Teaching a Combined Science/Technology Curriculum

Gabriel Ayyavoo
Dr. J.L. Bencze
Alex Corry
Roland van Oostveen

The educational curriculum is being restructured in the province of Ontario. Among other major changes, the restructuring has required that both science and technology are now to be considered in a common program for students in Grade 1 through to Grade 8. A debate has ensued among many of those who are responsible for curriculum implementation. This debate has focussed on the nature of the relationship between science and technology.

The Ontario Curriculum, Grades 1 - 8: Science and Technology was released in March 1998. The document provides the basis for the Science and Technology program which was to be implemented by September 1998. While the document attempts to briefly define the nature of science and technology, the bias of the authors in favour of a science orientation is fairly obvious early on. Science is acknowledged as “a form of knowledge that seeks to describe and explain the natural and physical world and its place in the universe.” Technology is much more vaguely described as “includ(ing) much more than the knowledge and skills related to computers and their applications. Technology is both a form of knowledge that uses concepts and skills from other disciplines (including science) and the application of this knowledge to meet an identified need or solve a specific problem using materials, energy, and tools.” (Ontario Ministry of Education and Training, 1998)

These definitions do give the reader (and hopefully the teacher) a general sense of the nature of the two disciplines. However, this sense is very limited especially when teachers are to use this information in order to prepare classroom-ready teaching materials in order to convey these definitions to their students. The big problem is that both science and technology are much more than just forms of knowledge. They also entail processes that are endemic to the disciplines. A term coined by Polyani (1958) and much used by Hodson (1993b), likens the ‘doing’ of science and technology to “connoisseurship.” Connoisseurship, used in this way, refers to the tacit knowledge that is acquired by participation in an activity. Medway (1989) agrees by suggesting that doing technology is highly tacit and idiosyncratic and requires apprenticeship to be learned well. Gott and Duggan (1995) believed that procedural understanding must be taught since there is a content piece to the procedural side of science which can be described and which must be recognized and planned for in curriculum design and assessment.

The remainder of this discussion focusses on a presentation given at STAO ‘98. It attempts to compare science and technology, compare the two disciplines in terms of teaching practices and then offer some suggestions which can be used to teach either discipline in the classroom.

There are a significant number of differences in how the two disciplines are viewed by society. As a result, or in conjunction with these views, the subjects are treated very differently in different schools.

Science has been very successful in its effort to portray itself as, not only an understanding of phenomena, but also having control over various aspects of nature. This has resulted in science gaining a fairly prominent position in society. The high status of science can be seen in the popular media. Scientists are often portrayed as financially successful and well respected. Newspapers and magazines and other print media tend to make light of what is viewed as a scientist's single-minded dedication to the enterprise while also paying vast amounts of attention and print space to the results of the latest findings in health, psychology and other areas of study.

By way of contrast, workers in technology, such as technologists and technicians, are often viewed as "blue-collar" production workers. The status of technology in society is much lower than science. How often has repairing an automobile been equated with rocket science? The perceptions of technology being of a lower class than science remain in spite of the usefulness of these practical technological skills compared to the relatively impractical theoretical skills of scientists.

Science education has followed the general societal emphasis. This is traditionally carried out by using a curriculum that is strongly "academic" in flavour. Bencze (1995) goes so far as to state that in order "to suppress criticism, an 'illusion of certainty,' a sanitized virtual reality, for academic science is perpetrated." Science education has also continued to promulgate other societal characteristics in that it is strongly masculine (reflecting traditional stereotypical male values): it is "hard-nosed, objective, value-free"; it eschews the ambiguous, the speculative, the vague, the beautiful and the good. (Mitroff and Kilmann, 1978)

Technology education tends to be taken by students who, for a variety of reasons, are not prepared to work in the "academic" scientific courses. These students tend to opt for the courses which are much more practical and active, but which also have a work force orientation. The Ontario Ministry of Education has stated general level courses (which includes many technology courses) are intended to supply good, reliable workers: develop skills relating to problem solving, domestic management, consumer judgement, recreational pursuits, personal fitness, and employment awareness. (Ontario Ministry of Education, 1987)

There are other differences between science and technology education when the school locations for these programs are noted. Science tends to occur in clean classrooms or dedicated science labs while technology classes are usually found in physically separated locations (ghetto-ized). This ghettoisation may be due in some cases to the need for large spaces and specialized equipment in some cases. However, this does not explain the location of many of the technology classes which do not have the requirements of the specialized equipment. Much of this discussion uses information taken from secondary school settings since, until this latest curriculum initiative technology education did not occur at the elementary school level except in design and technology classes in the intermediate (Grades 7 & 8) levels.

