in the second study. Analysis of videotapes of the lessons, survey data and interviews with the participants which included the regular classroom teacher provided insights into the dynamics of establishing a community of learners, and identified constraints and expectations held by stakeholders of what science teaching should be about. The implications for teaching science using these pedagogical practices are examined.

Introduction

This paper reports an investigation into ways of implementing a meaningful junior high school science program. The study describes the experiences of a researcher-as-teacher attempting to develop a learning environment that is based on the notion of a community of learners. Initially, the paper explores the notion of a community of learners and the relevance and salient aspects of this approach for teaching authentic science. We then highlight some major theoretical frameworks that inform the study. An analysis of the data is presented which describes the behaviors of the students. In conclusion, the study raises issues concerning the efficacy of implementing practices in ways that make learning effective and enjoyable to students and acknowledges contemporary social constructivist theories of learning that concentrate on the learning of complex ideas in authentic situations (Brown, 1994).

Community of Learners

Extensive research has shown that school practices in teaching science are alien to the routine processes of scientific endeavour in the real world (Lave & Wenger, 1991; McGinn, Roth, Boutonné & Woszczya, 1995). Furthermore, concerns are being expressed that the type of science being taught in schools is irrelevant to the needs of students confronting the uncertainty of the 21st century (Millar & Osborne 1998). The transmission-absorption model predominant in most classrooms contrasts with recent thinking in science education which asserts that the practice of science involves communities with distinct discursive practices (Lemke, 1990). Hence school science should provide students with opportunities to become socialised into the way of thinking and reasoning in the science domain involving an apprenticeship approach (Brown, Collins, & Duguid, 1989). This alternative notion of science education is based on the assumption that learning science is a process of enculturation into a community of practice in which ideas are substantiated by negotiation. Hence, transactions in the science classroom should be characterised by participants arguing, debating, and clarifying points of agreement or disagreement in ways representative of scientific reasoning as described by Kuhn (1993). In this environment, students build knowledge by listening to each other, engaging in conversation in which ideas are shared and voicing their opinions

(Bereiter, 1994; Orsolini & Pontecorvo, 1992; Richmond & Striley, 1996; Vellom, Anderson, & Palincsar, 1994).

Becoming scientifically literate involves being able to comment from an informed position on issues of science that affect our everyday lives. These issues are multifaceted with many possible solutions. Students need to see science as a tool and a way of thinking and understanding our natural environment. Science does involve uncertainties, ambiguities and is influenced by many social and emotional issues. It is a way of solving problems, but in the real world that students will confront as adults, expertise and problem solving is a social and collaborative practice. To achieve this disposition towards science, students need the opportunities to explore open-ended problems meaningful to their context. Students need to acquire the capacity to work collaboratively and to develop the ability to draw upon information and expertise from many sources. Self-efficacy, interest and enthusiasm needs to be developed by providing opportunities for students to be successful in using science to solve problems by personal investigation.

Bereiter and Scardamalia (1992) argue that the most important focus in teaching is knowledge building through autonomy, which requires that students are active in the process whereby they come to understand the role they play in the classroom. In developing autonomy, the perceived responsibility for the child's learning moves from the teacher to the child. Thus, the central task of teaching is to enable the student to perform the tasks of learning (Fenstermacher, 1986). Such an environment acknowledges the importance of both situated cognition (Brown, Collins, & Duguid, 1989) and the importance of personal and community motivation.

The major theories pertinent to learning and teaching that informed this study are now discussed.

Constructivism

Contemporary research supports the view that students build an understanding of their environment by the personal construction of meaning facilitated by social interaction with other students and adults. Evidence in support of this assertion stems from Piagetian and Vygotskian theories in developmental psychology (Doise & Mugny, 1984; Vygotsky 1978), and through research on naturalistic classroom practices (Johnson & Johnson, 1995; Slavin, 1991). Hence, effective teaching capitalizes on providing opportunities for students to co-operate, to develop skills in critical and creative thinking, and to explore new phenomena. Teachers are managers and facilitators of the learning environment working consciously to establish dynamic learning communities and modelling interest, enthusiasm, and cognitive practices exemplified in the community of learners identified in the research of Brown and Campione (1990), Bereiter and Scardamalia, (1992) and Lipman (1988). Bereiter (1994) argued that educational approaches influenced by constructivism may not go much beyond addressing academic problems and knowledge-building, exemplified by individual achievement and limited to content and procedural knowledge. He advocated that discipline-based education should imply a kind of enculturation that must go on if a student is eventually to become an insider, a participant in a discipline, rather than someone viewing the disciplines entirely from the outside. This approach is central to the cognitive apprenticeship model articulated by Collins, Brown and Newman (1989). They argue that students should be drawn into a culture of expert practice that involves teaching them how to think like experts. In this context, experts (teachers) support learning using strategies such as modelling, coaching, and scaffolding. Students are collaboratively engaged in problem identification and solution built around project work that is personally meaningful and hence motivating (Lee & Brophy, 1996).

