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AUTHOR	Skinner, Roy
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ABSTRACT

The focus on practical investigations in the National Curriculum is seen to be important if students are to attain a connoisseurship in science experimentation. The chain of processes involved in doing real science involves: non-linear thinking; creative flair; and critical evaluation within an authentic setting. The research presented in this paper focuses on authentic, open-ended practical project work and reports on the cognitive and affective growth produced through such student-centered contexts. It is argued that by allowing students, themselves, to choose a personally meaningful, real-world problem around which to structure the science investigation, total ownership can be induced with internal locus of control over the problem-solving and learning. It is concluded that project work can act as a remediation intervention for producing science task competency. Contains 38 references. (Author)

AUTHENTIC ASSESSMENT: PROJECTS FOR THE FUTURE

Dr. Roy Skinner, Edith Cowan University. Churchlands Campus, Perth 6015.

ABSTRACT

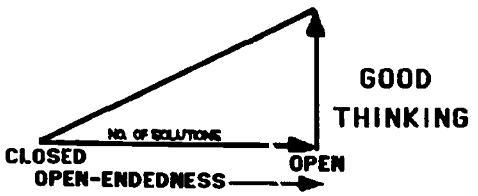
The focus on practical investigations in the National Curriculum is seen to be important if students are to attain a 'connoisseurship' in science experimentation. The chain of processes involved in doing 'real' science involves: non-linear thinking, creative flair and critical evaluation within an authentic setting.
This research focuses on authentic, open-ended practical project work and reports on the cognitive and affective growth produced through such student-centred contexts. It is argued that by allowing students, themselves, to choose a personally meaningful, real-world problem around which to structure the science investigation, total 'ownership' can be induced with internal locus of control over problem-solving and learning. It seems that project work can act as a remediation intervention for producing science task competency.

INTRODUCTION

The more traditional type of high school science practical laboratory work has been criticised widely for its low capacity for cognitive and skills development and for its inaccurate reflection of the way real scientists work (Soloman, 1980; Woolnough & Allsopp, 1985; Bryce & Robertson, 1985; Hodson, 1990). Hackling and Garnett's (1992) research on science students in Western Australian schools concluded that: most planning was low level, task specific planning in response to circumstances that arose during experimental work, none of the students verbalised an intention to control variables and that very few students could identify limitations in their experimental procedures (p. 175). Bryce (1994) also showed that lower secondary school laboratory work in Western Australia invariably involved little or no real problem-solving. Both of these studies support Tobin's (1986) earlier findings that in Australia, generally, most high school practical work followed recipe-style exercises at the lowest level of openness. In his study of tertiary students Skinner (1993b) established that few had ever had the experience of designing their own experiments and that recipe-following seemed to be the preferred practice in Western Australian upper secondary school science laboratories. Students stated that: there was very little discovery involved, tasks were too structured and merely involved the following of set procedures, and that answers were already known in advance (p.6).

There is an obvious link between the open-endedness of a task and the level of cognition required for the problem-solving involved. This relationship is illustrated by Figure 1.

Figure 1 The link between open-endedness and required cognition.



For totally closed tasks (recall, following set algorithms, etc.) only lower process and Bloomian skills are necessary to reach a single right answer, whereas with more open-ended problems involving the design and performance of experiments, higher order cognitive skills of synthesis, analysis and evaluation are brought into play. Many equally viable solutions are then seen as possible. It is suggested that the curricular emphasis on knowledge and low-order thinking prevalent in Western Australian schools has had the effect of suppressing the cognitive skills levels of students:

> *Fed on a diet of factual recall for exams it becomes difficult for any student to progress to any of the higher Piagetian levels of understanding* (Skinner,1995b).