Differences between science and technology occur in the areas of pedagogy and assessment as well. Science courses are usefully found to have a heavily weighted focus on theory and a small emphasis on skills. As a result the typical teaching methodologies found in most science classrooms are generally a mixture of Socratic (question and answer) techniques, demonstrations and some practical work. Practical work has, for the past few decades, emphasized the following of procedures that have been designed by teachers and publishers to validate some aspect of the concepts that are being transmitted to the students or the procedures attempt to allow the students to "discover" a conclusion which allows for continued conceptual development in the area that the teacher is attempting to explain. By far the most common type of assessment used in science courses is the traditional paper and pencil testing. Recently there has been some occurrence of performance testing on practical skills, although this is still rather new, fairly innovative and rare. (Perhaps use some of Derek's articles re. value of this type of practical work.)

Technology courses, by contrast, tend to shift in the other direction with a heavily weighted focus on skills and a small emphasis on theory. These courses put much time and emphasis on projects to be completed by the students. At times demonstrations are used when a particular technique must be shown before the students would be able to carry it out. Occasionally theory is addressed but even this theory focusses on procedural type knowledge rather than on an understanding of the phenomenon itself. According to Price and Cross (1995), inventors need to work only with "laws" as opposed to theories - or "why" things work. Assessment techniques in technology education tend to focus on the product or the skills practised by the student. This is usually carried out by peer or teacher assessment of the processes used by the student or an evaluation of the final product from the perspective of design considerations or perhaps efficiency. Technology has been relegated to secondary status in our educational system. Lederman (1992) suggests that there have been conscious efforts over the years to deny practical science (technology) a place in the school system. Lederman also states that at other times, science education tends to take aspects of technology which appear to be close to specific laws and theories of science and incorporate them into their courses without acknowledging that they are inventions, or technologies. According to Chapman (1991), it is regrettable that science education has achieved its status given that it is of limited use to most people. Technology, on the other hand, is much more relevant and deserves the prominence given to science education.

Since science and technology education has been combined in the elementary school curriculum it may be deemed prudent to attempt to focus on changing the methods that are used in presenting these disciplines to students. The last portion of this discussion outlines theory and some examples of how this theory might be used in classroom situations. A full discussion of this theory can be found in Bencze (1995). Parts of this theory have been implemented for the past several years in various schools around the Toronto area.

Theory (Goals of Science and Technology)

It has become increasingly apparent, while attempting to implement the new integrated science and technology curriculum, that teachers need assistance in defining the similarities and difference's between science and technology so that they can appropriately arrange their classrooms and the experiences that they provide for their students.

In our view, both Science and Technology share a fundamental characteristic or goal. The goal is an attempt to study the relationship(s) between CAUSES of a phenomenon and their subsequent RESULTS. While the goal is held in common, there are differences between the methods that are used in carrying out these goals.

