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**Enhancing creativity through  
investigative practical work in science**

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*Abstract*

School leavers who can think creatively are frequently perceived as desirable, with creative abilities recognised as being valuable for personal, social, technological and economic reasons. Many science curriculum documents worldwide assert that creativity can be taught and that engaging in practical work in science can enhance creativity in students. However, recipe following practical work had become pervasive in a majority of New Zealand science classrooms in the late 20<sup>th</sup> Century. One of the outcomes of such recipe following for most students was that they carried out their practical work unthinkingly. In contrast, many students who were engaged in doing 'research' for Science Fair projects were able to successfully engage in problem posing and problem solving. Some questions arose: Could practical work in the regular science classroom become more openly investigative in nature? If so, would this result in increased learning of science and about science? Could such an approach encourage creativity in students as they learn in science? Does such an approach encourage and/or challenge creativity in science teachers?

*Introduction*

There have been many claims made for the central importance of creativity in our lives with Csikszentmihalyi (1996, p. 1) stating that "when we are engaged in it we feel that we are living more fully than during the rest of life". As well as the excitement of the involvement, the result of being creative adds to the intensity and complexity of future life.

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It is often claimed that school-leavers who can think critically and respond creatively will more likely be able to meet the challenges of the 21<sup>st</sup> century by contributing positively to the personal, social, technological and economic worlds that they will inhabit as adults (Welle-strand & Tjeldvoll, 2003). Such an ability is seen as crucial by writers such as Csikszentmihalyi (1996, p.6) who claims that “our future is now closely tied to human creativity”. This wish for school-leavers who can think creatively is reflected in national curriculum documents throughout the world that include aims referring to problem solving, creativity, entrepreneurship and innovative thought. Such curriculum statements assert that creativity can be taught. There is support for this position from academics and researchers (Murdock, 2003; Runco, 2003). This stance is also supported by groups such as the American Association for Childhood Education International who assert that the creative process must be recognised as “socially supported, culturally influenced and collaboratively achieved” (Jalongo, 2003).

### *Defining creativity*

Definitions of creativity usually include notions of personal involvement, novelty and value. For instance Boden (2001, p. 95) defined creativity as a person’s “ability to come up with new ideas that are surprising yet intelligible, and also valuable in some way”. However, there are different kinds of creativity that should be recognized and rewarded (Kaufmann, 2003; Sternberg, 2003).

There are two major contrasting views of creativity presented in the creativity literature. The first refers to that extraordinary, or high, creativity displayed by geniuses with special gifts, often called ‘high’ or ‘big C creativity’ (BCC); the second refers to that more ordinary, everyday creativity, ‘little c creativity’ (LCC), displayed when an individual exhibits personal agency and self-direction (Craft, 2001, p. 46). LCC is different from BCC in that it is that kind of creativity that “we all share ... because we have a mind and can think” (Csikszentmihalyi, 1996, p. 7). Proponents of LCC indicate that LCC is a way of coping with basic daily challenges through use of prior knowledge to inform one’s response. It is “determined by the extent to which the agent is intentionally open to exploring possibilities and is taking

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action in the world” (Craft, 2001, p. 59). It encompasses innovation and development. A conscious intention may be involved, as may knowledge-based intuition. The innovative act will not be expected to be novel to the wider world. LCC involves a moving on, being open to possibilities and willing to try options. It is likely to involve problem identification as well as problem solving. LCC is frequently socially and culturally contextualised.

### *Creativity and the scientific enterprise*

Writers do not agree as to whether the affective and cognitive aspects of engaging in the creative act are the same for different domains. Whilst Csikszentmihalyi (1996) and Craft (2001) have identified commonalities of the creative act and frequently found characteristics of people who engage successfully in BCC and LCC respectively, other writers have suggested that being creative may differ in the domains of, for example, arts and science. Even though Medawar (1967) noted differences between the process and the effects of creativity in the sciences and the arts, he clearly did perceive of the scientific enterprise as a creative endeavour:

... ‘having the idea’ [in science] resembles other forms of inspirational activity in the circumstances that favour it, the suddenness with which it comes about, the wholeness of the conception it embodies and the fact that the mental events which lead up to it happen below the surface of the mind. (p. 173)

This view is still current. McComas (1998, p. 58), for example, states that “close inspection will reveal that scientists approach and solve problems with imagination and creativity, prior knowledge and perseverance” and asserts that this is similar for all effective problem solvers. Csikszentmihalyi (1996) noted that the work of scientists is creative and asserted that the “excitement of ... the scientist in the lab comes close to the ideal fulfillment we all hope to get from life” (p. 2). The NACCCE report (1999, p. 35) also indicated that it saw the scientific domain as a possibility for creative thought, and that children could engage in this creativity as well as scientists:

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The processes of scientific analysis and investigation can involve the highest levels of creativity and insight. Discovery in science is not always strictly logical. It often results from unexpected leaps of imagination: from sudden moments of illumination in which the scientist grasps the answer to a problem and then sets out to verify it by calculation. This can be true for children setting out as for experienced scientists.

If science is a creative endeavour then our students should be able to recognize this. Being able to “explain the value of imagination and creativity in doing science” is therefore seen as an important outcome of science education (Clough, 1998, p. 214).

### *Creativity and school science curricula*

That the scientific enterprise is a creative endeavour is also emphasised in many school science curriculum statements. McComas and Olson (1998, in Table on p. 47) analysed eight international science curriculum documents and found that in six of the eight the notion that scientists are creative was indicated in the Nature of Science learning objectives. One of the curriculum statements that they analysed was the New Zealand Science Curriculum statement (Ministry of Education, 1993). Whilst they accurately indicated that this notion was not present in this statement’s achievement objectives there are assertions regarding the creative nature of science to be found in this document:

Science involves people investigating the living, physical, material ...components of their environment and making sense of them in logical and creative ways. Using systematic and creative processes of investigation, scientists produce a constantly evolving body of knowledge ... (Ministry of Education, 1993, p.7)

There is, therefore, a strong intention in the New Zealand Science Curriculum statement (and the senior science statements that link to the scientific inquiry strand of the core document) that students should participate in science education both as a

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creative activity and in order to understand that there is a place for creative conjecture in the construction of scientific knowledge.

In this paper I will draw on data collected during a longitudinal study of students carrying out open investigative practical work in senior biology classrooms (Haigh, 1998) to make a case for engaging in such activity as a means of fostering personal and collaborative creativity. The students' and their teachers' understandings of investigative practical work as a means of encouraging students to engage creatively will also be considered. Since the findings from this research project both support and challenge the inclusion of open investigative work in senior biology programmes as a means of fostering creativity, I will indicate some of the implications for teachers of biology that arise from the findings of the study.

### **Context of study**

Recipe following practical work had become pervasive in a majority of New Zealand senior Biology classrooms in the late 20<sup>th</sup> century. Traditionally, students were not given much opportunity for freedom of thought, nor were they required to make decisions as to investigative design, validity or reliability of data. One of the outcomes of such recipe following for most students was that they carried out their practical work unthinkingly. Student engagement in practical work was not seen as particularly efficient as either a means of learning scientific knowledge, learning about the nature of science or in encouraging creativity in students. In contrast, many New Zealand students who were engaged in doing 'research' for Science fair projects were able to successfully engage in what Jungck (1985) has called the three Ps of science – problem posing, problem solving and peer persuasion. Some questions arose: could practical work in the regular classroom become more openly investigative in nature? If so, would this result in increased learning of science and about science? Could such an approach encourage critical thinking and creativity in students?

## **Research design**

The researcher worked with the teachers and students following a process of negotiated intervention (Simon & Jones, 1992) where the researcher and the teachers together determined the direction of the research project, an approach commensurate with action research (Cardno, 2003). The teachers who participated in the first and second phase of this research project were involved in a collaborative manner (Johnston, 1990) in defining the problem, selecting a design, selecting a sample, selecting measures, analysing the data and in interpreting and applying findings.