That this is indeed the case was shown in research by Pears and Skinner (1994b) who found that 2nd year primary teaching students possessed a science content knowledge little different to primary pupils and had only reached an average Piagetian cognitive level in science of Concrete Operational; only 7% of these students were found to be operating at a Formal level. These findings are supported by other studies on pre-service teachers in Australia (Tobin & Garnett, 1989; Ginns & Watters, 1995). Moreover, Linn, Clement, Pulos & Sullivan (1989) believe teachers with low science self-concept to be far less prepared to teach science to their own classes in the future . Self confidence can arise, of course, from successful experiences at school with mastering science concepts and problem-solving strategies.

In order to promote positive attitudes and high order thinking and creativity in a perceived curricular vacuum many schools world-wide may enter their students in various science competitions outside of school where open-endedness is a key feature. In the USA summer science schools, with an emphasis on research projects, have been running for several decades (Kimbrough, 1995), whereas in UK problem-solving competitions, such as The Great Egg Race (BAAS, 1983), Young Investigators (BAAS, 1982) and CREST (CReativity in Science and Technology) are well established. CREST is an innovative national scheme which has been operating for several years in UK and New Zealand (and lately Australia) which rewards student-centred, open-ended project work in science and technology through a system of Bronze, Silver, Gold and Platinum awards:

> *CREST places considerable emphasis on 'problem identification', 'negotiation' and links between the student or schools and a range of outside agencies* (Watts, 1992).

Also in UK open-ended project work has been assessed formally within some curriculum frameworks since the early 70's: Nuffield Secondary Science (Misslebrook, 1971) and Nuffield 'A' level Physics (Woolnough, 1994: 60) were world leaders in this respect. In Australia, Science Talent Search (STS) is a popular national project competition dating back almost 40 years and now involves several thousand primary and secondary students each year. The kind of independent research projects mentioned above should have the potential to develop key competencies for the future work force (Mayer, 1992). In his research on students entering the STS competition, Tytler (1992) indicated that important generic and science-specific competencies were indeed achieved which conventional laboratory work fails to develop:

- Students were led into the design and planning of complex experiments and information gathering not otherwise undertaken within normal schooling (p 402);
- Students became capable of displaying independence and commitment to a degree not normally assumed in their schooling (p 403);
- Students could acquire a whole area of knowledge, viewed in a quite different way compared with class-based learning (p 404);
- Students found this mode of learning more interesting, enjoyable and challenging than normal class work (p.405).

Roth and Roychoudhury (1993) found strong evidence that open-ended enquiry tasks in science were actually capable of developing higher order process skills without them ever being taught directly by the teacher. Skinner (1991) is equally convinced of the superiority of the type of investigative science embodied within the CREST science project scheme:

> *...its usefulness makes it the best thing that has happened to New Zealand science this decade. I decided all this last week as I was finishing the marking of my 6FC practical projects for physics and electronics, and a kind of elation filled me as I saw what real science they had done and how they had enjoyed the experience which I have to tell you about.*

But to what extent do open-ended student investigations of this type fully reflect real scientific research which develops from an initial stages of problem identification through to hypothesis-making and testing and the proposal of scientific principles and laws?
The traditional, inductive linear model proposed in conventional school science classes is obviously not comprehensive and flexible enough to reflect authentic, creative science experimentation:

> *Scientific work is necessarily a craft activity, depending on personal knowledge of particular things and a subtle judgement of their properties* (Ravetz, 1971)

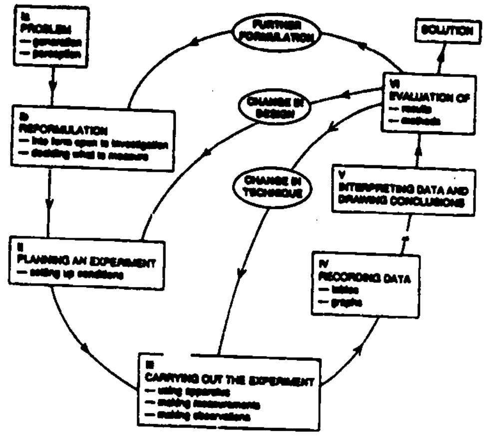
> *Real scientific research is more like play. It is unguided, personal activity, perfectly serious for those taking part, drawing unsuspected imaginative forces from the inner being, and deeply satisfying*. (Ziman, 1972).