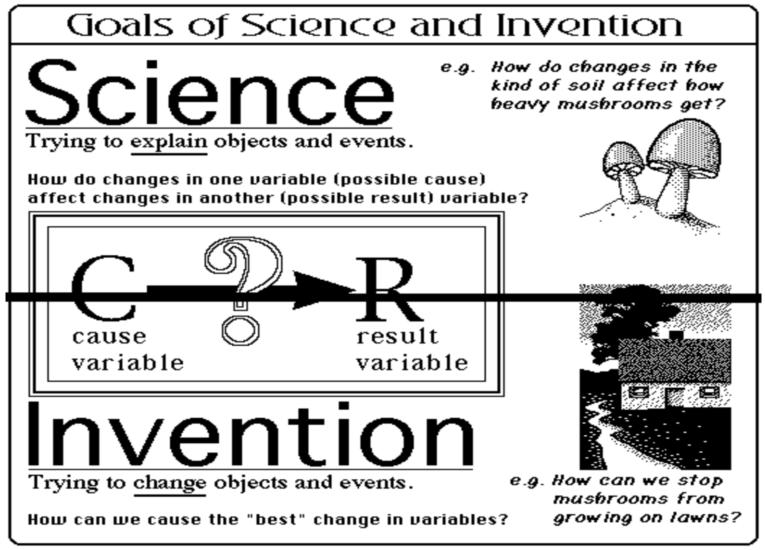

Figure 1: Science and Technology Goals

Essentially, we believe that science (inquiry) attempts to <u>explain</u> objects and events - the why's of the world. Science may be viewed as a quest to explain natural phenomena, both rationally and empirically (Millar and Driver, 1987; Solomon, 1995). The example given in the diagram attempts to show this kind of purpose in the type of <u>causal question</u> that is used, e.g., *How do changes in the kind of soil affect how heavy mushrooms get?* Causal questions can be formatted in the following way: "How do changes in one variable (*possible cause*) affect changes in another (*possible result*) variable?" (Bencze, 1995) Cause variables can be manipulated in set ways (as in experiments) or measured in natural situations (as in correlational studies) and the resulting changes can be studied.

Technology studies (or "inventions" as we term them), as contrasted to science (inquiry), attempt to <u>change</u> objects and events. Problems such as "*How can we stop mushrooms from growing on lawns?*" exemplify one of many types of situations that can be addressed by innovations. Technology strives for "know how" or "recipes for making or doing things" where "making" refers to developing certain physical products such as a particular glass lens, while "doing" refers to production of processes such as a method of purification of substances (Price and Cross, 1995). Kimbell (1991, p. 138) explains that "the differences [between

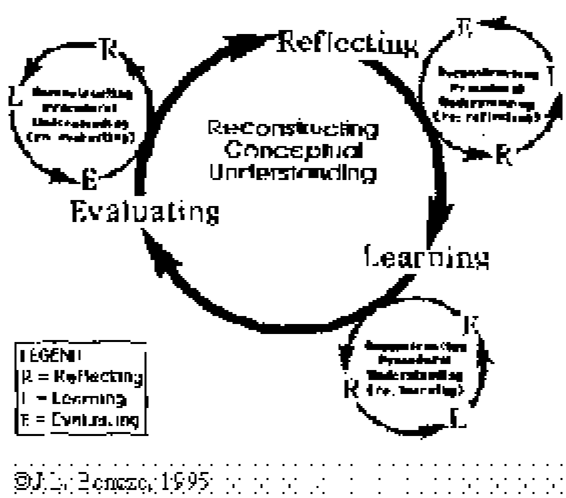

Figure 2: S/T Learning Model

science and technology] are of purpose rather than behaviour, for ... the point of technology is to intervene in the made world, to modify or improve it in some way in response to identified needs or opportunities." Usually a study of inventions leads the inventor to work in such a way as to determine how to "cause the 'best' change in variables." (Bencze, 1995) In this way a number of cause variables are manipulated so that the invention solves the posed problem in the best possible way.

The theory (see Fig. 2) for implementing inquiry and design in the classroom proposed here relies heavily on what Polanyi (1958) refers to as the tacit nature of scientific and technology knowledge, that is, the delivery of both require guidance in the areas of theory (conceptual understandings) and in "doing" (procedural understanding). It is also believed that the conceptual and procedural understandings are interdependent (Qualter et al., 1990, 12). As a result, a curriculum that purports to require science and technological concepts must allow for the teaching of both the conceptual and procedural understanding of the disciplines. Traditionally only the conceptual understanding is focussed on. However the procedural understanding must be explicitly taught. As well, "there is a content to the procedural side of science which can be described and which must be recognized and planned for in curriculum design and assessment." (Gott and Duggan, 1995, p. 34)

Both the conceptual and procedural understandings are illustrated by the model in Fig. 2. Bencze (1995) describes the model as incorporating two kinds of constructivist cycles, each encouraging: i) **Reflecting** on current conceptions, ii) **Learning** others', and iii) **Evaluating** competing ones. The large circuit describes the conceptual learnings that are, for the most part, itemized in the expectations of the Ontario Curriculum, Grades 1 - 8: Science and Technology. The smaller circuits describe the procedural learnings that must be undertaken by the teacher and student in each of the areas of the larger circuit. Further information regarding this model can be found elsewhere (Bencze, 1995).