Cognitive Apprenticeship

Scardamalia and Bereiter (1994) argued that classrooms need to move from traditional collections of individuals guided by a Socratic teacher towards a community with shared responsibility for engaging in practices that constitute knowledge building. In order to establish the environment necessary for cognitive apprenticeship, the teacher should assume a role different from that in a traditional transmission-absorption model classroom. Teachers should abandon the orchestrator role and join the fray, becoming active participants as they attempt to guide the group toward the disciplinary high ground (Prawat & Floden, 1994). In addition, teachers are not solely experts who demonstrate concepts or phenomena.

Motivation

The role of motivation has been acknowledged in recent models of student learning (Pintrich, Marx, & Boyle, 1993). These authors argue that, despite our knowledge about conditions for conceptual change based on cognitive models, effective learning does not always occur in classrooms despite the best of intentions of teachers. They point out that learning in classrooms is greatly influenced by peer and teacher interactions, sociocultural context, and the learner's motivational beliefs about his or her current knowledge or about the knowledge to be learned. Their arguments support the role of motivation as a contributing factor in developing effective communities of learners. The extent to which an individual engages in a particular problem solving task depends on three components that impact on motivation, namely, value (beliefs about the importance of the task), expectancy (beliefs about one's ability to undertake the task), and affective (emotional reaction to the task) components (Pintrich, 1989). Each of these components interacts in complex ways to influence the alacrity with which a student undertakes the task or co-operate in a particular situation (Dweck & Leggett, 1988; Elliott & Dweck, 1988).

Methods

This study utilised a problem-based methodology that aimed to resolve an educational problem by considering the research within the classroom context (Robinson, 1993). Problem-based methodology acknowledges the practical constraints of the problem (Walker & Evers, 1988). The study incorporated interpretative elements (Erikson, 1986, 1998) but adopted a position of scientific realism, which acknowledged that educational research is conducted in an open system, with a myriad of influences, rather than a closed system solely affected by a treatment (House, 1991). Theoretical perspectives articulated previously nevertheless guided actions and interpretations of events. The researcher-teacher (JW) implemented strategies informed by the theoretical perspectives. The second researcher was a participant observer who recorded events and engaged in support as part of the classroom. A research assistant who monitored recording equipment provided further data collection support. At the conclusion of each lesson the team reviewed the lesson, identified key issues and reacted accordingly. The classroom teacher was present as an observer but responded to student queries as needed.

Participants

Over a period of 8 weeks (90 - 135 minutes per week) students in a grade 8 class of 32 boys were introduced to a program of inquiry science in which they explored a common problem. The junior high school grade 8 class was identified on the basis of ease of access and cooperation provided by the school. Grade 8 – the first year of high school in Queensland – was selected because of the flexibility of the content of the school program. The teacher was a willing participant and the parents provided consent for their sons' participation.

The Teaching Program - Planning and Preparation

Several planning meetings were conducted prior to the commencement of the classroom-based activity work. The issues discussed in the planning meetings related to the major aim of the study, that is, the establishment and maintenance of a community of learners and a community of practice in a grade 8, junior high school, science program. It was recognized that pedagogical practices would be important factors in the development of any classroom environment that might, arguably, be identified as consisting of a community of learners engaged in practices that have a collaborative, group emphasis. What strategies should be planned and implemented, in order to establish a classroom environment whereby students would become effective learners of science and become immersed gradually into the culture of scientific practice involving open-ended problem solving, negotiation of ideas, argument and debate, and scientific reasoning?

It was determined that pedagogical practices may be reflected in students' actions and behaviors, scientific understandings, and the classroom teaching and learning climate. The discussions resulted in the construction of a tentative criterion sheet that would be used for the analysis of pedagogical practices and resulting behaviors during the classroom-based activities (Table 1).

The notions of authentic practice, situated learning and cognitive apprenticeship underpinned the decision to use the process of students' selection of an open-ended problem for investigation, and the teaching strategies that would be adopted by the teacher (JJW). The main tasks would be to establish an atmosphere of collegiality, a culture of argument and justification of ideas, and a learning environment modelled on an authentic science research program.

A broad plan of action, consisting of three phases, was developed. In phase 1 it was decided to introduce students to open-ended, independent inquiry by engaging them in problem solving activities and the use of problem identification and problem solving techniques. Phase 2 would require them to pose a problem to solve, and plan and implement the investigation. In phase 3, the students would be given the opportunity to evaluate the product of the investigation, as well as the processes in which they were engaged.