Clement, in his study of expert and novice problem-solving, acknowledges the necessity for creative thinking to bring about what he calls *Eureka events*, essential for the restructuring of ideas and the production of new mental models:

> *An important factor in producing this achievement is the subject's desire to ask 'why' questions and to seek a deep level of understanding beyond what is required for the solution of the immediate problem. Presumably this urge to penetrate surface features and to conceptualise an underlying explanatory model at the core of a phenomenon is a basic motive underlying creative theory formation in science.* (Clement, 1989: 375)

Real scientists conduct experiments in a dynamic, creative, interactive fash.on, constantly observing, making sense of results, hypothesising, evaluating, redesigning tests and generating new ideas. This non-linear, fluid interplay between person and system is captured in the APU model of problem-solving shown in Figure 2. We can see reflected here Tytler's (1992) notion of autonomous behaviour in action, where the student needs to choose appropriate atomistic science skills and knowledge to 'bring back' to the problem for application.

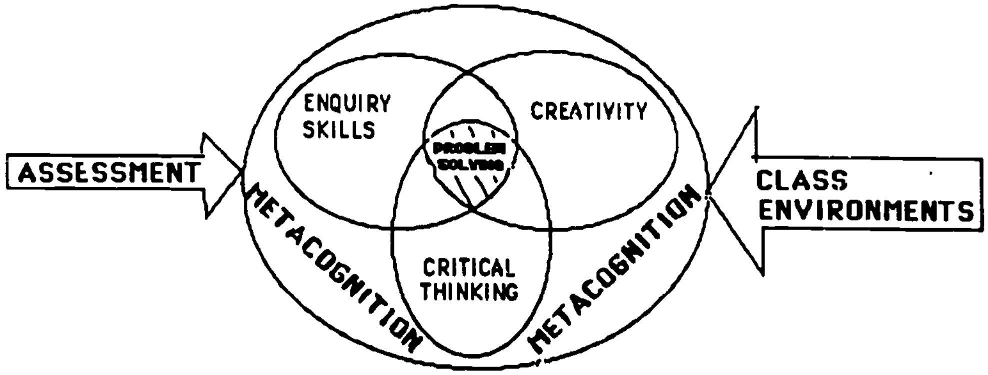
Figure 2 A model for problem-solving in science (Gott & Murphy, 1987).



This contrasts quite sharply with normal school science delivery, where these skills are tested individually and enormous amount of factual information is covered in case students migh. need it one day. We also see within this model the push for 'deep' learning (Biggs, 1988) and personal construction of meaning (constructivism) through the necessary use of three innate cognitive functions in order to solve problems:

- Enquiry skills - to ask salient questions and seek out relevant knowledge,
- Creativity - to generate alternative ideas for mental modelling and hypothesis testing,
- Analytical, or critical thinking - to evaluate findings and establish patterns.

Figure 3 The Pears (1995) model for good thinking.



Good thinking has been defined by Pears (1995) as the interplay between the three cognitive components used in science problem-solving (enquiry thinking, creativity and critical thinking) within a mental executive control system called metacognition. The mechanism by which the cognitive elements of this model are employed in science problem-solving is explained by Skinner (1995a) as an integrated oscillation process between left and right brain functions where a list of possibilities is initially generated by the right hemispherical functions to be criticised and evaluated by the linear left hemisphere. This process is iterative where the least valuable ideas are rejected in the process until a decision is made as to the most useful and practical method to implement.

