SCI-TECH ONTARIO

REAL SCIENCE:

USING PROJECTS TO ENGAGE STUDENTS AND MEET THE GOALS OF THE ONTARIO CURRICULUM

Grades 9-12

(First Edition)

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Introduction:

'Real Science' is a document for teachers, parents, and administrators who would like to involve students in project-based science. Project-based science is an effective tool for the development of critical thinking skills, and for achieving expectations of the Ontario curriculum. It allows young people to be involved in authentic scientific inquiries, which will increase their understanding of how science works in the real world. This, in turn, helps develop citizens who are scientifically literate and able to look at current and future scientific and technological issues with a critical and understanding eye.

The aim of 'Real Science' is to develop in all students the joy of doing science that matters. Science that matters means students are actively engaged in asking and exploring genuine questions. Empowering students to solve real world problems creates an excitement and energy in the classroom, and fosters an increased responsibility towards society. Through projects, students will enhance their science knowledge and skills, hone their communication skills, and develop more realistic ideas about how scientific knowledge is developed and the status of such knowledge.

"Creativity in scientific research is seeing what others have not seen, and making it visible to others."

Dr. Tom Brzustowski, President, Natural Sciences and Engineering Research Council of Canada

This document is divided into two sections. The first looks at the rationale for, and benefits of, achieving excellence in science through project-based investigations. The second section looks at teaching strategies that incorporate project based investigations in science classrooms and other school programs.

Project Based Science: A Holistic Approach

Project-based science capitalizes on students' natural curiosity to inquire and learn. Students who are encouraged to pursue genuine science questions and solve genuine technological problems are engaged in project-based science. Students actively construct meaning and are engaged in authentic learning when they are investigating questions that are real. These questions may arise in science class, in other subject areas, or from activities and interests that students have outside of school.

The Ontario Curriculum frequently invites students to solve problems using genuine ideas and techniques. Observing events or phenomena in class or in their environment actively engages learners to seek answers to questions. Providing students with open-ended investigations in class creates opportunities for students to use their strengths. A holistic science program enhances such authentic learning.

Curious learners want to solve problems by engaging in authentic methods. Science projects are natural culminating events that provide holistic learning that goes deeper into the curriculum and often beyond. Questions that arise in a particular strand may trigger student's interest and provide connections to technology, society and the environment.

> Tiffany was conducting an independent science investigation at the end of the Grade nine Chemistry unit. Having recently studied the physical and chemical properties of compounds she was interested in studying the effects of road salts on organisms in the environment. Her preliminary library research revealed data supporting the claim that road salt damages small invertebrates and stunts plant growth. She began her quest for de-icers that produced minimum impact on the environment.

Projects are natural culminating events for any unit of study. Empowering students to incorporate information from laboratory inquiries, demonstrations, class discussions, debates, videos and guest speakers supports the development of critical thinking and is purposeful. Purposeful inquiries get students thinking about the big concepts and questions and result in enduring or lasting understandings for the students. These investigations develop inquiry and design skills, and allow for the critical discussion of the key concepts in small and large groups.

Project-based science requires students to be critical about science concepts. Through a holistic approach to science, students share their preconceived ideas that emerge through active inquiry. Their conceptual understanding is often revealed through student skits, songs, drawings, poems and computer animation of a topic. When faced with alternative explanations, accepted by the scientific community, students' views may be challenged. Through lessons that incorporate readings of research articles, demonstrations of chemical, physical or biological laws, use of computer animations, video programs or laboratory activities, their knowledge and view of science may be challenged. They reconstruct ideas through discussions and want to test them by project work. It is vital that these inquiries engage students in constructing meaning and understanding; "hands-on" activities are not effective if they are not "minds-on" as well.

"Every great advance in science has issued from a new audacity of imagination."

John Dewey, The Quest for Certainty

Start small: Although projects are usually presented as an extended investigation, there is considerable value, particularly in the early stages of developing inquiry and design skills, for shorter-term 'projects' or challenges. Science Olympics events and engineering challenges are good examples of engaging short-term projects. The key to meaningful learning with short-term activities is effective follow-up and the opportunity to integrate new understanding and experience. Building a solar car once is simply a challenge. Building a second car – after discussing the effectiveness of designs with peers and exploring the strength and stability of various geometric shapes – makes the activity a meaningful learning experience.

Goals of Ontario Secondary School Science Program

The overall aim of the secondary science program is to ensure scientific literacy for every secondary school graduate. This aim can be achieved by meeting three overall goals for every student. The secondary science program, from grade 9 through grade 12, is designed to promote these goals, which are:

"*i)* *to understand the basic concepts of science*
ii) *to develop the skills, strategies, and habits of mind required for scientific inquiry*
iii) *to relate science to technology, society, and the environment.*"

(Ontario Curriculum, Grades 9 and 10, p.4, 1999; Grades 11and 12, p.6, 2000.)

In order to incorporate project-based science in the curriculum, it is important to understand the extent to which this approach will meet the goals and aims of the secondary science program. The Ontario Science Curriculum for grades 9 to 12 is organized around specific content areas or strands to promote the three goals. As a result, planning for these units often focuses on content and ways in which students can learn the "facts" about a certain topic. When planning courses, it is recommended that teachers link the required curriculum goals and expectations to the specific categories of the Achievement chart (Knowledge and Understanding, Thinking and Inquiry, Communication and Making Connections). Covering content achieves only the first of the three basic goals of the science curriculum and addresses only one category of the Achievement Chart for Science. A science program that incorporates project work is more likely to bring about an appropriate balance across the four categories of the Achievement Chart. Students who really know and do science are those who can complete independent projects by applying skills and knowledge from the four categories of the Achievement Chart (the achievement charts are available on page 46 of The Ontario Curriculum: Grade 9 and 10 Science, 1999 and on page 174 of The Ontario Curriculum: Grade 11 and 12 Science, 2001).

Independent inquiries and projects allow students to achieve the Ministry's science goals and objectives by allowing the learning of scientific concepts using investigative and communicative skills. Thereby, the project work promotes the application of student findings to science, technology, society and the environment (STSE). Without any 'minds-on and hands-on' practice, teaching basic science concepts and skills are neither adequate in achieving the Curriculum goals or providing links to STSE.

"The great tragedy of science -- the slaying of a beautiful hypothesis by an ugly fact."
Thomas Huxley

At the secondary level, science teachers often overemphasize content, and underemphasize scientific process. Project work insures that the full curriculum is being covered, and gives students essential scientific inquiry skills needed for students to be successful in future endeavours. Learning science becomes engaging and fun rather than simply a fact-gaining process.

Ontario Secondary Science Curriculum: Overall and Specific Expectations

"*Two sets of expectations are listed for each strand, or broad curriculum area, of each course. The overall expectations describe in general terms the knowledge and skills that students are expected to demonstrate by the end of each course. The specific expectation describes the expected knowledge and skills in greater detail.*" (Ontario Curriculum, Grades 9 and 10, p.5, 1999.)

The secondary science curriculum can be intimidating because of the number of overall and specific expectations in the curriculum documents. Teachers may avoid project-based science because of time pressures and the perceived need to "cover" the curriculum. A close look at the curriculum, however, shows that independent inquiries and projects address important goals of science and technology education— goals that are difficult to address in other ways — and still allow enough time to teach the entire curriculum.

Students pursuing project work can achieve the overall curriculum expectations related to the area of study and the specific expectations from D*eveloping Skills of Inquiry and Communication* and *Relating Science to Technology, Society and the Environment*. The skills identified in these specific expectations are inherent in project work.

"*The expectations in science courses call for an active, experimental approach to learning, with all students participating regularly in laboratory activities. Laboratory activities can* *reinforce the learning of scientific concepts and promote development of the skills of scientific investigation…"* (Ontario Curriculum, Grades 9 and 10, p.4, 1999.)

Consistent Curriculum Expectations and Inquiry Skills Across Grades

Inquiry, design and communication skills comprise two thirds of all the expectations in every science curriculum document. These skills, which are prevalent throughout the science curriculum expectations, can be summarized in five fundamental skills. These are:

i) Formulate scientific questions,
ii) Demonstrate the skills to plan and conduct an inquiry,
iii) Select and integrate information from various sources,
iv) Analyze qualitative and quantitative data, and where appropriate, apply statistical analysis
v) Communicate scientific ideas, procedures, results, and conclusions and make appropriate applications, based on their findings.

These recurring expectations represent essential skills that students must demonstrate to show that they have achieved the Curriculum. They are also essential skills that are needed if students are to successfully complete an independent project. Projects, then, are an effective and authentic way to assess inquiry and design skills.

The senior science curriculum documents go even further than the grade nine and ten document to identify the skills necessary for a real science investigation.

"In all courses, a list of expectations is given that precedes the strands. These expectations describe skills that are considered to be essential for scientific investigation (e.g. Skills in research, in the use of materials and in the use of units of measurement), and skills required for investigating possible careers in the subject area." (Ontario Curriculum, Grades 11and 12, p.9, 2000.)

The following are examples of a Gr. 9 (Intermediate) and a Gr. 11 (Senior) project that meet the three goals of the secondary science curriculum, the overall expectations for a particular strand, and many specific expectations.

An Example of Grade 9/Intermediate Science Project:
Tiffany applied the basic chemistry concepts ("Chemistry: Atoms and Elements" strand) from the Grade 9 Academic Science and applied its effects on the environment.