Table 1
Criterion Sheet for the Analysis of Pedagogical Practices

Teacher - Student Interactions	Result in observations of:
Teaching strategies:	**Students: Actions**
Setting expectations	Listening to each other
Guiding students' planning actions	Engaging in dialogue and negotiation
Guiding students' exploration and evaluation	Whole group exploration
Recording - individual note books (log books; journals)	Collaborative peer teaching and learning
Recording - group books (protocol books; shared writing)	**Students: Affective**
Reflecting questions; argument	Confidence to speak out, critical voice
Round robin review	Risk taking
Regular reporting	Valuing different approaches to problem solving
	Shared responsibility for understanding
	Shared responsibility for planning, exploration and evaluation
	Interest, commitment, motivation, self-regulation, self-efficacy
	Students: Cognitive
	Conjecturing (theory testing)
	Authority for knowing is internal and collective
	Conceptual change
	Theory - evidence continuum
	Dialogic argument

Preliminary work also involved briefing sessions with the regular classroom teacher. The details of the planning were discussed and critical comment sought from the teacher. The layout of the classroom, a typical junior science laboratory, was examined to determine a configuration of tables and chairs that would facilitate collaborative group work. Areas were identified for the conduct of any experimental work that might be done by the students, placement for display of any charts and artefacts produced by the students, and the location of cameras and other equipment needed for the study. Visits to the school library by the students for information gathering sessions were also arranged.

The salient features of the intervention included a period of social adaptation to the environment, followed by an interval in which students were provided with strategic guidance for solving problems. The program concluded with students reporting formally to the class on their projects.

The researcher-teacher met with the students prior to the term holidays and outlined the program for the following term. The students were informed that they would develop a series of independent studies, or projects, the purpose of which was to explore some interesting common problem – namely the colonization of Mars. Group projects would involve the collection, organization, and description of data; hypothesis generation; experimental testing of ideas; and report generation (Watters, 1985). The projects were group oriented but collaboration and interaction between groups in order to help each other on their problems was to be encouraged.

Establishing a community of learners

Developing the learning environment in a way that enabled students to function autonomously and to engage in personal learning required intervention at two levels. At the macrolevel the teaching intervention involved three phases – establishment of rapport and social interaction, development of specific skills and finally the Providian of opportunities for independent discovery and elaboration of knowledge. This framework was a modification of that used previously with younger students (Diezmann & Watters, 1998). The microlevel intervention was framed by a range of scaffolding processes, which were embedded in the day-to-day interactions with students. A description of the microlevel intervention will be integrated within a discussion of the three phases of the macrolevel intervention.

Teaching Component - Phase 1

The first task of this phase was to establish a classroom environment that was representative of a community of learners engaged in a common task of knowledge construction. 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 other's 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 (d) the development of motivational states oriented towards learning goals rather than performance goals (Dweck & Leggett, 1988).

Initially, the teacher presented a broad statement of the overall task confronting the students. This was followed by a period of settling-in where students were asked to identify working partners and to form eight working groups of four students each. The furniture was re-arranged to a configuration that was more conducive to group work. The same configuration was maintained for the subsequent lessons in the laboratory setting.

Problems in the form of puzzles, in which patterns could be identified, were presented to each group. The students were encouraged to share ideas and reflections on any solutions that were tentatively proposed during the activity. The pattern puzzle problems were then reviewed in a risk free environment where there was "no right answer," a variety of solutions were accepted, and students were encouraged to evaluate their solutions and ideas.

Clear expectations were set for the role of each member in a group – manager, speaker, recorder, and coordinator. The students were advised of group and individual responsibilities for recording information throughout. A Protocol book was allocated to each group for recording the ideas and deliberations of the group as a whole. Additionally, each individual was expected to maintain his own notebook (logbooks, journals) of his individual contributions to the group.

Teaching Component - Phase 2

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 for 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 for the settlement 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 school's Grade 8 science curriculum for that term.

The expectations established for work on the project were reiterated. The notion of a large class project (colonization and construction of a biosphere on Mars), which was divided into subprojects for each group, was reinforced. Group skills included allocating to each person a specific role in the group. Groups were advised that they would be required to report regularly to the class in formal reporting sessions.

Students engaged in additional exercises involving strategies for solving the problem such as brainstorming, and various heuristics for problem solving. These exercises included a set of team building problems in which the students had to predict what was inside a 'black box' that could account for unexpected observations, or account for movements of levers attached to the boxes. Students were encouraged to share ideas in groups and the relevant spokesperson contributed to a class discussion. They were also introduced to strategies such as "Plus-Minus-Interesting" (PMI) to evaluate a course of action before embarking on any plan. The researcher-teacher played a facilitatory role in these discussions to engender a risk free environment where there were vigorous and argumentative exchanges, and to guide students in the exploration and evaluation of their project. In particular, the teacher adopted strategies, such as modelling and scaffolding as suggested by theory (e.g. Collins, et al., 1989; Kuhn, 1993) and experience (Diezmann & Watters, 1996; 1997, 1998; Watters & Diezmann, 1997, 1998; Watters, 1985).