Obviously there is a particular need for creativity to be emphasised in schools as a crucial element in the process of conducting 'real' scientific investigations, as opposed to ones where the student is searching for the answer in the book. One of the main aims of school science laboratory work should be to acquire tacit knowledge (Ravetz, 1971) and achieve the scientific task competence embodied in Figure 2. Renzulli believes that to achieve task competence in any thinking skills it is vital for students to be:

a) up-skilled in thinking skills and the techniques of enquiry,
b) given the opportunity to practice these skills within the curriculum,
c) allowed to apply these essential abilities in authentic contexts (Renzulli, 1986).

In summary, then, we can see a general dissatisfaction with conventional laboratory tasks in terms of their capacity to develop cognition, motivation and a deep understanding of science. Australia, like several other countries has now recognised the necessity to include science investigations into the curriculum and has incorporated a Working Scientifically strand within the Student Outcome Statements profiling system (Curriculum Corporation, 1994). However the model of student-centred, long term, highly open-ended project work as seen in STS and CREST programs appears to have the potential to better fill the competency gap than single, one-off, laboratory investigations. Unfortunately, only a minority of students ever become involved in these programs, more often than not outside of school. Nevertheless, the question to be asked is whether a 'real science for all' intervention program embodying this same philosophy of holistic enquiry could be used as remediation for those students with poor scientific understanding, attitudes and skills in order to produce a measure of science competence.

BACKGROUND TO THE RESEARCH

For several years now students in their 1st year of primary teaching courses at Edith Cowan University have been required to undertake an open-ended practical investigation assignment as part of their science education unit. The rationale behind this work is that it:

a) gives students experience in methods used by scientists, not previously encountered at school,
b) encourages the use of good thinking and teamwork,
c) models a constructivist methodology in which 'deep' conceptual learning is encouraged,
d) increases confidence in doing science and, in turn, encourages future teachers to implement such activities in their own classrooms.

The organisation of this project has been modified over several years through analysis and feedback provided to the present format:

1. Students form groups of 2 and start from week 1 of the semester to 'scan' for novel ideas which will form the basis of their long term investigation (project). They are encouraged to discuss possibilities with their partners and lecturer to allow for *incubation* of ideas.

2. In the 2nd week a Project Brief is handed in to the lecturer containing a Brainstorm display of ideas generated for real-world practical projects which have some personal significance. Following the Brainstorm, a Creative Problem Solving (CPS) grid (Maker, 1982) must be applied which allows evaluation of each of these ideas for selection of the best one to continue with. The consecutive use of Brainstorm followed by CPS grid illustrates the application of the creative thinking/ critical thinking alternation (left brain/right brain) procedure mentioned earlier and seen to be necessary for effective problem-solving (see Skinner, 1995b).

3.The Project Brief is handed back to the student groups with comments which provide formative feedback on the viability, scientific scope and use of creative thought. Students are pushed to the perceived limit of competency (Vygotsky, 1978) and encouraged to take risks and be innovative. Lecturers are instructed to remain non-directive in their comments in order to encourage individual constructivism to occur; certainly no wrong or right methods are intimated.

4. From the 3rd week on student pairs continue with the projects, whilst keeping a diary as a journal recording all activities undertaken, raw results, intuitive feelings, interpretations and reflections upon meaning at each stage. At all times lecturers are available to give help and advice, but again the approach is a non-directive one.

5. On the 5th week each group of students has to give an On-Track seminar to the class lasting 10 minutes which is scored by the other students and the lecturer combined. For this presentation, groups inform the class about the problem chosen, activities undertaken, results produced so far, possible interpretations and future tasks needed to complete the project. Marks are awarded according to criteria chosen by the class, themselves, but these would invariably include such things as: communication skills, commitment shown and creativity used in the presentation. Further feedback on their project work is supplied by the class through questions posed at the end by the audience.

6. Finally in week 7 a project report is presented to the lecturer for marking in a format chosen by the student which could involve formal writing, computer disc word-processing, a poster display similar to STS, a video presentation of experimental methods, together with the reflective diary.