Tiffany Ngai
(Grade 9 Science Student)
Title: Environmental Impacts of Road Salt and Alternative
The objective of my project was to find an alternative de-icer that would be as effective in ice melting as well as less harmful to the environment compared to the industrially used material, road salt. I tested a variety of chemicals on ice surfaces and studied their effects on plant growth.
(Examples of student abstracts in this document are taken from 50-word submissions from the Canada Wide Science Fair 2002)

Tiffany's project used inquiry and design skills from the curriculum to complete an independent project that covers conceptual material from the grade 9 chemistry strand. Expectations covered included:

i) The overall expectations: "…of understanding chemical concepts and environmental hazards".

ii) The specific expectations:
   a) *Understanding Basic concepts*:"…describe using evidence of chemical change"
   b) *Developing skills of inquiry and communication*: "… formulate scientific questions about a problem or issue involving the properties of substance."
   c) *Relating to STSE*: "…local environmental concerns and health and safety issues."
   (Ontario Curriculum, Grades 9 and 10, p.18-19, 1999)

An Example of Grade 11/Senior Science Project:
Nazlee and Casey applied the basic Biology concepts from the "Diversity of Living Things" strand. Using the inquiry and design skills for their investigation, they applied their knowledge of bacterial growth and cultivating bacteria. They established the anti-bacterial properties of tea from their independent investigation.

Nazlee Zebardast, Casey Wang
(Grade 11 Biology students)
Title: The Antibacterial Effects of Teas S.mutans
The effect of different teas on the growth patterns of Streptococcus mutans, the main species of bacteria found in dental plaques, was studied. S. mutans were grown in THYE broth with various teas and the bacterial numbers were compared to controls. It was found that teas have anti-bacterial properties.

The following curriculum expectations were covered by their investigation:

i) The overall expectations included: "… Understanding diversity of living organisms, the use of techniques to classify and explain the use of micro-organisms in biotechnology."

ii) The specific expectations:
   a) Understanding Basic concepts: "…Define, compare and contrast the functions of prokaryotic cells"
   b) Developing skills of inquiry and communication: "apply classification techniques, according to their nutritional pattern, types of reproduction."
   c) Relating to STSE: "…their relevance in the field of biotechnology …. resistance to infection...."
   (Ontario Curriculum, Grades 11 and 12, p.19 & 20, 2000.)

Authentic Learning and Assessment

Open-ended student investigations are effective assessment and evaluation tools. Students faced with real problems often solve them using new strategies and techniques. These projects allow teachers to use authentic student-centered assessment strategies such as conferencing, presentations and visual displays. There are many rubrics available to teachers that can assist with the evaluation of project work (see Appendix 4).

Working with 30% - 70% split

In Ontario Secondary Schools, 70% of the student's final mark must be based on assessments and evaluations performed throughout the course. Science projects satisfy the conditions for a rich performance task, which can be used as a unit summative assessment, as they allow the student to demonstrate achievement across all four categories.

In some situations, teachers may encourage their students to incorporate a project as an extension of the unit. Allowing students to pursue the strand further and develop their ideas into project work may open doors to career opportunities.

Thirty percent (30%) of the student's final mark must be based on a final evaluation in the form of an examination, an essay or a performance based activity that may be suitable for the course. As a culminating activity, project-based work can be regarded as a relevant and authentic assessment of scientific knowledge and skills.

For example, in the *Light and Geometric Optics* strand of the Grade 11 Physics course, a suitable culminating activity is a technology challenge. Students could be motivated to solve a specific problem related to Science, Technology, Society and Environment as mentioned in the *Ontario Curriculum*:

"- evaluate, using given criteria, the effectiveness of a technological device or procedure related to human perception of light (e.g. eyeglasses, contact lenses, virtual reality "glasses", infra-red or low light vision sensors, laser surgery);

- analyse, describe, and explain optical effects that are produced by technological devices (e.g. periscopes, binoculars, optical fibres, retro-reflectors, cameras, telescopes, microscopes, overhead projectors)." (Ontario Curriculum, Grades 11 and 12, p.98, 2000.)

Whether a project is developed from the Ministry guideline suggestions or an alternative source, it entices students to be creative and innovative about the solutions. Developing an inquiry project as a culminating activity requires students to conduct open-ended investigations. Young learners are motivated to use scientific knowledge and laboratory skills to solve problems. Quizzes, tests and assignments are valuable techniques to establish knowledge-based learning while cumulating activities go beyond the understanding of scientific concepts. Culminating activities assess all four categories of the achievement chart, assessing skills and applications that can be difficult to assess using paper and pencil methods alone.

Maintaining Scientific Curiosity and Enduring Scientific Literacy

Young learners are naturally curious. Maintaining curiosity through project-based learning heightens their awareness of their environment. Student's eagerness to pursue inquiry-based learning is encouraged through open-ended investigations. They investigate topics that matter to them and which engages them in realistic science. It empowers students to understand science and its mechanisms.

Occasionally, projects can allow students to make a fairly significant contribution to ongoing research. Especially if their project involves the local scientists and technologists in the field, student research may become an asset to the professionals. The collaboration with field researchers and scientists is a valuable relationship for students. They develop essential skills in management, leadership qualities and scientific literacy. An open-ended investigation brings rewards and engages students in experiences that are unique to science education. By encouraging student's own questions through investigative work, eager learners become actively engaged in realistic scientific understanding and inquiry.

Although many science students may not pursue careers related to science and technology, the many skills learned through investigations are advantageous to other careers. Through hands-on science, they learn science concepts that develop lifelong scientific literacy. Students learn to understand the process of science as it relates to controversial issues such as stem cell research, cloning, use of space stations and environmental issues. Hypothesizing, interpreting data, supporting and defending issues and opinion are important critical thinking skills. These investigative skills are crucial components of the scientific process. Project work allows critical skills to be learned and transferred to other aspects of education and life. It also nurtures self-confidence and excitement, which is paramount to learning.

"Facts are the world's data. Theories are structures of ideas that explain and interpret facts."

Stephen Jay Gould "Evolution as Fact and Theory", in Hen's Teeth and Horse's Toes, W.W. Norton, 1984.

Constructivist Learning and Theory Formation

When students learn, they construct ideas of the world around them. These ideas are often quite persistent, but can be reconstructed as new perspectives or ideas are introduced. If the word "OIL" is mentioned in class, different perspectives are revealed. Some students think of cooking oil, while others (being teenagers!) think of sebaceous gland oils secreted by the skin. Yet others, who may be "into" cars, will think of petroleum, engine oil and lubricants. What each visualizes depends on their present experience, and past memory, of an event.

Learning is an active process. Students modify old ideas and reconstruct old concepts to develop new understandings. Grade 11 Chemistry students learning about atmospheric pressure are told that a strong atmospheric pressure is exerted on our body at sea level. But if they look around them, they don't see objects being crushed nor do they feel the pressure on their bodies! The "simple" idea of atmospheric or air pressure is not so obvious to the students, who have always been exposed to atmospheric pressure and so are not even aware of it. It is crucial for learners to investigate the concept of pressure both at sea level (i.e. low altitudes) and mountaintops (i.e. high altitudes) in order to understand the topic. In constructivist learning, students are exposed to situations involving pressure changes, as demonstrated by heating and later cooling a plastic bottle. Through investigative science projects, students construct and reconstruct meaningful understanding of events in the world around them.

Children are great storytellers. They develop theories, scientific or not, as they see events unfold around them. At an early age, children rely on their experiences to develop many of their new theories. Touching, feeling and seeing are vital ways of attaining new information to modify past beliefs and concepts. Conducting an investigation involves the use of observation, prediction and hypothesis, collecting test data, and making conclusions. The use of these inquiry skills is essential for constructing knowledge, developing theories and forming lasting and enduring understanding.

Coverage of every Ontario Curriculum expectation in equal detail (or working through a textbook from cover to cover) to "teach" the curriculum is problematic because students often are unable to distinguish the key ideas, or do not develop a deep understanding of them. A grade 10 student may memorize and recite the factors that affect fundamental processes of weather systems, but will usually resort to his or her own understanding of weather to explain and understand everyday events. Children are active theory makers from the time they are very young, and come to grade 9 and 10 with many well-formed (though often unscientific) conceptions of how the world works. These understandings are rarely acknowledged or explored in most classrooms, but research has shown that these "alternative conceptions" serve the student well and are remarkably resistant to instruction. Inquiry and design activities and projects encourage the student to put his/her conceptions to the scientific test, setting the stage for him/her to construct a new and more scientific understanding.

"Mathematics is the chief language of science. The symbolic language of mathematics has turned out to be extremely valuable for expressing scientific ideas unambiguously."

American Association for the Advancement of Science. Science for all Americans.

Theory Building and Importance of Dialogue

Talking in science classes is an important, dynamic and social component to theory building. Providing students an opportunity to explore their alternative concepts, and those of others, enables them to develop new theories. Alternative concepts may also be provided by teacher's Socratic lessons and textbooks. But encouraging students to discuss their discoveries brings about real meaning to learning. A classroom atmosphere that challenges students to critically think about and discuss their findings increases understanding of concepts. Students need teachers and fellow students to assist in developing newly constructed meaning through individual or groups discussions. Classroom discussions certainly highlight issues and help students to reconstruct their previous beliefs.