Classes based on the S/T Learning Model call for students to design their own scientific investigations (inquiries) and technological inventions (designs) in the procedural understanding section of the evaluation portion of the conceptual loop. To do this students draw on their own experiences to determine the causal questions and practical problems to be addressed. They are taught some of the basic methodologies of science and technology and then they apply these methods to the questions and problems posed. The teacher attempts to organize opportunities for students to be exposed to alternative conceptions and methodologies in reflecting, learning and finally evaluating. The teacher also learns with the students in how to design investigations that are appropriate to the contexts that students bring to the classroom. In this way, the teacher and student become co-investigators. According to Freire (1970), the teacher and student"come to see the world not as a static reality, but as a reality in process, in transformation (p. 7), i.e., capable of change.

It was felt that teachers required further assistance with the procedural understandings of science and technology. In order to give this help additional clarifying models were designed. These models are described in the following section.

Investigational Methodology

While the processes are similar, each has features that are unique. The following part of the discussion focusses on a brief description of the models of procedural knowledge that are being used in the TDSB. There are separate, though related, models for Science (Inquiry) and Technology (Design). It should be noted that these models were designed primarily to assist elementary (including intermediate levels) school teachers in incorporating processes (the teaching and doing) of inquiry and design into their programs. They are not intended to be comprehensive nor exhaustive.