There were three main phases in the data gathering for this study. The first two phases of this research project were conducted in a large, urban, co-educational state secondary school. All four of the school's biology teachers participated in the initial introduction of investigative practical work during one school year and one of these teachers worked with additionally developed material for a second year. A teaching package relating to the introduction of partially open investigative practical work was developed during the second year. Teachers from 22 other secondary schools from around New Zealand participated in the third phase trial of this material. In all, 27 teachers and more than 400 students were involved in the study. The students were all Year 12 Biology students.

### ***Nature of the classroom intervention***

The intervention introduced practical work that required students to carry out investigative problem solving. A degree of openness was introduced as students were required to design their own investigations in order to come up with answers to a given problem. The investigations were linked to content teaching and the students were expected to apply their prior declarative and procedural understandings to these new situations. The intervention investigations were linked with different parts of the Year 12 Biology programme. An example of the type of investigation that the students were carrying out is one used during the ecology section called "Green streams!" (Figure 1). The students were asked to develop and test ways of finding

answers to the problems posed in the investigative worksheet. In this way they were, initially at least, being asked to be reactively creative (Kaufman, 2003).

### **Green streams!**

A small slowly moving stream flows through the corner of your school grounds. You have noticed that the water has become much greener than it usually is. When you discuss this with other members of the class someone mentions that the school playing field had been fertilised recently. Another student suggests that the green colour could be due to the presence of microscopic plants in the water. Perhaps the fertiliser had washed off the field into the stream causing the increase of microscopic plants?

How could you test this hypothesis? Does it matter how much fertiliser has been washed into the stream? Or how long the fertiliser is in the stream? Design and carry out an investigation to demonstrate what could happen when fertiliser gets into a small stream. Write a report for your school newspaper explaining what you did and what you discovered.

*Hint: Start with some pond water and plant fertiliser. Read the instructions on the fertiliser **pack** carefully. Make sure that you design a "fair test"! What factors would you have to control?*

When you think you have got an answer to your original problem what other questions could you ask about this system that you might be able to investigate?

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**Figure 1: The "Green streams!" investigation**

All investigations were presented to the students in the following manner. The students were first asked, as individuals working alone, to consider how they might go about solving the problem that was posed by the worksheet and to design an

investigation that they thought would help them answer the questions posed. Then, working as groups of three or four, the students were asked to discuss their approaches. They were asked to be prepared to defend their own method and to challenge others', in order to develop a group approach to solving the problem. Thus the students were being asked to think of other possibilities and to evaluate these. After the students had carried out the investigation they were asked to evaluate their procedures and findings and to indicate how valid and reliable their findings might be and what they had learned.

### **Findings**

Although the research project's findings were much wider only those focussing on the students' and teachers' responses to investigation as an activity that fosters creative endeavour will be presented.

Creativity is often linked to possibility thinking and problem solving (Craft, 2001). In this project problem solving was perceived as an inherent part of the investigative practical work process (see Figure 2). Practical work was defined widely and inclusively and did not necessarily indicate controlled experimentation, though many of the contextual situations presented to the students did require this. The problems could have a large canvas or be of decreasing dimension as students refined or focussed the investigation (Figure 2). During the refining/focussing process the students had several opportunities to engage in possibility thinking.



**Figure 2: Model for relationship between investigating, problem solving and practical work.**

The students first encountered a general problem area. They then designed an investigation to help them solve this specific problem. In turn, problem solving may be part of the investigation, for example the students may have needed to solve a problem regarding the development of specialised equipment or a particular chemical test, to help them complete the investigation. The students were required to answer a number of ‘what’, ‘how’, ‘how many’, ‘when’, ‘where’ and ‘why’ questions (Haigh & Hubbard, 1997). Thus, at each stage of problem solving the students were engaged in possibility thinking and making decisions. Worksheets were designed to scaffold the students through these challenges<sup>1</sup>.

Many of the students and teachers in the research project made considerable reference to creating knowledge and being creative when they were asked to describe their

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<sup>1</sup> Planning worksheets and evaluation sheets to guide the students were developed during the research project. Details can be found in Haigh (1998) or on request from the author.

response to the introduction of open investigative practical work in a senior biology programme. Student and teachers' references will be addressed in turn.