Cooperative learning strategies, small group work, and paired group work are effective methods to learning and developing science concepts. Teachers facilitating discussions and prodding groups to view alternative suggestions can lead to lively discussions and debates. Class debates simulate the process of theory formation and acceptance that exist in democratic scientific communities.

Such an environment for project work can provide the opportunity needed for learning new concepts and theory building. It allows the use of scientific inquiry skills to test new key concepts, generated by initial questions or problems. Many of these problems surrounding the key concepts are student generated and tested, which can generate new and sometimes fascinating ideas. Collaborating with their teachers through out the process of developing a project, the student's weaknesses and strengths can be identified via their science work. Erroneous concepts and skills can be checked through conferencing with teacher and student.

Literacy Integration in Secondary School

"Students need literacy skills to enable them to receive and comprehend ideas and information, to inquire further into areas of interest and study, to express themselves clearly

and to demonstrate their learning. Literacy skills are important for higher education and for eventual entry into the workplace. Students who are preparing for post secondary education must develop these skills in order to succeed in the challenging academic work of college and university programs. Students who are preparing for careers in business and industry also need these skills in order to adapt to a workplace that is constantly changing." (The Ontario Curriculum, Guides 9 to 10: English, p 2, 1999)

In a successful science project, students incorporate their writing skills to present the observational data, to interpret and analyze the findings, and formulate a discussion to compare their hypothesis with their findings.

Science project work provides a great opportunity for the integration and assessment of multiple curriculum strands across different disciplines. Successful integration brings teachers together to collaborate and assist in student academic development. Project work can provide holistic and uninterrupted learning when specialized teachers collaborate in subjects like science, mathematics, humanities, language, visual arts and technology. This way of learning through several subjects brings added meaning to secondary school education.

"The important thing is not to stop questioning."
Albert Einstein

For example, students may utilize the principles of visual arts to put the project display board together. Presentation of projects requires language skills and visual skills. Technologically equipped learners may gain expertise in Powerpoint presentations and the use of other computer animation programs in their presentation. In innovation projects, robotics and computer programming trigger much excited learning. In both experimental and correlational studies, enrichment opportunities invite students to use statistical analysis to validate their findings.

Today the demands on high school graduates to prepare for tertiary institutions and workplace success are many. The development of scientific literacy skills are important and prepare students to succeed in challenging careers, not only in science and technology, but in constantly changing business and industry settings as well. Science projects assist students in meeting these demands.

Extra-Curricular Clubs and Associations

Despite increased curriculum content and demands, many students are enthusiastic about conducting science and technology projects outside their course time. Being part of a biotechnology, science or technology club motivates students to develop in their chosen fields. The voluntary nature of this sort of project/research is highly motivating for students, and allows freedom in choosing topics to investigative in many curriculum domains. Teachers in science, math, technology and other areas may collaborate as teacher advisors or mentors. As project mentors, they provide guidance through conference sessions with students. Local educational and research associations could also be liaised to utilize laboratory facilities that schools lack. The result is enhanced scientific literacy by making real and relevant science connections to technology, society and the environment.

Section Two: Teaching Strategies That Incorporate Doing Real Science Projects

Developing Student Directed Authentic Science

The scientific inquiry process is more than training students to understand a body of knowledge associated with a particular topic. It is a framework that employs logical methods for finding *student answers to student questions*. Project-based science is an ideal method for giving students greater control over their learning. In completing authentic investigations of personal significance, projects allow students to develop their own topics and foster more genuine and persistent learning.

Science inquiry activities can be informal opportunities for students to practice a variety of design and inquiry skills. These include questioning, predicting, hypothesizing, designing the method, analyzing and communicating the results. Frequently, students also conduct investigations through formal labs that provide them with the opportunity to develop science inquiry skills. This may encompass an individual or a group activity using various equipment and materials in investigations from different strands or units.

Encouraging the development of the scientific habits encourages students to use inquiry skills and critical thinking both inside and outside the science classroom. However, students often have misconceptions about scientific topics and concepts, as well as the processes and nature of science. Research has shown that these misconceptions are robust and resilient to change. Before pursuing the teaching of inquiry skills needed for doing open-ended science investigations, a few commonly held misconceptions must be addressed.

"Learning often requires more than just making multiple connections of new ideas to old ones; it sometimes requires that people restructure their thinking radically. That is, to incorporate some new idea, learners must change the connections among the things they already know, or even discard some long-held beliefs about the world."

American Association for the Advancement of Science. Science for all Americans.

Misconceptions about Science Teaching and Project Work

- **Misconception 1: "Cookbook-type laboratory exercises are considered to be true experiments."** Laboratory activities with 'cookbook type recipes' come with pre-established solutions and are, therefore, not true, open-ended experiments. An authentic experiment arises with an unknown problem or situation where the answer is not pre-determined, and where teachers can act as facilitators to help students develop a method to answer the question or solve the problem.

  Some activities will teach the use of laboratory techniques for various procedures that requires the set-up and use of specialized apparatus. This type of activity is an important component of a science program, but sometimes lab activities tend to focus too much on procedures and technical know-how. Using the procedures and techniques to solve real questions is when authentic, engaging science takes place. For example, grade ten students may learn the procedure for detecting the presence of carbon dioxide gas using Bromothymol Blue or calcium hydroxide solution. This may be an important skill, but there is no discovery involved, only a pre-determined answer to the test. But when students apply these skills to identify gas liberated from a water plant (e.g. Elodea) undergoing a certain environmental stress, they are using critical science thinking skills along with the laboratory techniques learned in class.

> **"Technology extends our abilities to change the world: to cut, shape, or put together materials; to move things from one place to another; to reach farther with our hands, voices, and senses. We use technology to try to change the world to suit us better."**
>
> American Association for the Advancement of Science. Science for all Americans.

Unraveling the Misconception: Encouraging student project work promotes authentic problem solving as students design and develop their own experiments. Science students genuinely search for answers by carrying out their own creative projects. Understanding the process of how to conduct an open-ended investigation to solve the problems is an important feature of project work. Students must be taught the scientific design and inquiry skills and be given opportunities to use them to do self-designed, relevant experiments.

- **Misconception 2: "Experiment: The only way of doing science."** Both teachers and students are often taught, from the earliest age, that science is conducted by doing experiments. However, experiments are not the only method of doing science. There are other methodologies of doing investigative science projects that should be taught in the intermediate and senior science program. Correlational studies and technological innovations (or technological problem solving) can be taught and encouraged with project work. Each method varies from experimental work because each requires different criteria for selecting the appropriate investigative design.

Unraveling the Misconception: Correlational Studies involve observations of variables as they change naturally, while an experiment involves artificially forced changes in a particular variable. Correlational studies are conducted to monitor and compare changes in possible causes and results, just like in an experiment. This incorporates questioning, predicting the results, hypothesizing the event, designing the procedure with the focus on investigative design, analyzing the results and communicating them.

For example, scientists could compare incidence of anthrax symptoms with natural levels of anthrax bacteria. It would be more *ethical* to do a correlational study in this instance, rather than purposefully injecting people with possible pathogenic bacteria. In short, correlational studies can often provide a viable alternative to experimenting on living organisms.

Technology problem solving methods attempt to change objects and events. Technology strives to modify variables or features of a product in order to meet certain needs. It may also involve development of a new method. Problems such as "*How can we stop dandelions from growing on lawns?*" exemplify one of many types of situations that can be addressed by technological innovations. Students learn the skills of technological problem solving by designing, planning, constructing, evaluating, revising, and communicating about the product.

- **Misconception 3: "Linear development of investigative ideas"** Scenario: After an experiment in a typical classroom, students reflect with dismay: "*Our experiments did not work. It gave us the opposite results and our* *hypothesis was disproved. Do we fail our science project? If not, can our hypothesis change as we progress in the investigation?*"

Unraveling the Misconception: Good theories develop from good hypotheses that explain and predict novel situations. In the world of discovery, investigative procedures are often rechecked, rewritten and modified. Unfortunately, in most classroom investigations, science students are not encouraged to make modifications after a set procedure is established. This often leads to an **obsolete and linear development of ideas** (van Oostveen et al, 2000).

In an effective classroom, the interpretation of scientific data is frequently challenged, mirroring what occurs in real scientific communities. In the history of science, many hypotheses and theories have been vigorously discussed and debated. Answers in the scientific circles are constantly modified. With new hypotheses come new investigative designs that conjure newer insights. In the science class, invigorating controversies spark questions that require re-evaluation of the procedural design. Discussions within small investigative groups also enhance critical thinking, which leads to a better understanding of doing science.

- **Misconception 4: "Scientific investigations are better than technological studies."** The perception among many students is that experimental projects are somehow "better" or superior to technological projects. This erroneous perception is embedded in how we approach these investigations. There is a natural bias towards teaching the 'nature of science and technology' in our school curriculum. Science is viewed as an intellectual pursuit of knowledge that describes basic structure and function of the natural, physical world and the universe. Technology is seen as a more "hands-on" discipline that uses knowledge and skills of science and other disciplines to solve problems. As a result, using technological skills to improve a product or process appears to be less elite and intellectual than scientific investigations.

  Unraveling the Misconception: As in any scientific investigation, technological studies or innovations approach problem solving by addressing the *independent* variable's effect on the *dependent* variable(s). Technological investigations incorporate not only 'how it works' but also 'how to make it work better'. In examining the strategies employed in science, technological studies will utilize a number of dependent variables, manipulated so the invention solves the problems in the best possible way, (van Oostveen et al, 2000).