Marks are awarded in the following categories:
Project brief - 5; Experimental design -10; Data presentation - 10; Data interpretation 5; Problems and improvements - 5; Class seminar - 5.

THE RESEARCH

The methodology for this research was of qualitative analysis where student projects from 2 classes were scrutinised for the various qualities which indicated science task competence. The written reports and diaries of 15 student pairs were further analysed and from these 8 students chosen for in-depth case studies and pair interviews. Choice of students reflected the full range of grades awarded for the project assignment, however, space here only permits full analysis of two of these student projects. Interview questions sought to clarify organisational details presented in the reports and also to gain information about students' educational background and opinions on the open-ended project experience. To gauge science task competence the question foci were:

- Past background and experiences with science,
- Conceptual understanding achieved,
- Experimental skills levels,
- Science process skills levels
- Proficiency in using the skills of good thinking (enquiry skills, critical thinking, creativity),
- Attitudes towards open-ended project work,
- Competency in co-operative group work.

Evidence for proficiency in investigatory science came both from the interview transcripts and the reports and diaries to produce an overview from which to address the research question:

> *To what degree does student-centred, open-ended project work enhance the conceptual understanding, scientific attitudes, science process skills and thinking levels of tertiary students towards the production of science task competence?*

Total class data (N = 50)

A list of the project titles for the 2 classes will give the reader some appreciation of the great breadth and variety of projects undertaken:

Visibility of letter boxes;	The most durable battery;	Evaluation of pens;
Easily-found keys;	Ant repellent;	Keeping cheese fresh;
Effective fly sprays;	Protecting eggs;	The best sticky tape;
Snail attractant;	The best toilet paper;	The effects of alcohol on reaction times; The
best nail varnish;	Plastic bag strength;	The best tea bag;
Paper planes;	Home-made speed humps;	Automatic sink-filler;
The best hair spray;	The effect of T.V. on pulse;	Study of gender seating in class;
A better hamburger bun;	Trampoline fatigue;	

Preventing evaporation from swimming pools; The effect of grease on cricket ball trajectory.

The average mark for these 25 projects of 27.7 out of a total of 40 (69%) indicates a high level of achievement by the class in this kind of work, as judged by a lecturer with considerable experience in assessment of such project work over a number of years.
Before focusing on the 2 main case studies in detail it is worth, perhaps, mentioning facets of several other projects which showed novel or interesting approaches.

<u>The effect of grease on cricket ball trajectory.</u>
At the time of controversy about England bowlers 'spiking' cricket balls with sand from the pocket and sun cream these male students set out to see exactly what effect could be produced by rubbing substances onto a cricket ball. A VCR was set up in an indoor cricket net pitch and balls bowled at a wicket from a bowling machine. Rubbing cream onto the ball clearly showed quite a large average deviation of the ball and by sandpapering the opposite side of the ball as well consistent deviations were produced of about 30 cm from the straight line.

<u>Home made speed humps.</u>
This pair of mature mum students were worried about their children being run over by fast-moving cars coming down their road to bypass the main road. They set up a fake speed hump made out of grass-

clippings to measure the effect and found a significant drop in average car speeds, measured over several days. An interesting observation noted was that men slowed down more often than women drivers.

A better hamburger bun.
This project was a Design, Make, Appraise-type investigation where the aim was to produce a bun which allowed less of the filling to fall out whilst eating it. The female team firstly surveyed several eating establishments and hamburgers to see the extent of filling lost and then baked several new designs of bun to see if they were any better - recessed buns with a lid, tubular buns, hollowed out buns, etc. The novelty with this project was in the presentation which took the form of a video-recorded documentary containing humorous episodes of husband and wife in a restaurant with hamburger fillings dropping out.