***Student responses linked to aspects of creativity***

The students' responses highlighted an understanding of the creative nature of scientific processes, for example:

*It makes you draw conclusions, helps you to understand your mistakes and create new experiments.*

A small number focussed on the challenge and mystery associated with open investigative practical work:

*[Yes, I would like to have done more investigation because] it is fun finding out what the problem was by ourselves instead of already knowing it before you start the experiment.*

*[Yes, I would like to have done more investigation because] it makes you think about all the possible outcomes you can create. It gives us a challenge!*

The students were also very aware of the need for each student to be actively and individually engaged in thinking through the given situation so that they could contribute ideas and make decisions. One previously reluctant learner identified this for himself very clearly one day when very unselfconsciously he indicated first to his teacher, and later to the researcher:

*Miss, Miss, I'm thinking, I'm thinking!*

During the third phase of the research one group of students reported an incident indicating that they could demonstrate agency and take the initiative during their biology lessons. After following an open investigative programme for the first half of the year they were presented with a carefully detailed experiment from their textbook.

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When asked how they responded they explained that they read the investigation through, thought that they could improve it and so made changes to the design before carrying out the practical work:

[Researcher: You felt that you were able to do that?]

Student: Yes, it was much more fun than following the instructions.  
It can be boring you know [following instructions].

As they reported this incident to the researcher it was clear that they did not consider that they had done anything very surprising. They claimed that they felt more responsibility for carrying out the investigation carefully if they had planned it themselves and that they learnt more when this was the case.

### *Teacher responses linked to aspects of creativity*

The teachers engaged in the research project strongly endorsed open investigative practical work as a means of enhancing students' creativity:

*I would carry out a similar programme in future years because it is one of the few subjects at school where students can think for themselves and be creative in their ideas.*

They also emphasised the role that teachers play in encouraging students to think in ways that are wider, more creative and different from that they are used to. However, less frequently mentioned was this way of working as means of increasing their students' understanding of the role of creativity within the scientific enterprise.

The teachers indicated that as their students carried out a number of similar investigations the students became both more creative in what they planned and worked more co-operatively (Graves and Graves, 1990), a skill that had not necessarily been part of the students' previous repertoire, for example:

*[Open investigating] allows originality and creativity. Initially individually, and then another skill that it develops, which I think is important as well, is the working in groups and communicating and co-ordinating activities in the group.*

The teachers perceived that when working in a situation that encouraged individual creative input the students also gained work independence and learnt to evaluate their work more critically and honestly. They felt that the students approached investigative work very positively and many previously reluctant workers were quick to become involved when required to individually contribute to the direction of the work. However, a number of the teachers reported that some students did have difficulty making the adjustment to a situation that required them to think for themselves:

*A small group can't make the adjustment and don't achieve a lot over the year. Many do learn that they must 'think for themselves' if they wish to succeed at open investigative work.*

In free responses more than 30% of the teachers reported that most students' attitudes and approaches to their study did change over the year, for example:

*I am not sure that they were aware of any change themselves - they gained some confidence in group work (co-operative model), formulating hypotheses ... The evaluations helped them accept that they were in charge and they often expressed satisfaction.*

*[The students] found that they were more actively involved in the thinking process and planning process in practical work ... They found that they had to analyse their own data and present criticisms.*

One indicated that she preferred to think that the students were more creative in their thinking in these situations but she had not put that to the test:

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*I don't know. I mean I haven't really assessed [the gains accruing from placing investigations into contextual situations]. I suppose I would like to think that it's given them an element of lateral thinking ability. I haven't tested that.*

On the other hand, this teacher had also noticed that when students were carrying out other practical work that required them to follow a series of set instructions they did not engage closely with the task.