Student Theory Development for Real Science Projects

As students develop ideas for their investigation, their active minds begin to formulate ideas and theories that explain observed events. Project work can extend and enhance students' understanding of the conceptual or theoretical aspects of their research.

Frequently in science "labs", students are excited about carrying out laboratory procedures, without understanding the reasons for the steps. Independent and critical thinking occurs if they are allowed to design and perform the task on their own, with proper supervision.

Bencze (2000) has encouraged the implementation of authentic project work, where students develop the inquiry question and an experimental design for testing it. In authentic project work, it is vital to focus on both procedural and conceptual knowledge. Whereas the traditional approach has been to "teach" the concepts and theories through rote memorization of textbook passages or teacher lectures, this approach allows students to construct and test their own theories.

In classes where students are allowed to talk about their own scientific investigations (inquiries) and technological inventions (designs), students feel confident and empowered to conduct further research. Talk and debate can insure cognitive engagement as learners discuss the theories behind their work.

"There are no mistakes, no coincidences. All events are blessings given to us to learn from."

Elizabeth Kubler-Ross

With open class discussions, teachers provide opportunities for students to share their findings and support or defend their ideas. Allowing class discussions and debates replicates what is done in real scientific communities. Encouraging these debates and discussions amongst their fellow classmates, as well as with their teachers, corrects misconceptions and introduces new ideas. In this way, teachers and students can collaborate and, through the active process of theory building, negotiate ideas for their investigative research.

Exploring Ideas, Topics & Research Techniques

Empowering students to do project work of their own choice brings a lot of excitement into a science program. Student confidence is increased, knowing that their teacher trusts in the ability of the student to successfully complete a project. 'Real Science' deals with students' reconstructing their conceptual ideas of the world around them. Learners need the opportunity to devise their own investigations from their personal experiences. Past experiences, both inside and outside the classroom, motivate and direct the development of suitable topics, as well as procedures or methods for investigating them. The following sections look at idea development, research techniques, and project organization - key considerations for developing and completing a successful project.

Real Life Events to Real Science Projects: How Ideas are Formed and Tested

Pesticides used in the environment sometimes triggers allergic reactions in some individuals. Crystal, a Grade 10 student from Toronto, observed her sister's breathing difficulty with chemical pesticides. Curiosity drove her to look for alternatives to chemical pesticides by using a safe biological product:

"Are there biological mechanisms that could replace the use of chemical pesticides?"

Crystal prepared her project by reading newspaper clippings, abstracts of company chemical data sheets, and finally discovering scientific journals from the library and

Internet sites. With guidance from her science teachers, she established a preliminary method in culturing the respective bacteria. This led to extending her project to incorporate the safe use of soil bacteria to manage insects in the environment. With her innovative project, she competed at her school fair and moved to the regional science fair to win the first prize award and a trip to the Canada Wide Science Fair. At the National Fair, she won the Gold medal and a special Agriculture Award for its possible application in farming.

Crystal's science project exhibits many of the typical characteristics of a successful, innovative project:

i) Choosing an interesting, appropriate topic leading to relevant inquiry,
ii) Researching related curriculum topics in biology and chemistry,
iii) Developing an experimental method suited to her investigative inquiry,
iv) Applying the results to solve a genuine problem, in this case with chemical pesticides.

"There are many examples of old, incorrect theories that stubbornly persisted, sustained only by the prestige of foolish but well-connected scientists. ... Many of these theories have been killed off only when some decisive experiment exposed their incorrectness"

Michio Kaku, Hyperspace, Oxford University Press, 1995, p 263.

The following constitutes the steps taken to incorporate the teaching of "Real Science" in science classrooms. The most important and difficult task is to assist in developing student's own ideas and interests. Providing the students a timeline of 10 weeks or more to complete the investigation is ideal.

The Importance of Researching Before Doing the Projects

Professional science and technology researchers do not always start conducting experiments and investigations as soon as they have an idea. Before they commence testing their hypothesis about a topic, they attempt to find out what others have already done. Not surprisingly, the process followed by students doing independent research is often similar: science students ask causal questions, develop hypotheses and think of investigative designs. However, an often overlooked step is the secondary research of background information, gathered prior to doing the primary investigations.

The student investigators need to use the library, media resources, periodicals, popular magazines (e.g. Popular Mechanics) and the internet as research tools. This exposure to alternative views of the topic, dissenting opinions, and previous research can help to focus their investigation, and can be a rich source of ideas for investigation topics. All sources of information that contribute to the student's project must be acknowledged and cited appropriately. There is a Citing Resources Guide provided in Appendix one.

Seven Questions That Lead To A Good Science Fair Topic

To help determine if a topic is appropriate, students should be able to answer the following questions. If they can answer YES to these questions, they have a reasonably 'do-able' topic to investigate. Teachers can give these questions to students, or use them as a checklist when helping students develop and discuss possible topics.

1) Would I enjoy learning about my topic?
2) Did I develop this original idea?
3) Is this idea realistic to investigate (Do I have the resources/equipment needed)?

4) Are the activities within my ability to perform (i.e. feasible)?
5) Can I explore my topic by experimenting, or via other investigative methods?
6) Will I be able to collect results or data for this investigation?
7) Is it within my budget to conduct this investigation?

Teaching Strategies for Helping Students Find Ideas

One of the hardest tasks for a student is to choose an interesting and engaging topic. There are several things a teacher can do to help students develop project topics:

a) Look for Ideas and Extension within the Curriculum

Teachers and course instructors can encourage students to look for topics that are an extension of the science curriculum strands being taught. Topics may also be chosen that overlap with other disciplines. While this process can be an individual activity, students are encouraged to interact by discussing their ideas with teachers or other students in the class.

With the constructivist model of teaching science, teachers can expose students to a wide range of activities that allow students to build knowledge and theories about a topic. By doing so, teachers become aware of student's perceptions and sometimes their misconceptions about various concepts. These misconceptions tend to be enduring, and can be a rich source of project topics.

Using a variety of activities, such as research articles, discussions, lab activities, videos and demonstrations, introduces many topics and ideas to students. Throughout a unit of study, the new knowledge and skills that students develop should lead to further questions. At the end of the unit, relevant or important questions can be used as a starting point for further research. The goal is to research information about possible topics, and to decide if it is suitable as a project idea.

For example, in the grade 10 biology strand, the concept of bioaccumulation is one of the specific expectations in the Ministry guideline, (Ontario Curriculum, Grades 9 and 10, 1999.) **Fickle Nickel** is a correlational study that involved the concept of bioaccumulation, as well as other concepts from both the biology and chemistry strands of the Grade 10 science curriculum. In this case, the students' hometown ecology was the driving force behind their choice of topic:

Kathleen Lee, Jenn Provost
Sudbury
Title: Fickle Nickel
Fickle Nickel investigates nickel bio-concentration levels of earthworms taken from environments which model the ranges of nickel concentrations found in areas where nickel rich ore is mined and processed, such as Sudbury. Our purpose was to investigate the correlation between the nickel concentrations in the soil and in the worms and then relate our findings to actual environments.

b) Start a Science Journal
As a meta-cognitive tool, have students start a science journal. It provides a way of checking on how and what they have learned about their topic (i.e. their cognitive development). Misconceptions about relevant topics may be revealed through the journal, and can be a rich source of topics for debate or discussion. Keeping a journal gives students a way to keep track of their research information, organize their thoughts and can be a place to record on-going, scheduled observations during their experiments.

When a journal is used in the initial stages of project planning, sifting through the journal and filtering the information and ideas can help students find a topic. Allowance should be made if students need more time to explore possibilities that go beyond what is typically expected in high school research. In senior sciences, biotechnology research may require individuals to venture into microbial studies dealing with bacteria and cell cultures. In the physical sciences and engineering, topics may deal with innovative ideas, such as "Boundary Layer Acceleration", a project from two Toronto students that won the Canada Wide Science Fair's "Best in Fair" award in 2002:

Faizal Ismail & Mahvish Jafri
Toronto
Title: Boundary Layer Acceleration
Creating the first active parasitic drag reduction method by reversing the formation of aerodynamic boundary layers was our goal. We analytically observed the effect of accelerating the surface fluid and then engineered an electrical plasma accelerator to verify theoretical results. In wind tunnel experiments we observed drag reductions of 31%.

c) Start a Class Bulletin Board
A bulletin board in class with the latest ideas, topics, discoveries and images from the pure and applied sciences can be a rich source of project ideas. Students can be encouraged to bring in ideas, photos, or articles that interest or inspire them. In doing so, students not only help find topics for themselves, but may provide resources and ideas for their classmates.

d) Encourage background reading of books, magazines and reliable internet sites
Classroom teachers frequently find insufficient time to present various topics of interest in their specific subject areas. As a supplement, students can independently read from a wide variety of different sources. Some of these readings will not be limited to one science strand or unit, but may overlap between various units, depending on the topic. The teacher may wish to give students a list of optional readings on top of regular classroom work. In addition, some school textbooks also show web links to articles for further study of a certain historical or technology link.