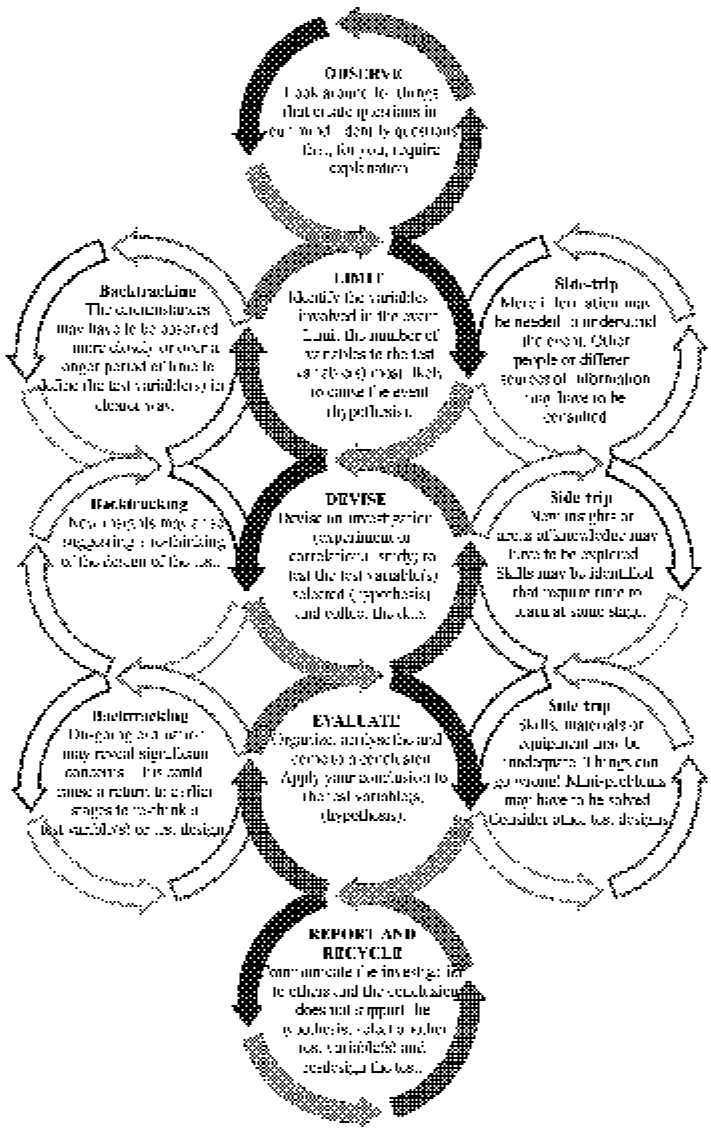

Figure 3: Inquiry (OLDER) Model

Inquiry

The "OLDER" model incorporates many of the features of traditional models of scientific methodologies. However there are also significant differences. While traditional scientific methods imply a linear development of ideas and processes, this model allows for teachers (and students) to see that scientific investigations can be initiated in a number of ways and that 'backtracking' and 'side-trip(ping)' is allowed, and even encouraged. For the sake of simplicity, larger loops from each of the main, central sections back to the beginning are not included but are implied by taking several sequential 'backtrack' loops.

Use of this model in class would include allowing students to be exposed to situations or contexts that would illicit some observations. These situations cause the students to ask questions. These questions could be of a scientific nature (determining the reasons for the situations or context) or of a technical nature (posing problems that require solutions). If the questions were scientific, student thoughts would be directed to think of hypothetical answers. This would be done by focussing on only a few variables (limiting the scope). Ultimately, the students must devise scientific investigations that could possibly answer the questions previously posed. The data collected must be evaluated by organizing and analysing it and applying it to the original hypothesis so that decisions can be reached as to whether there is adequate information to answer the original questions. Finally, the nature of the investigation, the data and the conclusions reached by the students would be shared with peers and a consensual understanding would be reached through discussion.

Design

The 'SPICE' model used for design methodologies is similar to the science methodology. Figure 4 outlines the steps involved in this methodology. Again the same type of 'backtracking' and 'side-stepping' is possible, reflecting that these procedures are not necessarily sequential in all circumstances with all participants.

Use of this model is also initiated in a situation or context. This situation or context could be of the teacher's making or the student's. A practical problem can be defined and a possible solution designed to solve the problem. The solution could be a product or a process (technology). The technology would be built and tested by the student. The testing of the solution would be evaluated on the basis of how well the solution met the conditions of the situation, generally including a variety of characteristics such as efficiency, creativity, and aesthetics.