However, the teachers also indicated that some tensions arose for them as teachers of biology when they worked with their students doing open investigative practical work. These tensions were linked with the ability of their students to cope with this new way of learning, with externally imposed assessment regimes, and with the availability of resources (time, equipment and ideas). The teachers found that some of their students required considerable help before they could function efficiently as investigators. A tension arose for the teachers between giving cues to students and their wish that the students would be creative in their approach, for example:

*I think the idea really is to get them to think for themselves. Because if you spoon feed, you say you are going to need five test tubes and ten beakers, what are we doing it for?*

*I try to keep direct information to a minimum. Often they will ask me a question and I simply look at them and they will then come up with the answer. And I say, good, away you go. So they have thought of it. But I think it's maybe a confidence thing, in some cases. ... I think the whole system would fall apart if we gave them too many cues ... it would just become teacher directed again, wouldn't it?*

Some judicious cueing however was seen as a means of increasing students' creativity since a lack of understanding of suitable practical techniques may limit the students' ideas during the planning stages of an investigation.

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Another major concern repeatedly stated by these teachers was a perceived tension between teaching biology to enhance creative thinking and the necessity to prepare their students for internal and external examinations that emphasised theoretical understanding and recall. They queried whether contextually situated problems might have made identifying and understanding the biology concepts more difficult for the students. For example, in response to an observation from a colleague that their school's emphasis on examinations had produced students who were not very creative but instead were 'desperate for the right answers' one teacher commented:

*In an ideal world we would produce scientists and I have got this terrible dilemma, you know, do you produce a scientist who can cope with tertiary education, or do you produce a pupil who gets a great mark in bursary? You know, its a terrible position to be in. It would be lovely to be able to teach everything in an open-ended manner.*

One teacher noted that when the students were spending longer doing practical work they had less class time for learning biology content knowledge. However, she valued the investigative approach sufficiently to say that she felt that adjustments to the programme were necessary:

*[Being involved with this project] provided a new way of providing experiences to challenge and involve students and reinforced my own gut feeling that it is the experiences that students have that most influence the way they think. I committed continuing time to some of the investigations because the students became so involved - it seemed to me a more constructive use of time than 'getting on with the syllabus.' ... I recognise the tension between 'process' and the 'body of knowledge' the students need to acquire. I come back to the conviction that my students learned more, and increased their confidence in their ability to 'do biology' when making their own decisions.*

Availability of equipment was also a significant issue for the teachers. There was concern over the lack of readily available equipment for the students to use when

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early notification of need could not always be given to the school's science technician. In an attempt to address this the teachers found that they tended to cue the students to use certain equipment that they had already ensured would be available in the laboratory. But they admitted that this was problematic for them, since clearly identifying possible equipment could act to restrict creativity of design. Additionally, clearly indicating to the students that it may be better to use alternative equipment was seen as possibly casting doubts as to feasibility or appropriateness of the students' design, thus possibility inhibiting students' confidence in their decision-making.

Another limitation related to the design of contextually situated open investigative situations for their students. Teacher creativity and time were required to develop investigative contexts that were of appropriate standard, curriculum linked and relatively comparable with regard to the demand on the students. Some of the teachers responded by developing investigative scenarios that were additional to those developed by the researcher. Others struggled to develop new ideas.

For a number of the teachers, as well as impacting on the students' ways of working in biology classrooms, introducing open investigative work into their biology programme challenged their view of themselves as biology teachers. They had to consider strategies other than the didactic approaches they were comfortable with. They were being challenged to be more "unusual" in their approaches. One, in answer to a question regarding the teacher's role in the student change process said:

*I think that having these scenarios available meant that I put them in open situations and pushed them into thinking/planning for themselves. I found it quite sobering that this felt like an exciting new idea ... to me!*

## **Discussion**

Introducing an open investigative practical work approach to learning and teaching in biology can enhance creative thinking of students within the LCC framework described above (Craft, 2001). It is also likely to enhance and/or challenge the creative thinking of the teacher.