Eugene Savchenko
Ottawa
Title: 3D Scanner
The 3D Scanner is an automated system for remote, non-contact recreation of 3-dimensional computer models of real objects. I designed original software that allows processing 2-dimensional images from a web-camera into an accurate 3-dimensional computer model and viewing it from different angles. Technology applications are in medicine, anthropology, security systems and biometrics.

e) Encourage Students to Investigate Topics of Personal Interest
Projects may arise because of curiosity about a certain personal issue or interest. Independent research about a topic of personal interest has the added bonus of being intrinsically rewarding and motivating to students. A science program that promotes questioning, curiosity, and critical thinking will encourage students to see science questions or technological problems in every aspect of their daily lives.

Nichele Lomas
Simcoe County
Title: Highs and Lows
Being diabetic myself I know how difficult it is to acquire necessary diabetic information. I created "Highs and Lows", a computer program using Excel and Visual Basic, to teach newly diagnosed diabetics. It also can be used as a reference for anyone that would like to learn more about diabetes.

"The technologies which have had the most profound effects on human life are usually simple."

Freeman Dyson, Infinite in All Directions, Harper and Row, New York, 1988, p 135.

Establishing Relationships in Causal Questions

Asking Questions

Given a chance, students love asking questions about their surroundings. For example, curious students may develop simple questions as their parents grab a bottle of antibacterial detergent from the grocery store shelf. Applying knowledge from the grade 11 biology strand (Diversity of Living Things) may be necessary to develop a good investigative question:

"*Does that antibacterial detergent truly kill all bacteria?*"

Conversely grade 11 chemistry students may wonder if that solution has properties that may be useful for solving problems other than the one it was designed for:

"*Can antibacterial detergent remove grease from gasoline stains?*"

The true value of a question lies in how effective it is in attaining the answer. Often, the question will help students understand what they need to do in their project, as well as understanding what they should not do. The answer may not always be scientifically impressive or important, but the process of asking questions, developing a procedure, and developing an answer, is important.

Finding Relationships between Variables

Mechanics, physicians, scientists, technologists and students often attempt to establish relationships between two of more events. The 'cause - effect relationship' is a foundation of scientific investigations, and enables the investigator to test for a causal relationship between two variables. Combining variables to develop a possible relationship may sound easy, but investigators need to have a rational reason for believing the variables are linked, and must prove it with as much certainty as possible.

For example, a student is interested in investigating the effect of electromagnetic radiation on humans who live near transmission wires. For obvious ethical reasons, proving a direct cause – effect relationship in this case would be virtually impossible. Instead of using human subjects a student familiar with concepts and skills from Grade 11 Biology and Physics might decide to use microorganisms. E. coli, a type of bacteria, could be studied and changes in the bacteria's reproduction as a result of electromagnetic radiation could be monitored. In this case, the relationship between the variables is clear, rational and applicable to human conditions.

Developing Causal Questions

Traditionally, the "independent" variable is manipulated or changed to observe the effect on the "dependent" variable. However, students often have difficulty in understanding and using these traditional terms. It is easier for students to make the connections with the terms cause and result variables.

Traditional Relationships:

Independent Variable -Dependent variable
(Manipulated Factor) (Observed Factor)

Student Valued Relationships:

Cause Variable -Result Variable

A causal question clearly defines a Cause variable that interacts with a result variable. Guiding students to develop a causal question can be accomplished using the following format:

What are the effects of (Cause Variable) on the (Result Variable)?

Examples of Causal Question:

What are the effects of different types of impurities/minerals in the photographic solutions have on the brightness of the colours of the film developed?

What are the effects of different solutions on the needle-loss rate of Christmas trees?

Framing questions in this format allows students to visualize the variables and the proposed relationship between them. The format provides a good guide for students to develop authentic questions for their investigative projects.

Sample Causal Relationships:

Cause Variable	Result Variable
- Type of impurities	- Quality of crystal growth
- Soil temperature	- Growth of moulds
- Amount of minerals	- Weight of bean sprouts
- Soil vibration	- Speed of sprout growth
- Magnetic intensity	- Film development

The Rationale for Associating Two Variables: Correlation is not Causation

A difficult concept for students to understand is the relationship between the variables. Just because the independent, or cause variable, is shown to be *related* to the dependent, or result variable (***correlation***), does not mean that *the cause variable* brought about the change in the *result variable* (***causation***). Students must keep in mind that other factors, sometimes unknown to the experimenter and uncontrolled, can influence the variable in question.

An Example Of A Study Where Correlation and Causation Can Be Confused:

Mia and Tony conducted a study that showed the number of pedestrians injured by automobiles in North Bay increased as the daily temperature increased. Tony concluded, from these results, that higher temperatures caused an increase in pedestrian accidents. Mia, however, felt that other variables could be involved. She felt there was a correlation between the two variables, but not necessarily a causal relationship. Specifically, she wondered if higher daily temperatures resulted in MORE pedestrians being on the street, thus resulting in an increased number of accidents.

One way for students to deal with the uncertainty surrounding correlation and causation is to use mathematical (statistical) analysis to help establish if there is a high or low probability of finding an association between the variables. The Chi-Square Test is the most widely used non-parametric test. This is frequently used to test statistical independence of the variables. Senior science students who have used the Chi-Square or 'T' test can validate their work and show increased confidence in the results. For more information on the chi-square test and other statistical methods, refer to any standard, introductory textbook on statistics. There are also many websites that review basic statistical concepts and have chi-square calculators. For an example, go to http://www.physics.csbsju.edu/stats/chi-square.html.

Successful Investigative Strategies

As mentioned earlier, sometimes the most difficult task for students is coming up with an interesting topic for their project. A second problem that faces students, once a question or area of interest has been obtained, is to determine the appropriate investigative strategy needed to complete their project.

Whether it is an intentional manipulation of the variables (experiment), observation of a variable that already exists in the environment (correlational study) or designing a new and improved procedure or product (innovation), selecting the appropriate investigative style is an important step.

Choosing the Appropriate Investigative Style

i) Investigative Design Type 1: True Experiments

The method that is most often associated with scientific investigation is an experiment.

The identification of variables and their associations with each other is vital to any investigation. Traditionally, the independent (causal) factor is manipulated or changed to observe the effect on the dependent (result) factor.

Julia Lane
Summerland, British Columbia
Title: Trapping Plant Toxins
Previous experiments found that Walnut and Alfalfa are toxic to Planaria. An experiment by a local Trout Hatchery showed they were toxic to fish. This experiment tested the effect of soil on inhibiting toxicity. Compost soil was most effective in inhibiting Walnut toxicity. Silt soil was effective in inhibiting Alfalfa toxicity.
This project won a gold medal in the senior division at the 2002 Canada Wide Science Fair.

This form of investigation is well known and widely used in many of the sciences and other related fields. In general, it is the type of investigation that is most widely taught in high schools. However, correlational studies and technological innovations are important scientific methods widely employed by many investigators.

ii) Investigative Design Type 2: Correlational study

This type of investigation is sometimes mentioned in non-science classes, but seldom gets acknowledged as being important or producing good reliable results. However, much of the current medical and consumer research utilizes this strategy to gain valuable results and answers.

Richard Miron, Alex Omiccioli
North Bay
Title: CAST-Chironomid Algonquin Sampling Technology
Current methods used to measure lake water quality are inaccurate and virtually useless to measure trends. This project uses the retrieval and speciation of chironomids to determine and track water quality. This is an innovative approach to measuring water quality in Ontario. Thanks to our work, North Bay may move its water intake.
This project won a Senior Earth & Environmental Sciences Gold Medal, CWSF 2002

In a correlational study, the independent (cause) variable is NOT manipulated to measure the effect on the dependent variable. Instead, the variables are allowed to change naturally and are not changed intentionally. These factors are simply recorded and the relationships between the variables are studied.

iii) Investigative Design Type 3: Innovations
For students, relevancy breeds innovation if the result improves their lives. Students love inventing, especially if it brings a 'WOW" effect to their peers. Designing a new product or modifying and creating a new method are considered to be innovation strategies.

Ben Schmidt
Waterloo-Wellington
Title: Robotic Surveying System
The purpose of my project was to design, build and program a system capable of generating a contour map of a terrain using small inexpensive probes rather than a single large mobile robot. This has application in exploration of remote places, such as other planets or the ocean floor.

The sample projects cited above show some of the investigative methods that students have pursued to test their hypotheses. Award winning projects are carefully designed, and consider the different criteria required to successfully conduct the investigation.

Designing an Investigative Procedure: The Project Proposal

Having carefully selected their topic and investigative approach, students should present a proposal to their teachers. The proposal enables students to clearly build, in their minds and on paper, the crucial components of a good investigation. It also provides an opportunity for teachers to discuss key misconceptions or any erroneous approaches to solving the problem. Regardless of the method chosen for their project work, it is important for the student to understand the key design features for any investigation.

Checklist for Designing an Investigation

1) **Cause variable (Independent Variable)**
   - Students must have a clearly defined cause or Independent variable.
   - To obtain a simple qualitative measurement use different senses.
   - Accurate volumes or mass of substances need to be recorded, not estimated.
   - Observations, including colour changes and other qualitative measures, are documented. Observations should be written in a lab manual or record book.
   - Students should be encouraged to make provision for a wide range of values of the independent/cause variable. For example, when testing fertilizer amounts with different plants, use 2, 4, 6, 8, 10 ml of fertilizer

2) **Have Duplicate Quantities of the Cause Variable**
   - Students should be reminded that a larger sample tends to create more accurate results. A small sample size is insufficient to make any reliable inference about the results.