Teaching Component - Phase 3

The final phase, which lasted for about four weeks, involved the students in working independently (as groups) on their projects. Students had to identify their particular problem, speculate on solutions, consider the efficacy of the question, develop and implement these solutions or experiments and to reflect on the outcomes. The problem was multifaceted in that it involved the discovery of properties of Mars as well as studying the characteristics of particular biological organisms. All groups were required to investigate their respective problem empirically. For example, some groups examined the effect of growing various types of plants or insects in artificial environments that purported to contain various amounts of carbon dioxide. All groups were able to use the library and computing laboratories on demand to retrieve information. During phase 3, students were required to make group reports progressively on the development of their project, which included reviews of their empirical research on the Martian biosphere and research on biological adaptation. The conclusion of this phase consisted of seminar presentations in which each group described their problem, the solutions attempted, and their findings. The class was encouraged to question and discuss the findings.

Data Collection

The documentation of patterns of behavior was achieved by the collection of data by the non-participant observer, and a research assistant. Student interactions, discourse patterns, and attitudes were recorded during the preliminary phase and the main phase of the intervention. Lessons were videotaped to facilitate analysis of classroom interactions. The tentative criterion sheet (Table 1) was used for part of the analysis of pedagogical practices and resultant students' behaviors. Selected students were wired with microphones and their individual conversations recorded at intervals. As appropriate, students were interviewed at intervals in order to explore changes in perceptions of the classroom environment and associated changes in their attitudes and beliefs about science. All groups were interviewed in an hour-long focus session at the conclusion of the term's teaching. Because of limited time five facilitators were used. The focus group facilitators were briefed on the project and its objectives. A modified learning environment survey was administered a week before the teaching began and in the last week of the program (Fraser, McRobbie, & Fisher, 1996). Thus the database included multiple sources of both qualitative and quantitative data. The strategies and experiences of the teacher and students were monitored and their behaviors interpreted in terms of changes in motivation, richness of scientific reasoning and patterns of discourse and co-operation. The transactions were coded and analyzed using constant comparative methods (Strauss & Corbin, 1990) for salient elements and coherence with the espoused theories examined by the team.

Findings

The interactions, transactions, and relationships that developed in the class over the term are representative of the three levels of activity in a socio-cultural activity identified by Rogoff (1995). The class involved members of discrete groups, a community of groups and the teacher, each of whom played a role as a resource, and a challenger in exploring a myriad of activities. The interpersonal involvement and arrangements led to the establishment and recognition of certain constraints, behaviors, values and responsibilities. Firstly, individuals and groups behaved in idiosyncratic ways depending on their capability, previous experiences and motivation. Secondly, the community behaved in particular ways defined by a social level of activity. The class was accustomed to strict discipline and limited social interaction. The opportunity to engage in discussions among groups debating issues was a radical change that stretched the students' capacity to self-regulate their behavior. In time, the students' focus turned more towards themselves as learners and away from the adult teachers whom they seemed to appropriate as fellow group members. The high level of knowledge extant in the group further enhanced the vitality and cohesiveness of the community. Thirdly, the teacher set about attempting to implement a model of learning inspired by constructivist principles that mandated certain actions. This included recognition of students' prior knowledge, assumptions about the nature of scientific knowledge, assumptions about what constituted worthwhile learning, assumptions about the responsibility of learners and patterns of instructional behaviors that appeared in ways of discourse. For example, a belief that scientific knowledge lay in the way people made sense of their environment and that identification and justification of knowledge sources led to a pattern of discourse in which students were challenged to state why and how they came to have specific beliefs. Scaffolding of thinking was supported by questioning that frequently involved utterances such as "Tell us how do you know …?" or "Does every body agree …?" and if not "Tell us your opinion." The researcher-teacher behaved frequently as a facilitator and model within the framework of implementing cognitive apprenticeship principles. Videotape evidence reveals that the students responded gradually by imitating the behaviors of the researcher-teacher and over the period of the program assumed more responsibility for implementing processes. Thus in addressing the set problems, the colonization of Mars, students identified problems, developed problem solving strategies and implemented their own procedures to test propositions. In exploring biological concepts they engaged in pursuing information through individual and group processes and shared and discussed procedures, products and solutions.

In analysing the data we present evidence from the focus group sessions, videotapes of lessons, and from participant observer notes to substantiate claims that the intervention provided students with an environment that enacted aspects of a community of learners. We also will analyze the strategies and effectiveness of these strategies in achieving our objectives. A community of science scholars (Bereiter, 1994) actively engaged in the processes of science knowledge construction and problem solving, would demonstrate a range of characteristics. The learning environment should provide a context for the exploration of an ill-defined problem. Students should experience uncertainties, ambiguities and the social nature of scientific work and knowledge. Students' learning (curriculum) should be predicated on, and driven by, their current knowledge state, and an acknowledgment that they are part of a community of inquiry in which knowledge, practices, resources and discoveries are shaped by collaboration. In these communities members can draw on the expertise of more knowledgeable others whether they are peers, or teachers (Pizzini, Shepardson, & Abell, 1991). Firstly, we describe the learning environment and contrast it with the normal environment in which these students learn science. The key strategy to facilitate collaboration was the use of group work. The issues emerging in this practice, and how students' learning was shaped by this experience, will be discussed and finally the nature of learning that took place will be described. The findings will be concluded with an analysis of the implementation strategies.