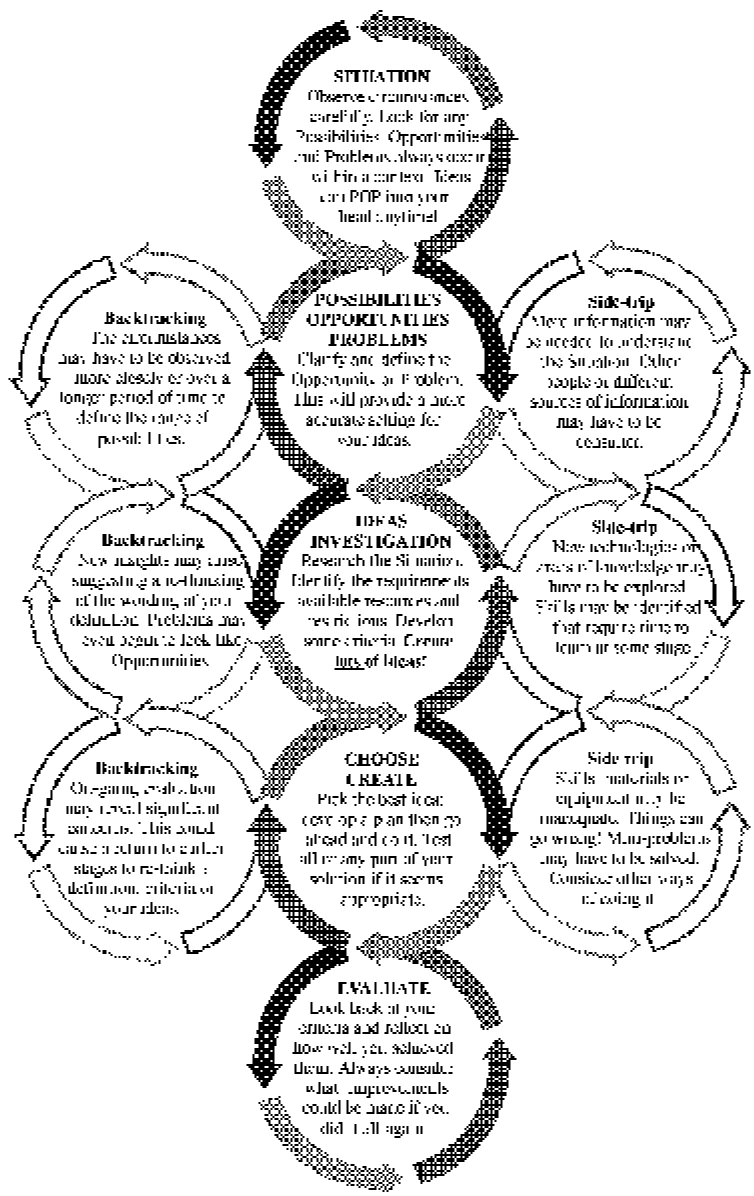

Figure 4: Design (SPICE) Model
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Challenges and Investigations

Examples of how these processes (inquiry and design) could be used in the classroom are included in this paper (see Figure 5 and 6).

The "Bugscopter" (Figure 5) activity is intended to give students the opportunity to devise their own experiment to give them experience in developing procedural knowledge of scientific methodology. When teachers are introducing this methodology it is suggested that an activity such as this be used, in that the conceptual knowledge should probably not be related to the topic at hand. This is suggested since students have a tendency to use examples that can be directly related to the concepts being studied rather than exploring their own ideas and preconceptions. After working through the initial attempt to devise their own investigation, students should be given an opportunity to apply the procedural knowledge gained to the topic or unit currently being studied.

In this example, students are given the 'Bugscopter' and are encouraged to 'play' with it and observe what occurs when the 'Bugscopter' flies. Essentially, the students will be identifying variables that can be manipulated at this stage. If this is the initial time for the students to participate in this type of procedure, it may be wise to provide the causal question as in this example. The hypothesis can also be structured to enable placement of the chosen variables in the Limit stage for students who are not familiar with these stages. Working with the teacher, students then should be given the opportunity to devise their own procedure, and once inspected with the teacher, the procedure should be carried out by the students. Data must be collected, organized and analysed. Again, students may need to be taught to carry out these functions. Conclusions must be reached by comparing the results to the original hypothesis. Students must be given the opportunity to reach a consensus with others who studied the same type of variables, just as 'professional' scientists attempt to by entering into debates regarding their understanding of the gathered data with their peers.

The "Flying Machine Challenge" (Figure 5) activity is intended to give students the opportunity to design their own invention to give them experience in developing procedural knowledge of technological methodology. Again, teachers should use a neutral (not specific to the concepts under study in the unit) topic to introduce this methodology to students for the first time to allow students to concentrate on the procedural part of the program rather than on the conceptual side.

Teachers who use the "Flying Machine Challenge" can set the context for their students using the given situation. The problem is stated, however if students are advanced in these types of design they may specify the problem for themselves. The stated questions can be used by the students to aid in their thinking about the design of their solution to the problem. Ideas can be stimulated using a variety of methods beyond the questions listed here. Teachers should be prepared to work with individuals and/or small groups to expand the repertoire of ideas that students can choose from in formulating either the solutions or how the solution will be constructed. Once the invention has been constructed students must be directed to evaluate the design to decide whether the solution adequately solves the original problem. This is probably best done by having the students devise a modified experimental procedure. This procedure would allow a few variables, present in the invention, to be isolated and tested. The final step should also include students sharing their ideas and solutions with each other in the same way as in the inquiry example.