• Duplicate quantities of the cause variable (e.g., three plants with 2 mL of fertilizer, three plants with 4 mL of fertilizer, three plants with 6 mL of fertilizer) helps to increase the sample size and the reliability of results.

3) **Result variables (dependent Variable)**
- List all the result or dependent Variables.
- Record all quantitative and qualitative data.

4) **Unsuspected variables**
- The focus is often to record expected variables. The key is to observe and record all changes in the investigation, not just those that were outlined/identified in the project proposal.
- The suggestion is for students to monitor not just the suspected variables but also the unsuspected events. Advising students to observe and record more than one kind of variable is suggested. The intention is to have students develop their skills of observation.

"All modern subject areas are grounded in non-obvious ideas: The Earth does not appear to move; there are no obvious signs of our being descended from primates..."

Wiggins, G., and McTighe, p. 112-113

5) **Repeat the measurements**
- To allow students to visualize researchers in the real world, they have to realize the need to repeat their measurements when looking at the result variable (e.g. measure plant height 3 times). Frequently, students realize the need for several observations. The total measurements are later averaged to obtain a more accurate reading of their data.

6) **Use of Tools in Science**
- Depending on their projects, senior students are recommended to use photo-spectrometers, voltage meters, ammeters, photographs or video to assist in recording all observational events.
- If photographs of individuals are taken, student researchers must obtain special permissions from the teachers and also of the subjects.
- In a correlational study, data is obtained by measuring directly with a tool or via a survey. Oral questions, phone calls, mail, and paper survey are just a few ways of obtaining data that is not manipulated.

7) **Using Statistical analysis**
- Students serious about their project may find statistical analysis very rewarding.
- Statistical analysis may be used by students who have attained some senior mathematical exposure.
- Inferential statistics employs procedures that allow a broader generalization from sample data about the population.

This checklist is an important guideline for students doing any kind of investigation. Remember, the attitude of students that sees experimental investigation as being more "impressive" than other, non-experimental investigations is a myth that teachers must work to dispel. With any non-experimental investigations, there are clearly important investigative design criteria that must be obeyed to conduct a properly devised investigation. By abiding with these criteria in designing an investigation, student projects will exhibit good science skills development.

Developing the Project with a Time Line

In high schools, time management is a crucial component with project work. For successful completion, learners need to manage their projects within a timeline. The submission of proposals provides students with better control of their investigation. Teachers should monitor the skill development with checklists throughout the project work.

10 Week Timeline Schedule

Students should prepare a week by week schedule of their investigation. This should be included in the submission of their first project proposal. Their first submission should be handed in 2 weeks after commencement of class. The final project could be scheduled to be due on the 10th week, or such a time as agreed upon by the course instructor. If properly timed, their final, completed project can coincide with a school fair or a regional science and technology fair.

Providing at least 2 submission dates, one for the initial submission of their investigative proposal and the second for their progress report, brings structure and guidance to students and helps to insure success.

Submission 1: Investigative Proposal

Having contemplated the key investigative features, which includes the theoretical as well as the practical concepts of the student investigations, a proposal should be submitted for approval.

The proposal constitutes:

1) Project title.
2) Names of students involved, if it is group work.
3) The Causal Question(s) involved in their project.
4) The identification of Independent Variable (Cause) & Dependent variable (Result).
5) Their brief hypothesis and predictions about the outcome of their investigation.
6) Investigative procedures.
7) Safety regulations.
8) Suggested timeline for their project.

The proposal should be carefully evaluated with the students in a brief discussion session.

Submission 2: Progress Report

To keep the students on task and allow them to monitor their own progress, they should submit a second report about half way through their investigative schedule.

The progress report constitutes:

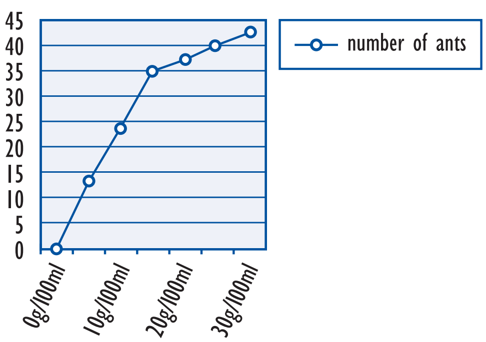
1) The data collected and the prediction.
2) The inferences of the data in relation to the hypothesis.
3) If possible, the next direction in the investigation.

This second submission can also be assessed with the students in a brief discussion session. During this conference, each progress component is carefully discussed with the students. This is a valuable component of the learning process, and gives a sense of collaboration between teacher and student.

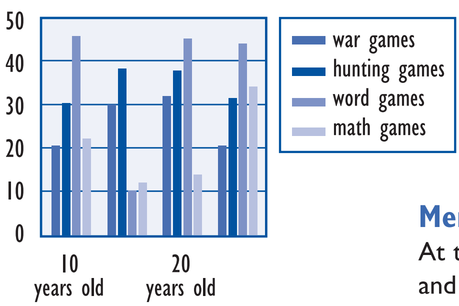
Each component is carefully discussed with the students. There is also a possibility of evaluating this proposal, to insure the development of a good understanding of the project. Appendix Three of this document has a sample of an investigative proposal.

Analyzing, Transforming, and Interpreting the Results

Science students, like scientists and technologist, collect data from their investigations. A table is frequently used in collecting and organizing the data. These data need to be transformed into readable information that reveals meaning.
"A picture paints a thousand words" is a saying that depicts collected data that can be visualized. Graphs transform qualitative and quantitative data and help reveal meaningful trends in the investigation. The three most useful kinds of graphs are:



a) Line Graph - When the cause and result variables on the axis are quantitative and continuous, a line graph is selected. In the example to the left, the relationship between the two variables directs one to conclude that as the concentration of sugar increases, the number of ants arriving to the sugar solution will also increase.
b) Bar and Circle Graph - When data is in categories or groups, a bar or circle graph is used. For example, a brand name is a discrete, categorized unit, so graphing results that relate to brand name preferences would go on a bar or circle graph.



The bar graph to the left shows a survey of 10 and 20 year olds and their preference of video games. The data falls into discrete categories (which game they like), so a bar graph is a good choice.

Circle graphs are used in the same way as a bar graph with one discontinuous variable. To show the total population studied, the values are often converted to percentages.

Mentoring: Who is Involved?

At the high school level, teachers, parents, and other mentors often assist in developing and completing the students' projects. Many projects require special assistance from the professional communities. Private sector industries and business, or tertiary institutes such as colleges and universities, may be involved. Schools with cooperative education programs may enable students to receive access to such facilities for their apprentice programs.

Mentoring opportunities are designed to provide guidance and technical support, especially in the use of expensive equipment and resources that high schools can't afford. When mentored, it is important to monitor these investigations closely. With the help of the project proposal from students, teachers get an opportunity to monitor students' scientific skills development. Conceptual understanding in the form of idea development and procedural understanding of their investigation must be assessed through discussions, journal keeping, and interviews.

If the students work with a mentor, their mentor's role must be clearly defined.

1) All project hypotheses and investigative procedures should be prepared by the student and approved by the teacher before consulting with a mentor. However, these procedures can be modified during the investigational stage upon approval by the teacher.
2) Mentors must be informed that it is student's work, and students should not be completing work or projects designed by the mentor. In the end, it should be the student's ideas, conceptual understanding, and performance that are being evaluated.
3) The students should keep a record of their visits and all work carried out at the facility.
4) 1) Any contributions to the project by the Mentor must be noticed and recorded. (Refer to the Mentor Form in Appendix Six).

When students are being mentored by a professional researcher, supervision is a key consideration. Especially when new apparatus is used that students may not be familiar with, students should be supervised and properly trained. The use of specialized instruments such as the micro centrifuge, Thermo cycles, gas chromatography equipment and other relevant apparatus are encouraged but students must be involved.

Presentation Skills: An Important Component

Communication is an important component of scientific skill attainment. In preparing for any presentations, students are naturally stressed. A key to lowering the stress level is to be well-organized and prepared to convey the information.
To be comfortable in presenting, the following suggestions can be helpful to students:

1) Students are encouraged to use their project boards to help plan the presentation.
2) Students need to know before hand the time allowed for their presentation sessions.
3) Have students prepare their speech using cue cards or computer multimedia presentations (e.g. Powerpoint).
4) Cue cards or multimedia presentations should highlight key talking points. Students should not read to an interviewer/judge.
5) Students are reminded to review their investigative methods, especially any details involved in their particular research.

Displays: Presenting your Project

A project board that is attractive and well displayed captures the reader quickly, and invites them to take time to examine the project. Here are some ideas to consider when displaying your investigation.

1) An attractive, catchy, and well constructed title gets instant attention.
2) Ensure that the display is neat, with proper spelling, grammar, and syntax.
3) Organize your board according to the guideline set by organizers.
4) Use photos to show steps in your design process, and to display results.

5) Have clearly labeled sections that show the investigative process followed:
   - the situational problem or question,
   - the introduction with hypothesis,
   - the summarized investigative procedure,
   - the results displayed in charts and graphs (if appropriate use photographs)
   - the discussion and conclusion of your findings,
   - the application of your results, and
   - the acknowledgments.

Safety Regulations

Regional science and technology fairs have an extensive list of safety rules and regulations that detail what can or cannot be used or displayed in a project. Many of the regions abide by Canada Wide Science Fair rules, and live organisms will not be allowed to be displayed. This also includes any material that can cause or enhance decay, including water. In such situations, photographs are encouraged to show the before and after effect of the investigation.