Snail attractant.
The aim here was to get rid of snails from the garden by attracting them into a trap. Preliminary experiments showed they were attracted by foods such as vegetables, beer and Go-Cat dried cat food and so combinations of these were tried out in order to find something which not only attracted snails, but also killed them. Very consistent results were obtained from a rigorous experimental procedure involving the use of 10 snails previously starved and then counting the number found drowned later in the various liquids. The ultimate trap contained beer with Go-Cat floating on the top - this attracted and killed 34% of the snails.

Case study No. 1: Reducing evaporation with swimming pool covers
(Marie and Jane. Highest class mark: 35/40)
Background: Both are mature mums who each left school after Year 10 with a poor grasp of science skills and understanding. Marie became a graphic artist and Jane a housewife. Their attitudes towards science at school were poor:
Marie: *I got good marks for science, but I wasn't particularly wrapped in it.*
Jane: *Actually I did COC chemistry (Year 10) which was a waste of time. When I went into the exam I got a Grade 3 CSE. I was devastated!* (interview)
Some background information on swimming pools was gained initially using enquiry skills (pamphlet from a pool company) to gain a better understanding of the problem. Other knowledge discovered included the fact that aluminium foil was best at preventing evaporation and that salt water evaporates at a slower rate than fresh water (report).
Experimental competency was shown in their rigorous control of variables: ice cream containers of same colour, containing the same volume of water, in same position in the garden. These were buried to simulate a real pool and water height measured at the same time each day. A control was used and the whole experiment replicated by the partner for pooling of results. No mention was made of the experimental pool covering materials being of equal areas, but this could have been so.
Had they acquired experimental skills through doing the project?:
Well I certainly gained a lot by way of just doing an investigation because I hadn't done it before. And also the graphing, the collecting of data, the looking for variables (Marie, interview)
With regard to process skills, good observation skills were displayed:
An interesting observation was the rate of evaporation which occurred in the salt water...
as the water evaporated it left a salt residue clinging to the sides of the container ...(report).
An unprompted hypothesis was generated: *An hypothesis for this is that salt does in fact slow down the rate of evaporation* (report).
Graphing of results was very competent (see Appendix 1) even compared with students who had had experience of this before:
I had never done it before on a computer, so that was pretty big. I did it but I had a bit of help from my husband (Marie, interview).

Enquiry skills were not used a great deal to elicit initial background information as the students probably did not see the relevance of this in their case. However, obtaining the pool pamphlet and using the husband as mentor demonstrates the way skills and knowledge were 'brought back' to the problem. Creativity showed itself in Marie's highly original Brainstorm (Appendix 1) where she 'drew in' and expanded on a multitude of ideas. The experimental design was fairly standard; not particularly creative, but adequate. However, the final display of results showed creative flair: this was a poster fabricated from blue plastic and made to look like a pool of water. This was accompanied by a model swimming pool, complete with a roller covering system. Marie's artistic skills showed, but did the students display creativity in the experimental work?
..I dunno, we hoped it would be different from everyone else - we didn't choose a plant or anything like that - but I don't know...(Jane, interview).
I mean, on the presentation we were creative a bit (Marie, interview).
Critical thinking skills shown throughout were of a high level, for example:

Problems occurred when Marie couldn't find a suitable full sun position but this situation was turned to our advantage when we decided to collect two sets of results, one from full sun and one from part shade. In this way we were in effect carrying out two different, but similar, experiments by controlling an extra variable amount of sunlight (Jane, diary).

Did they enjoy doing the project?;

I don't know whether 'enjoyed' is the right word. I didn't dislike it but I don't know whether it's something I would go out and do for fun (Jane, interview)

I enjoyed the fact that it opened up new realms for me and it's certainly made me more aware of a lot more investigatory things I can do with my own children. Since than I have been heaps more sensitive to their inquisitive natures in that area, whereas I hadn't really been sensitised before (Marie, interview).