Conclusion

It is possible to combine Science (Inquiry) and Technology (Design) in the classroom. The Science and Technology Model of Learning gives a constructivist method of teaching procedural and conceptual knowledge. By concentrating on both types of learnings simultaneously within the contexts set in the class it is possible to provide learning opportunities for students to experience more than just concepts presented in unending procession. The models of Inquiry and Design give additional ideas for teachers to use when providing students opportunities to investigate ideas in either Science or Technology. Finally, the two Activities show concrete examples that can be used by teachers when working with the procedural side of the learnings in the new Ontario Science and Technology currirculum.

The Bugscopter

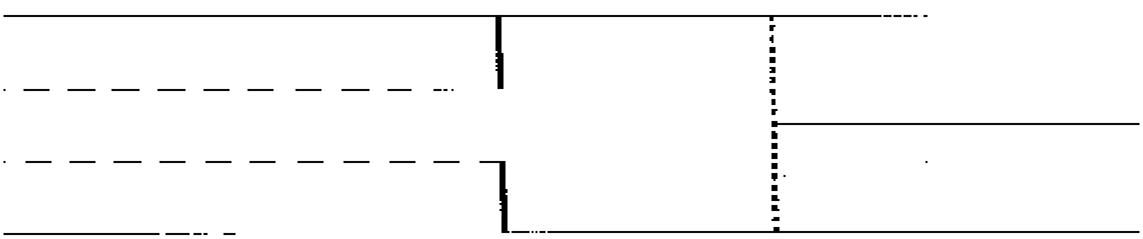
Alternative Science Methodologies

Biology

Many plants produce light weight fruits that are carried by wind. Maple trees have winged fruits that aid in wind dispersal. People have often turned to nature to copy some of these unique flying structures. The *Bugscopter* is a flying innovation that allows for the testing of different variables that enable the flying machine to stay aloft as long as possible. In this activity, the student 'flight engineer' teams will design an experiment and carry out the scientific investigation on the factors that enables the *Bugscopter* to stay flying in the air .

MATERIALS:

1) 3 *Bugscopters*
2) timer
3) paperclips
4) scissors



Student Experimental Design Report:

Expt. Design	**Student's Experimental Design**
1) Causal Question:	e.g. What is the effect of the **length of the wing span** on how **long** (time) they stay aloft ?
2) Hypothesis:	If the **length of the wing span was increased** then the ***Bugscopter* will stay aloft longer** because ....
3) Method Outline:	- steps followed
4) Observations:	- data chart and graph
5) Conclusion:	- based on the data

Figure 5: Inquiry Activity Example

Flying Machine Challenge

Situation: You are a famous geologist (rock scientist) and have been hired to find rare minerals. Your search constantly takes you into mountainous areas which are difficult to climb into. You would like to have a device which would allow you to set a very small electronic instrument package at a specific target below you.

Problem: Design and construct a flying machine which would be able to descend slowly and land in a precise location.

Investigation and Ideas:

1. What materials will you need?
2. What type of flying machine do you need to construct?
3. How will you make the flying machine?
4. Something to think about:
   -fixed wing aircraft such as airplanes can travel long distances but have difficulties travelling up and down in a straight line
   -flex-winged (or no-winged) aircraft such as helicopters easily travel up and down
5. How accurate will your flying machine be and how much mass will your flying machine be able to carry?

Your team must submit ONE competed report of the experiment for evaluation, including the following sections:

Technology Challenge/Situation
Describe what is happening

Technology Problem
Describe what your project must do

Ideas
Draw picture(s) of your chosen idea or design remembering that innovations are produced by:

- combining "old" inventions in ways which produce a new invention,
- making changes (improvements) in "old" inventions,
- inventing new uses for an "old" inventions,
- inventing a new product or process by combining parts of "old" inventions.

Construction
Things I need
How I will make it:

Evaluation
Make up ways to measure the success of your invention. Keep the following in mind:

- steadily increasing cause variables;
- keeping most other known variables constant;
- measuring both the cause and result variables, where possible;
- repeating each test several times (eg. 10 times);
- repeating each measurement a few times (2 or 3 times);

Plan the data tables in which you will record the results of the tests of your invention.
Make sketches of any graphs which show the results which you hope to get in your tests of your invention.
Communicate your conclusions to others.

Figure 6: Design Activity Example

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