When constructing the science fair boards, strict fire safety rules need to be followed. Please refer to the YSF safety regulations for more details, which can be downloaded as a PDF file from the Sci-Tech Ontario website at: http://scitechontario.org/rulessafety.asp The PDF document includes a safety checklist, which can be helpful when students are doing a project, and when they are creating their display.

Project Work Goes Beyond School Work

A well-balanced science and technology program will help develop students who are critical thinkers with good problem solving, inquiry, and design skills. Science projects are intrinsically rewarding, and displaying them for the class or school can and should be a positive experience. The skills learned are valuable for academic success and career preparation. As well, there are opportunities outside the classroom for students to further develop their skills and have fun with science and technology:

Regional Science & Technology Fairs

In Ontario, there are 30 Regional Science and Technology Fairs and more are being organized as educators see the value of project work. Organized by volunteers, these events are a great venue for young scientists to showcase their work and to experience the wide variety of scientific and technological work of their peers. A listing of the regional fairs is available at the Sci-Tech Ontario website: http://scitechontario.org/regionalfairs.asp

Canada-Wide Science Fair

The best young scientists from the Regional Science and Technology Fairs in Ontario are selected to attend the week-long Canada Wide Science Fair as members of 'Team Sci-Tech Ontario.' The Youth Science Foundation of Canada (YSF) coordinates this annual event, which is held in a different host city each year. For more information, visit the YSF website at: www.ysf.ca

OCAD (Ontario College of Arts and Design) Sumo Robotics Competition

This challenge provides students and teachers the opportunity to build from a wide and varied range of robots. There are 6 classes of robots in this competition. Depending on

the skill level and budget restrictions of your participants, a robot can be controlled using battery with cable attachment or using more sophisticated computer electronics. The classic sumobot will compete in a sumo-style wresting match. Its objective is to push its opponent off a 6 foot diameter platform. The 'artistic' class of robots will either perform a dance or demonstrate its talent by producing a painting.
Further information can be found at www.student.ocad.on.ca/info/sumo/

ENO Canadian National Marsville Program
The purpose of the Canadian National Marsville Program is to create a positive vision for young Canadians of the technological society they will inherit in the 21st century. The program shows students how they can play a role in establishing the kind of society they want for the future. Marsville has been designed for students in Grades 5 to 12. While the primary educational thrust of Marsville is math, science and technology, the project uses a cross-curricular, holistic approach integrating various disciplines. For more information, visit their website at http://mars2002.enoreo.on.ca/

ENO Robotics Challenge
The Robotics Challenge is a unique multi-year educational project aimed at students in grades 4 to 12. It provides opportunities to learn about science, technology, math and design through the development, programming and testing of autonomous robotic devices. For more information, visit their website at http://challenge.enoreo.on.ca/

Aventis Biotech Challenge
This is a valuable research opportunity for high school students. Students interested in the specialized area of biotechnology can participate at two levels. The intermediate level invites application from gr. 9 and 10 students. Each year the intermediate level is provided with a topic area to research. Senior students in gr. 11 and 12 have total freedom to select any area of research within the guidelines of the Aventis Biotech Challenge. For more information, go to their website at www.AventisBiotechChallenge.com

Ontario Envirothon Challenge
Visit the Ontario Envirothon Web page (www.ontarioenvirothon.on.ca) for Envirothon information and their hands-on Environmental Educational Program.

Real Science: A Summary
Projects Work to Engage Students to Meet the Goals Of the Ontario Curriculum

Providing a meaningful and engaging science program is a challenging task. Project-based science and technology is the natural culmination of a program that involves students in developing inquiry and design skills, and that helps students to connect science and technology to each other and the outside world. Through authentic investigations, students construct an understanding of how science works, and develop critical thinking skills that will serve them well in their future endeavours. Important connections exist between projects, a classroom program that is both hands-on and "minds-on" and the Ontario Curriculum in science and technology:

- Projects effectively address the 3 overall goals of science and technology education.
- Projects integrate many curriculum expectations in science and technology.
- Projects are an effective culminating assessment activity for a unit.
- Inquiry and design skills needed to complete a project are found in the expectations for every unit of the Ontario science and technology curriculum.
- Project-based science and technology incorporates constructivist learning, and encourages students to explore the important questions and concepts related to a topic.
- Project-based science and technology can be used to integrate knowledge and skills from many different curriculum subjects.
- Common misconceptions about science and technology often hinder effective science and technology instruction and independent project work.
- How does _________ affect __________? is an effective framework for generating inquiry and project questions.
- Strategies are available for helping students develop inquiry and project ideas.
- Tips on displaying a project can help students communicate their work.
- Project-based science and technology can benefit students with exceptionalities.
- The role of parents and mentors in projects must be clearly explained.
- Several key features distinguish a great project.
- Students can complete a project in stages, breaking it down to manageable pieces.
- There are many exciting opportunities for students involved in project-based science and technology.

References

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Van Oostveen, R, Ayyavoo, G, Bencze, L & Corry, A. Correlational studies in school science: beyond experimentation. OISE Papers In STSE Education, 3, 221-230, 2002.

Van Oostveen, R, Bencze, L, Corry, Alex & Ayyavoo, G. Teaching A combined Science-Technology Curriculum. OISE Papers In STSE Education, 1, 145-159, 2000.

Wiggins, G., and McTighe, J. Understanding by Design. Alexandria, Virginia: Association for Supervision and Curriculum Development, 1998.

Appendix One:
CITING RESOURCES

MLA (Modern Language Association) http://www.mla.org/

APA (American Psychological Association) Format Style
The following is taken from: http://www.crk.umn.edu/library/links/apa5th.htm

Journal Article, one author
Simon, A. (2000). Perceptual Comparisons Through the Mind's Eye. Memory & Cognition, 23, 635 - 647.

Magazine Article, one author
Garner, H. J. (1997, July). Do babies have a universal song? Psychology Today, 102, 70-77.

Newspaper article, no author
Study finds free care used more. (1982, April 3). Wall Street Journal, pp. A1, A25.

Book, two authors
Strunk, W., Jr., & White, E. B. (1979). The elements of style (3rd ed.). New York: Macmillan.

Edited book
Letheridge, S., & Cannon, C. R. (Eds.). (1980). Bilingual education. New York: Praeger.

Entry in an Encyclopedia
Imago. (2000). In World Book Encyclopedia (Vol. 10, p. 79). Chicago: World Book Encyclopedia.

Report From a Private Organization
Kimberly-Clark. (2002). Kimberly-Clark (Annual Report). Dallas, TX: Author.

Videotape
Mass, J. B. (Producer), & Gluck, D. H.(Director). (1979). Deeper into hypnosis. (Motion picture). Englewood Cliffs, NJ: Prentice Hall.

Electronic Formats

Internet Article Based on Print Source
The citation is done as if it were a paper article and then followed by a retrieval statement that identifies the date retrieved and source.
Sahelian, R. (1999, January). Achoo! Better Nutrition, 61, p. 24. Retrieved September 17, 2001, from Academic Index.

Web page, no author, no date
GVU's 8th WWW user survey. (n.d.). Retrieved September 19, 2001, from http://www.cc.gatech.edu/gvu/user_surveys/survey-1997-10/

Web page, no date
Thompson, G. (n.d.). Youth coach handbook. In Joe soccer. Retrieved September 17, 2001 from http://www.joesoccer.com/menu.html

Appendix Two:
STUDENT HANDOUTS

Science and Technology Projects
HELP I DON'T HAVE A TOPIC!

As mentioned in class, this is the hardest part of an investigation for most people. Don't give up! There is lots of help available for you. Follow the steps below to help you come up with a topic, but keep one thing in mind: Choose a topic that is of INTEREST TO YOU!! It will make it much easier to work steadily and achieve a good result!

1) Begin with Your Own Interests

Science is a part of every aspect of your life, whether you know it or not. Begin with your own interests--if you enjoy music, consider an investigation into sound (What gives each instrument its characteristic sound?; How does the material of a string affect the sound produced?)

If you like history, perhaps you can research an experiment by an early scientist and repeat it yourself. If you are an artist, you can examine processes like silkscreening or ceramics--these areas contain many topics of scientific value!

Without listing every possible interest here, it should be obvious to you that your own interests can lead to interesting investigations. In the spaces below, list 4 or 5 general areas of interest for you:

____

____

____

____

____

____

____

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____

2) Research/Investigate the Topic

From your list of interests, choose one topic that you think might lead to an interesting science inquiry.

Then use the public library, CD-ROMs, or classroom resources to develop a specific question about the topic.

Note that classroom resources are listed on the chart paper at the front of the room.

In the spaces below, please list the resources you used, including specific page numbers. Two resources is the minimum you should use.

(Example: Gleick, James. Chaos. pp. 47-63.)

____

____

____

____

3) Develop a List of Possible Focus Questions from Your Research and Select One.

A good focus question is specific and clear, and avoids having YES or NO for an answer. A good format for your question is:

How does ____________________ affect the

________________ of __________________ ?

This format creates a simple cause and effect question. Does one thing (independent variable) have an effect on another (dependent variable)?

Some examples:

How does <u>temperature</u> affect the <u>bounce height</u> of a <u>tennis ball</u>?

How does <u>wind direction</u> affect the <u>pH of rainfall</u> in <u>Scarborough</u>?