The Learning Environment

Normal science classes experienced by the students 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 print resource of the program and formal testing impacted strongly on the teaching. The reflections of one focus, which were representative of comments provided by other focus groups group, graphically described the normal environment:

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'."

There were some seven Grade 8 classes, all of which did a common examination but were taught by several science teachers. Students saw themselves as learning science for examination purposes: "We just learnt the material, studied it, forgot about it." The regular teacher was acknowledged as a good teacher and she showed interest in the welfare of the students but she conformed to a transmission model of teaching. She would explain ideas if a student asked a question.

While students perceived the term 4 (project) environment as a lot "friendlier" they did acknowledge 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 we're 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 "its learning to learn – we still had to put in the hard work".

The nature of the problem, the individuality of tasks, 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."

The responses of students in one group summarized the feelings of most students about the learning environment established in the study. They believed that the learning environment provided a context for students to develop autonomous learning capabilities. Fred described changes in the learning environment, which demonstrated that the students were actively engaged in understanding, as follows: "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. 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." 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."

Using the tentative criterion sheet (Table 1), the participant observer noted that students engaged in a range of behaviors including listening to each other's ideas, engaging in negotiation about meaning, exploring issues as a group, and engaging in peer teaching and learning. The environment also facilitated students' confidence to speak out, to have a critical voice, and take risks. There was acceptance of a shared responsibility for understanding, planning, exploration and evaluation of problem solving tasks.

The teaching strategies identified using Table 1 were accompanied by clear demonstrations of actions that involved students listening, negotiating, sharing ideas, exploring problems and collaborating within groups. Some groups engaged enthusiastically while others were less committed or focused. In the affective behaviors, students were eager to contribute ideas and suggestions to the class. Indeed the regular teacher described them as "a vocal class" that became even more so given the opportunity to engage in discussion. There was clear evidence that motivation was high.

The students acknowledged the role the researcher-teacher played in scaffolding learning. It was noted that the researcher-teacher asked for their ideas and did not provide information all the time: "Mr Watters always came by and said 'oh, do you think that'll work?' and 'tell me how it would work', 'tell me what you're gonna (sic) do' and "if there's any problems, tell me what they are, and maybe we can get the class to solve it for you."

A comparison of pre- and post-test responses on the modified learning environment survey (Fraser, McRobbie, & Fisher, 1996), designed to explore the frequencies of a range of classroom practices, indicate that students perceived changes in the learning environment (Table 2). Six scales, represented in the 60-item questionnaire, are interpreted as indicators of: the social context (Sc); teacher interest and support (Ts); independence (In); level of autonomy (Al); involvement in investigations (In); and sense of commitment and organization (To).

Table 2
Changes in perceived learning environment

Scale	Pretest (mean, stdev)	post-test (mean, stdev)	*p* (two-tail)	Effect size
Sc	35.9 (4.2)	39.2 (6.1)	.02	.60
Ts	29.7 (7.7)	33.3 (9.7)	.06	.44
In	32.1 (5.1)	35.8 (7.4)	.01	.54
Al	27.4 (5.8)	26.9 (7.4)	.7	-.1
Iv	29.2 (7.3)	35.1 (8.9)	.001	.70
To	39.1 (6.8)	40.0 (7.9)	.5	.12

df = 27, Comparisons made with paired sample t-tests
Effect size = change / pooled standard deviations. Effect sizes above .5 are usually considered meaningful changes.

The interpretation of these results was consistent with the evidence emerging from the focus sessions, classroom observations, and analysis using the tentative criterion sheet (Table 1). The results confirmed that the social context was more harmonious and supportive of sharing of ideas. Students perceived that they were able to contribute ideas, give opinions, discuss what is already known and engage in discourse, which may be reflected in the In scale. The opportunity to engage in independent investigations to solve problems also increased. Given that the researcher-teacher designed the program there was limited opportunity for students to display full independence and hence little change in the Al scale was noted. Similarly, the students understood the program and were committed to conforming to the structure. The change in teacher support (Ts) scale, while positive could have been confounded by some students' perceptions that they wanted more structure and guidance from the teacher. A small number of students, especially one group, were concerned that the researcher-teacher was not detailing exactly what had to be learnt.

Collaboration in a Community of Learners

Group work in which students genuinely co-operated was not a normal mode of operation of the class. Most students acknowledged that their normal science involved individual work with groups of 4-5 forming every fourth or fifth lesson in order to conduct an investigation. The formation of groups in the normal science program appeared to be a strategy to cope with resourcing and management issues.

The groups in this study were initially self-selected and with minor changes the original groups were retained for the duration of the term. Strategies to develop cooperation were implemented in the first two weeks when students undertook a range of puzzles that required collaboration, brainstorming, and a group approach. Furthermore, the furniture in the room was rearranged to accommodate face-to-face seating. Roles were assigned to members of each group – recorder, manager, speaker, and co-ordinator, and students adopted names for their groups.