The introduction of open investigative practical work to Year 12 Biology programmes was expected to be multi-dimensional, involving the use of new materials and/or new teaching approaches and possibly requiring an alteration of beliefs (Fullan, 1991) on the part of the students and their teachers. The findings from this the research study indicate that such a change was required of both the teacher and the student body when investigative practical work was introduced. It was clear that both the students and the teachers were learners in this context. They were working together to construct knowledge of biology (new to the students at least) and new knowledge about learning and teaching in school classrooms. Roles previously understood, either implicitly or explicitly, by the participants had to be renegotiated so that teachers and students had common expectations of learning in biology. Intended goals had to become more visible in the classroom. If this had not taken place then changes in expressed goals would not have necessarily resulted in changes in the classroom (Penick & Bonnstetter, 1993).

It is generally accepted that “creative thinking cannot happen unless the thinker already possesses knowledge of a rich and/or structured kind ... [including] a culturally accepted style of thinking” (Boden, 2001, pp. 95-96). For both the student and the teacher working with this new style of practical work there is a challenge to understand and adopt a new cultural style of thinking. The cultures concerned are the culture of biological inquiry and the culture of the classroom. Working in this way requires understanding of a very complex interactive system and there is considerable demand on the teacher as the experienced member of the learning dyad:

The teacher who lacks the relevant knowledge, who thinks in rigidly prescribed fashions, who cannot try to make their intuitions explicit and who lacks the self-confidence to say ‘Let’s try this!’ or ‘I don’t know’ will feel helpless and threatened if asked to teach” in a manner to enhance creativity in their students. (Boden, 2001, p. 102).

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Boden (2001) outlined three types of creativity – combinational (combining old ideas in new ways), exploratory (being creative within the rules of the domain) and transformational (permitting changes to the rules of the conceptual space). Within the frame of this research project linked with investigative practical work the students and the teachers were engaging with all three of these types of creative endeavour.

The students were required to make associations of many different kinds between different aspects of their previous knowledge of biology concepts – both declarative and procedural. In addition to the structured support of the prepared worksheets that the students were provided with, their teachers had to help them to make these associations. The teachers learnt how to cue their students and to identify how much help individual students required.

For a person to be creative within exploratory and transformational frames he/she needs to have knowledge of some culturally accepted style of thinking. Exploratory thinking “investigates the possibilities inherent in the space” (Boden, 2001, p. 96). It involves a consideration of what the rules of the culture enable you to do. In the context of this project, the knowledge may have been about a particular aspect of biology, for example, knowledge of aquatic ecological systems. It may have also been knowledge about the generally acceptable ways of working in a school laboratory – an understanding of the culture of the school laboratory. Transformational creativity “involves some significant alteration of one or more of the rules of the current conceptual space” (Boden, p. 96). One has to know the rules in the first place and it was this that presented difficulties for a small number of the students in this study. Others, however, felt confident enough to challenge usual classroom practice. The role of the teacher and his/her attitude to change/difference is also significant here and some of the teachers in this study found it easier to adapt their approaches and give students more control over the activities they were doing than others.

## **Conclusion**

If engaging with information, resources and ideas is a central feature of the creative endeavour, then encouraging students to carry out investigative practical work in

biology in the manner described in this paper is a means of enhancing their creativity, at least of the LCC type. There were many opportunities for socially supported and collaborative possibility thinking and decision making.

In addition, the system that the students were working within is arguably similar in structure to the three-part system proposed by Feldman, Czikszentmihalyi and Gardner (1994) for BCC. Within the system there are individuals (or groups of individuals) developing ideas (novel to them at least), within a cultural domain (of biology and of school), that are validated by 'experts' (their peers or their teacher). However, careful planning and thoughtful oversight of the students' engagement in the activities by the teacher are crucial if students are to gain maximum opportunities for critical thinking and creative response from this involvement.

Whilst the findings from this project support the contention that useful and positive creativity learning results from engagement in investigative practical work in school science and biology programmes there are aspects that need further exploration. Some possible questions might be: Can we nurture both individual and collaborative creative activity through science education? How context specific are possibility-thinking skills? How might we increase the opportunities for open investigative practical work within the context of a rigidly assessed senior school system? What are the differences, or commonalities between creative teaching and teaching for creativity? Do science teachers need to be creative themselves if they are to enhance creativity thinking in their students? How might the creativity thinking of science teachers be encouraged and nurtured?

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