Case study No. 2: Automatic sink filler

(Amanda and Jodi, Lowest project mark in class: 24/40)

Both students are in their early 20's and have rather unhappy recollections of science at school:

...mine (science)*was mainly from books, just step-by-step, not investigating. After Year 10 I did none, I hated it* (Jodi, interview)

We had to do science up to Year 10 then after that I didn't because I didn't like it (Amanda, interview).

This design project used a garden hose timer adapted to fit the kitchen sink tap so that when Amanda's forgetful grandmother turned on the taps it filled automatically to the preset level at the correct temperature. Amanda stated that she had gained a better understanding of pressure and both students claimed to now know how the garden timer worked.

The experimental procedure for this project involved a lot of trial and error methods, but assignment marks were lost through lack of precision and poor communication about activities in the report and diary: measurements of water levels, temperature ranges achieved, trials performed, etc:

The water temperature was worked out by feeling it and then drawing up a diagram showing how far each notch (for hot and cold water) *should go* (report).

Diary entries were very scanty and it was not used at all for any reflective thought. It is likely that the poor quality of experimentation was a result of the students' poor capacity to reflect upon ideas: *Personally I prefer to go straight from the Brainstorm and then get right into the subject - not writing in diaries and reflecting because you do that in your conversation when you talk to each other anyway* (Amanda, interview).

...it's just the concept of the diary. Pieces of paper, yes I would use, but 'Oh, I must grab my diary!' - it just doesn't happen (Jodi, interview).

Overall, the experimentation lacked rigour with no instrumental measures taken, but this may reflect a lack of awareness by these students about exactly what is expected in science, or perhaps insufficient drive to produce a quality product.

Enquiry skills were used to find out how to fit the timer onto the tap - a local hardware merchant helped with this. Creativity levels seemed quite high for this project, with evidence supplied in the diary of several unique ideas of which the automatic sink filler is one. Another idea from the Brainstorm was a Toothbrush Tablet Reminder design, where a toothbrush automatically dispenses a pill every time it is used (see Appendix 2). The students also produced a video to present their project and the suggestion for further development into a custom-made tap timer for blind people showed some lateral thinking:

We wanted to come up with something no-one else had that was also relevant (Jodi, interview)

A fair degree of critical thinking was also displayed: *As each household's water pressure is different the experiment needed to be carried out at Mrs Kelley's house. After much testing we were able to establish where the gauge had to be to achieve the water pressure needed* (report).

We found that our invention was quite unattractive, very large and quite complex to work (however) *the aim of the project was achieved as the tap automatically turned off at the required level* (report).

Did they think the Brainstorm and CPS combination was an effective tool for generating ideas?

Very Useful because I've used it in other subjects too. We went with Brainstorming but now every time I have to make a decision I get a list of the pro's and cons (Jo, interview).

What did the students feel about open-ended tasks?

RS: *Did the openendedness worry you?*:

Jo: *Very much. Now it would be different but then I just felt 'Oh!'*

RS: *So what were you expecting?*

Jo: *Structure! That was what we've always been given.*

RS: *How do you view that* (openendedness) *now?*

Jo: *I think it's great.*

Initial attitudes to science work were poor:

Both of us lack confidence in the field of science and were quite overawed by the size of the project. After much discussion and coming to the conclusion of attempting the tap timer project we became quite enthusiastic about the idea (report).

DISCUSSION AND CONCLUSIONS

We have seen here many students who have been turned off science by the unattractive face it presents. This seems particularly true in Western Australia where the majority of females undergoing primary teacher training have never done science at Year 11 and 12 levels, or take only human biology in order to avoid the physical sciences. The question could arise as to how representative this cohort is of the general population because of their low ability levels compared with students in other courses (primary teacher trainees have the lowest TEE entry score for any course). However, the cohort would still represent the upper end of the general school population cognitively and so there must be many students in the system with lower science understanding skills and attitudes than these. Poor attitudes towards science are passed on to the children the cohort of students teach eventually reinforcing the cycle of avoidance.