Working in groups as an extended process was universally noted as the most significant change in their science course. Most groups required some time to come to grips with the structure and develop appropriate listening and organizational skills. While some competition among groups was fostered, the involvement of all groups in class discussions of issues was a regular feature. Nevertheless, a number of groups were concerned that other groups "stole ideas" and that the researcher-teacher failed to act to prevent this. Co-operation was valued but also perceived to be a difficult skill to develop. For example, Luke believed that "we'd have to work in the communication skills just a little bit better, ... people thought their idea was it, they just wanted to do that and they didn't want to sort of listen to other people and say 'well we can do this as well as that.'" He elaborated on his concern by saying: "I think what we found out at the end was we were getting nowhere, working separately and saying. 'I'll just do this and let yous (sic) do what you want to do and all create another experiment.' We just weren't really getting anywhere." However, according to video evidence other groups made considerable progress in developing communication skills, sharing tasks, retrieving information and reporting findings. One group that the researchers had perceived as somewhat disruptive later were found to have spent time researching at the weekend in museums and the state library as a group. Another group met at one of their homes to develop their reports and posters. Some described the opportunity to work in groups as a "tremendous" experience and helpful to their learning because they could turn to others for support. Group work was not seen as competitive: "you're not trying to learn competitive – it's just working out ways as a group to form new ways of ideas and things." They acknowledged the importance of roles for each person in the groups and the value of discussions and joint decision making.

Of the eight groups in the class, five were strongly committed, responsible and engaged in regular on-task behavior. One group, comprising only three students, was seen as a "left over" group of students not interested in science and with weak ability. Nevertheless, this group did contribute in a number of ways and demonstrated initiative in developing a project that stretched their capabilities. The remaining two groups were problematic in behavior and appeared to lack commitment. One was particularly in need of structure and guidance and exhibited considerable lack of self-confidence that seemed to relate to previous experiences in science in primary school. One member of this group lamented the lack of drive in his group and was dissatisfied with their performance as a group. The remaining group appeared to be frequently off-task and uncommitted. However, they defended themselves vigorously during the focus session. They argued: "I think we have been wrongly judged. We know a lot of what has been going on. Some of the teachers might think we have been mucking around but we have been having a little bit of fun while we're there, but we have been working, we have been working constantly." Indeed, their conceptual knowledge revealed during the focus session confirmed that they had been researching and developing an understanding of the content of living things and Mars.

Working as a group was seen to be a significant outcome for all groups. After describing how they can ask questions of each other one student, Anthony, noted: "with other people who are your same age, can teach you their own way, and since it's sort of the way they were taught and then they've changed it into their lingo (sic) they know then you can understand it much more easy if the teacher told it the way they learnt it." They acknowledged that they had learned to work in groups and that they had learnt "how to work as a team group." In a segment of the interview they collectively described themselves as: " a group of people ... coming together ... yeah, and working individually yet the same ... towards a common goal. So one day the highway will meet." James highlighted a widely held belief when he stated that his biggest achievement was: "To finally work as a group and know that you can work with other people, and you develop group skills, and you figure out what you're best at."

The recognition that the students were working in groups but that the groups were also working towards common goals was clear to Conor who stated: "It's like we're all working as a team, as a community, like you said, but we're all working on individual things but in the end it all comes together to be a group community goal, like, achievement." On further exploration of the dynamics of group work friendship was perceived as important. Students in one group acknowledged that they were friends and knew their different strengths and limitations: "Me and Dylan talk a lot"; "James can always translate"; "I don't always make sense"; "I was the organiser, I kept everybody in line. Yeah the motivator"; "I was the recorder, so I recorded all the stuff - wrote it all down."

Clearly it would be desirable for students to have previously developed many of the skills necessary for group work but given the individualistic structure of schools, co-operation was viewed almost like cheating by students. 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 program. Of the eight groups only two, already discussed previously, conceded that their group work was not very effective in achieving their goals..

Conceptual Understanding

The objectives of Term 4 in this school's science curriculum required students to develop an understanding of vertebrate and invertebrate animals. Hence the project contained this feature as a concurrent theme. The prescribed textbook focussed on classification and description of animals in a formal zoological approach. The content that students were required to learn in the project was similar but couched in the context of surveying living animals to decide which ones would be suitable contenders for a voyage to Mars and then being part of the settlement on Mars itself. Each group had to select a vertebrate phylum and an invertebrate phylum and research the characteristics of each phylum for their project.

Students were provided with open access to the library as well as organised 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 – 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."

The depth of understanding revealed during the focus group sessions, when the focus group facilitator explored some of the content areas, supported these perceptions. They seemed to have an understanding of a range of discrete topics related to Mars and a generalised conceptualisation of vertebrates, invertebrates, groups of invertebrates and a deeper understanding of specific organisms, for example, fish, echinoderms and arachnids. One student even spontaneously recalled the scientific name for the black widow spider. Most students were able to detail information about Mars related to seasons, temperatures and atmospheric conditions.