Open-ended investigatory work initiating from students' own interests seems promising in providing the motivation for engaging in science activities where these were previously avoided at school. The APU's non-linear model for investigations starts with problem generation and it has been suggested here that the Brainstorm/ CPS combination is an efficient and under-used system for initiating studies which are interesting to the student, useful in the real world and therefore motivating. The knowledge and skills necessary for problem solution need to be acquired by the student as much as possible, rather than supplied by the teacher. This approach seems to encourage 'deep' understanding and autonomous learning behaviour through ownership of the problem in the first place and a more active participation through internal locus of control. Project work, as exemplified by the CREST scheme, differs from other current investigative science activities in several important regards:

They are long-term undertakings with most work performed outside of the classroom,
They involve authentic contexts, not contrived ones linked to syllabus content,
They may involve the help of other outside people as consultants, or mentors,
They must be evaluated holistically, rather than atomistically (Hodson, 1991).

Evidence is apparent of a constructivist learning paradigm in operation through the necessity for active learning of science concepts and skills. The open-endedness of the task provides a less threatening environment in which to discover, without the drive for correct answers. According to feedback from surveys students value open-ended project work and feel this has made the difference to their views about science.

Data from case studies also reveals a good level of conceptual understanding and process skills development, even with the poorest performing students. In spite of an emphasis on creativity in project work logical, linear thinking styles still seem favoured by the mark schemes: although Amanda and Jodi were the most creative pair the other two components of the good thinking skills triad (enquiry skills and critical thinking) were used concurrently to a greater effect by Marie and Jane in the maintenance of science task competency. The male/ female competency levels discussion is an important one here. It seems from this and other previous studies that project work is the female preferred mode of learning science and one where they can certainly compete on equal terms:

> *An interesting pattern is apparent here which is similar to that found in Britain: With CREST-type science, girls out-perform boys.* (Skinner, 1993a)

Not only that, but due to the allowance of cross-curricular context choices girls often find knowledge of physical science aspects unavoidable if they are to succeed in their chosen problem.

Here is an example of this from two other female students with poor attitudes towards physics whose chosen project was on Sand-boarding:

RS: *So how do you feel about it now that you know it's going to involve physics? Do you want to give it up and do something else?*

Student 1: *No, I don't want to give it up. I really want to do it; it's really interesting. I'm prepared to go and look it up for sure.*

Student 2: *Definitely not!*

Critical thinking and enquiry skills shown in their work is at a consistently high level of sophistication despite lack of direct intervention but competence in these seems directly on the amount and depth of reflective thought students are prepared to engage in. A pair of students from another group decided to simulate the effect on oceans caused by global warming by melting ice cubes in water and noting the resultant rise in water level. They actually found in their experiments that melting made no difference to the level but still went on to rationalise that:

Glaciers will melt and fall into the ocean, breaking off into icebergs - this will cause the ocean levels to rise (project report).

We see here an attempt to rationalise their findings (no rise in water level) in the light of what they knew to be true from the media. Here is an example of how misconceptions can be formed when students lack the critical thinking skills to probe deeply in reflection and to ask the question 'why?' (see Skinner, 1994). An important point here which is often missed by educationalists is that:

Good constructivism can only occur with people who have good thinking skills.

Of all the personal qualities such open-ended project work develops it is students attitudes to science which seem to benefit the most. Some individuals, for the first time, have come to appreciate the relevance and enjoyment of doing science in a non-threatening environment. Here is motivation, indeed to reach science task competence. In spite of the real-world focus (as opposed to science curriculum focus) we have seen powerful evidence that good science can be performed by students hitherto left unskilled and unmotivated by conventional school course work. As educationalists, if we are serious about emphasising the processes of science, we must be prepared to move away at times from small-scale investigations done in laboratories, centred often within a fixed context of biology, chemistry, or physics. We need to make the move towards student-centred, cross-curricular thinking-skills approaches.

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