> Indeed they expressed surprise at how much they could achieve: "(we were) surprised at the quality of our work." They were aware of the issue of quality and quantity acknowledging that "we haven't learnt a greater say mass of stuff, but we've learnt it better, learnt it more thoroughly."

However, students noted broad objectives that were beyond content. Learning to learn, learning to problem solve were dominant issues. A common assertion was that "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." Thus, the intervention provided the opportunity for developing those generic skills, problem solving, working in groups, co-operating, resourcing and evaluating information, which were valued by the students as a life skill. In their discussions students almost saw these skills as more important than the science content. They noted: "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." They were aware of strategies such as brainstorming and listening to other opinions. They also acknowledged the more metacognitive aspects of learning in that the experiences provided them with enhanced learning skills: "it's taught me how to learn." The students acknowledged that the strategies "motivated (them) to go beyond the notes given by the teacher."

It is difficult to judge the conceptual understanding developed in comparison with the other year 8 classes. A limitation to the study was that we did not post test on content primarily because the students were engaged in exploring diverse areas. Some gained considerable depth of understanding of the specifics of certain classes of animals by personal research and a superficial understanding of others gained through group and classroom reports. The context afforded opportunities to argue the suitability of animals for the voyage to Mars, which required debate about various animal attributes. Interviews conducted early in the term revealed a general understanding of biology such as food webs based on primary school. However, in focus sessions at the end of term the students were able to detail substantial particular knowledge about scientific concepts. It should be noted that the content learned by these students may have been markedly different from the content prescribed in the year 8 curriculum.

Teacher Perceptions

The regular teacher was an experienced teacher having worked at the school for seven years and was responsible for co-ordination of the junior science program. She was present for all lessons and played a supportive role in answering individual student's questions or providing resources. She was interviewed at the conclusion of the program. Her perceptions at times differed from the researchers and from the data provided by the students through interviews and analysis of critical events. The teacher noted that this particular class was of relative high ability but also a difficult class being vocal and sometimes disruptive. She was concerned that many of the students did not perform to her expectations and constantly referred to lack of structure as a constraint:

> This is a very vocal class. On the other hand there were a lot kids who had a lot of ability and could have handled a more unstructured situation better but, I forgot about the situation that there was also a group that are quite disruptive, and that became more apparent in a lack of structure in the classroom where I would have had them moved around so they were not near one other. I would have separated them.

She re-expressed a sense of lack of structure several times in the interview highlighting the disappointing performance of particular students who appeared to be seeking more guidance. These points were valid comments and reflect the contrasting models of instruction. Her suggestions for alleviating this problem included more handouts and scripted activities. A problem that she perceived related to structure was that students were frustrated by having to wait to implement their project because resources were unavailable.

> 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 I think, I am not being critical of anybody here, because I 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.

Her perceptions of the change in levels of motivation did not reinforce the qualitative or quantitative data from the students: "so I don't think they enjoyed the science as much as they normally do." Indeed, her view of the classroom environment was less favorable in terms of the goals of the project than the students. However, she did believe that the approach was useful:

> Well I guess they got an opportunity that they would not normally have to toss ideas back and forwards and gain from other people's 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. We don't have the opportunity unless kids work in groups outside the school time to work on things like some projects.

She also reported concerns that the library was unaccustomed to students accessing information resources that had not been previously identified by teachers. Prior discussions with the library staff had alerted the researchers that this may be a problem but in fact the library staff had indicated their interest, warmly welcomed this approach but acknowledged structural difficulties if it were implemented on a large scale.

Limitations to this study

Undertaking a naturalistic study of this nature presents many problems and difficulties that may influence the outcomes. The study was conducted by the researcher-teacher who was unknown by the students prior to the commencement of the teaching. He also had limited prior knowledge of the individual capabilities of the students. The project was implemented in the fourth term of the foundation year. The students had settled into high school but also were, as their teacher put it, "testing the system" in terms of behavior. A longer period of time was needed to establish a rapport that the researchers believed would be effective. Analysis of the modified learning environment survey findings indicated that some students considered that the researcher-teacher was not interested in their welfare. This perception presumably grew from an expectation of independence being exhibited by the students. For these students, greater scaffolding and structure was necessary, which was not forthcoming.

Many of the strategies adopted in the instructional program depended on a range of basic skills that needed to be developed. For example, students did not possess strategies for management of group discourse and recording, library skills, oral presentations, and report writing. Resources were also a problem in that location of equipment and facilities were unfamiliar to the researcher-teacher, hence many items required by students were transported from the university.

The environment was also perturbed by the presence of four adults and substantial technology. Whilst it was not the intent for the classroom teacher, the participant observer or the research assistant to become engaged in teaching, students nevertheless capitalized on their presence and often sought information from them. The technology was initially intrusive but students eventually became less conscious of its presence.

The size of the classroom was also problematic. The room, although a modern flexible science laboratory, was designed for less than the 32 students who were involved. There was little physical space. The custom of teachers moving from room to room also impacted on the availability of space for storage of on-going project work and a capacity to modify the physical environment to suit the project. This is not a problem in primary schools and the issue was indeed highlighted by the regular teacher as a limitation. Lessons were short in duration and with time being lost while the room was rearranged the students often only had forty minutes at a time to work on their projects.

The study has been replicated in a different environment and some of the limitations have been addressed. These will be reported in a later communication.

Conclusions

As science teachers and researchers we are concerned about the effective learning of science by students. Uncertainty about the future and changing social conditions are introducing many new issues that have to be grappled with in maintaining students' interest in science and supporting their development of a useful understanding of science. The rapid pace of technological change and the growth of knowledge over the last fifty years have added a new dimension to this uncertainty. Today's school students will be confronted with a future in which there is no guarantee of continued employment in one vocation. Indeed the nature of the workplace is changing so rapidly that new disciplines and enterprises are emerging superseding traditional professions and industries. The conceptual knowledge acquired by students may be redundant by the time they reach adulthood. Being able to access information and use information in a productive and critical way will assume greater importance and become a minimal necessity for citizens of the future. Additionally, as adults they will need coping strategies that will help them negotiate the challenges of a social world and flourish in a democratic society (McCaslin, 1996). Students of today will need opportunities to develop a disposition towards learning that will empower them throughout their life to be proactive seekers of knowledge, that is lifelong learners keeping pace with and informing the process of change (Dearing 1997; West 1998). The development of this disposition will start with the educational environment that students are experiencing today. The community of learner's approach is one way of achieving these goals. The key to providing this environment lies with individual teachers, schools and systemic initiatives that support effective teaching.

The principles that guided this study were grounded in the concepts of community of learners. We explored strategies that restructured the learning environment of this grade 8 class in ways that approached a community where ideas were shared, individual students developed responsibility for their learning and where motivation and interest were enhanced. Evidence for the achievement of learning behaviors detailed in Table 1 was present in the classroom observations, field notes and interview data. The students clearly endorsed the approach in terms of what they learnt about co-operation and independence. They enjoyed the experience and seemed to value the learning that occurred. The majority of students believed the innovation was effective. We learnt much about differentiating the program to support those who were uncertain about their own ability. Most students adapted to, and developed self-confidence to persist with, situations where explicit instructions and guidelines were not provided. A small number of students had difficulties adjusting to these circumstances and became frustrated and uncooperative. The level of frustration could have impacted on the effectiveness of the groups comprised of these latter students. These are issues that need to be addressed in future research. Some of these issues may have been less of a problem if the program had been implemented over a longer time span and with greater continuity of teacher contact. Group cohesiveness is an important predeterminant for the success of this approach and further research is needed to determine ways of developing this cohesiveness in the context of a science class. A particular question of concern raised by this study is how to achieve differentiated scaffolding of the groups in the class?

Several significant concerns emerged that impacted on the regular teacher and the students. The regular teacher was apprehensive about the lack of control, accountability and extent of coverage of traditional content knowledge. What would students learn about science that can be "tested" and reported? Furthermore, students "could not be trusted" with the level of autonomy provided. This reflects a common criticism of investigatory science that there is too much noise and disruption to other classes. However, close examination of the dialogue reveals that the noise was more often productive than unproductive. While some students may have been off task for much of a lesson, this inattentiveness was perhaps more obvious than when they were copying mindlessly from the board. Students were also concerned that they were not learning enough compared to their peers in other Grade 8 classes. For example, they were concerned that their peers were attending to particular problems in the textbook while they had not even opened that chapter. These issues are part of a culture of teacher directed learning that has been challenged by this study. The traditional class does provide some comfort zone or boundary to regulate student lives. Going beyond the boundary required them to take risks and accept responsibility for their own learning. Restructuring the classroom climate may be simple compared to restructuring more global perceptions of curricula, and effective classroom management and planning, held by parents, teachers and administrators.

The study complements a previous national study sponsored by the Australian Academy of Science into junior high school science teaching (Watters, Diezmann, & McRobbie, 1997). In that study the researchers worked in collaboration with twelve teachers who attempted to implement constructivist-inspired teaching based on a structured text based program. There was evidence that the teachers wholeheartedly attempted to teach in a way that for most of them was a major "paradigm shift." For many the approach was radical and required substantial effort and energy and support. Even with considerable support several found the approach problematic. While many of the strategies adopted were similar, the study reported here provided a more open inquiry and less structured approach. However, both approaches are consistent with those advocated in contemporary syllabuses, including the recently released Queensland Science Syllabus (Queensland School Curriculum Council, 1999). It is clear that implementing changes in teaching science in ways that adopt constructivist principles and provide a social learning environment conducive to self-regulated learning will be difficult without substantial and on-going professional development.

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