An important feature of a good question is that it suggests some method of answering it! In both examples, you can probably think of a method that could be used to help answer the question.

A good question also tells you what NOT to do. In the first example, you would not test the bounce height of an India-rubber ball. Although it might be interesting, it is not part of the investigation question. If you changed the question to "How does heat affect the bounce height of balls?", then testing an India-rubber ball and others would make sense. Changing just one word can make your investigation quite different!! Take time to develop a good focus question, and don't expect your first version to be the final one. Check your question with other students and with me, and check with me before you use it for your project.

NOTE: There are other possible formats for your question as well, such as:

How does the violence in police/crime shows of the 60's compare to 2000?

How can the freezing temperature of water be changed from 0°Celsius?

The format described above (How does ____________ affect the ____________ of ____________ ?) is a simple, effective way to formulate a good question, but not the only way.

Your focus question is due on

____

?

Science and Technology Projects
I HAVE A FOCUS QUESTION.......NOW WHAT?

Now that you've developed a focus question, it's time to thoroughly plan what you will do for your project. Careful planning is essential for a successful project. The attached Project Outline has sections to fill out important information about your project, things you'll need to think about and know before you begin the actual "hands-on" science. They may change as your experiment progresses, but good planning at the start can save you work, and trouble, later.

a) Focus Question

This should be your final focus question for your project and should be worded clearly. Make sure it can be answered, and avoid yes/no types of questions. See the previous section for more details. If possible, put it in the form of

How does _________________ affect ______________.

The first blank is the variable you will change, and the second is the variable you will observe.

b) Concepts

You should have a complete list and description of all the concepts (ideas) that are related to your topic.
This might require some additional research, and can include research you did as you developed a focus question

c) Procedure and Materials/Equipment

In this section, you describe exactly what you are going to do in order to answer the focus question. It should be detailed enough that another student at your level could read the procedure and conduct the experiment. A list of all necessary materials and equipment should also be given.

The Project Outline is due for all classes on:

____

This will give you plenty of time to conduct the experiment, record results, prepare transformations of your results, and write your knowledge and value claims (what you learned and why it is important). More on that will come up in the next handout. For now, you should have enough on your plate to keep you busy!

Science and Technology Projects
PROJECT OUTLINE

Student Name: ______________________________

Partner's Name (if applicable): ______________________________

Type of Project (check one): Experiment ❑ Study ❑ Innovation ❑

Focus Question:

____

____

____

____

Other Related questions I have:

____

____

____

____

How I plan to answer my question(s):

____

____

____

____

____

Scientific Concepts involved (list and define them):

____

____

____

____

Special Requirements/Equipment needed

____

____

____

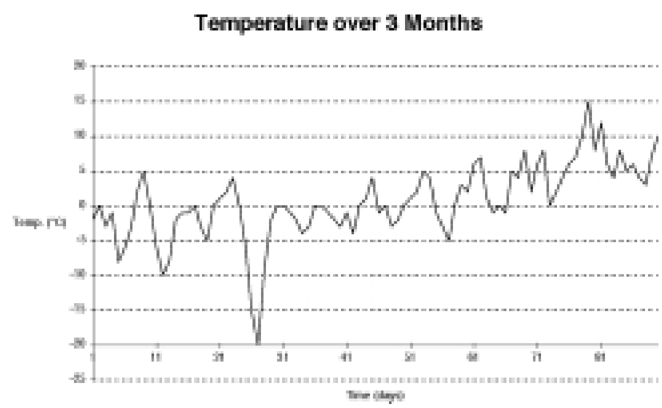
Science and Technology Projects
TRANSFORMING AND DISPLAYING YOUR DATA

Transformations are a very important part of any scientific presentation. Their purpose is to transform large amounts of data into an easily understood form that displays some interesting aspect of the data. Graphs are probably the most common form of transformation, but they are often misused. Two of the most useful graphs for scientific work are line graphs and bar graphs.

Example:
Suppose you measured the temperature every day for three months. You'd have about 90 pieces of data that aren't very interesting on their own. Further, it would be difficult to see any sort of pattern. "A graph would help." you think, but what type of graph? "What does it matter, a graph's a graph, isn't it?" Actually, no. The type of graph you make depends on your data, how you've organized it, and what you're trying to show.

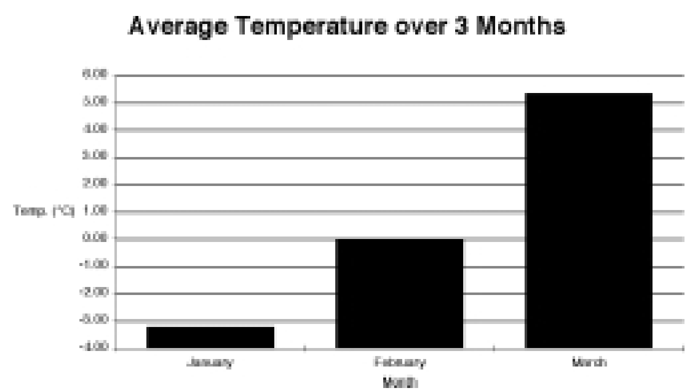
Line Graphs

Line graphs are probably the simplest, because they usually show all the data points and the data are not organized in any way before making the graph; however, one thing must be true about the data in order to use a line graph: The scale on both axes of the graph must be continuous, that is, the data could have any value on them. For example, on our "Temperature over 3 Months" graph, if the x axis represents time in days, the data could have any value on the scale: 2 days, 5.56 days, 1.004 days. Of course the temperature could be any value as well. This graph shows the temperature record rather well, but if you were simply trying to show that the temperature increased gradually over the three months, there's too much data here – the pattern is obscured.



Bar Graphs

Another possible transformation to show this trend more clearly would be to group the data into the three months, calculate an average, and graph these 3 values. As soon as you group the data (or if the data are already grouped) you cannot use a line graph. On the x axis now you'll put January, February, March. These are categories and they are not continuous – a day is either in January or February, it cannot be any value in between. Data in categories or groups are shown on a bar graph.



Science and Technology Projects
CHECKLIST FOR REPORTS OF SCIENCE & INVENTION[1]

For all major reports of science or invention, use the following general format:

TITLE
- The title is related to the question/problem being studied.

INTRODUCTION
- This section is written in paragraph form.
- The question or problem being attempted to be solved is stated.
- Some predictions, with reasons (hypotheses) are mentioned.
- The most likely prediction is explained (with reference to outside sources).
- A brief summary of the over-all methods is mentioned.

MATERIALS AND METHODS
- All materials used in the project are listed.
- All methods are listed in numbered steps (like a "recipe").
- There is evidence of proper attention to 'Test Design Factors'; i.e.
- A wide range, with many values, of the possible cause variable under study.
- All variables were measured in at least two ways, where possible.
- Possible cause variables besides the one of interest were controlled.
- All tests and measurements were repeated an appropriate number of times.
- Qualitative descriptions of objects and events are conducted.
- A diagram or sketch of the methods is included.

OBSERVATIONS AND RESULTS
- All observations and results are reported.
- All observations are organized into appropriate tables, charts, and/or graphs.
- Any calculations which were necessary are shown.

DISCUSSION
- This section is written in paragraph-form, as a continuation of the INTRODUCTION
- A qualitative and/or quantitative description of all results is given.
- A critical evaluation of the actual methods, according to 'Test Design Factors,' is given.
- A careful conclusion about the value of the original prediction, with reason(s), is given. .
- Possible applications of the conclusions are discussed.
- Further work in science and/or invention which might be done in the future are discussed.

GENERAL LAYOUT
- The document is neatly printed, written or typed (not absolutely necessary).
- The document consists of the four sections, as indicated above.
- All references are properly noted in the "Endnotes"
- A complete and correctly alphabetized "Bibliography" is present.

TEACHER'S COMMENTS (over):

Appendix Three:
SUBMISSION 1: INVESTIGATIVE PROPOSAL

Submission 1: Investigative Proposal

Due Date: ____________________

Student Name: ____________________

Partner's Name (if applicable): **1)** ____________________

2) ____________________

Investigative Title:

Causal Question(s):

Cause Variable:

Result Variable:

Prediction Of The Test:

Hypothesis:

Type Of Investigative Procedure: Experiment ❑ Study ❑ Innovation ❑

Steps to Investigative Procedure:

Possible Results and Explanation:

Budget and Timeline:

Submission 1: Investigative Proposal
FOR TEACHER USE: Brief Explanation

Due Date: ______________________

Student Name: ______________________

Partner's Name (if applicable): **1)** ______________________

2) ______________________

Investigative Title:
Include a descriptive title that is under 10 words. ______________________

Causal Question(s):
A possible question that shows a cause and effect/result relationship. ______________________

Cause Variable:
Identify the Cause variable in your investigation. ______________________

Result Variable:
Identify the Result variable(s) in your investigation. ______________________

Prediction Of The Test:
State an estimated/possible event to observe that might occur in your investigation. ______________________

Hypothesis:
Your educated REASON for the observed event. ______________________

Type Of Investigative Procedure:
Experiment ❏ Study ❏ Innovation ❏

Choose the appropriate investigative method for your investigation. ______________________

Steps to Investigative Procedure:
Provide the necessary steps required for your investigation. Note all design features needed for your investigative type. ______________________

Possible Results and Explanation:
State the possible Positive and negative results and its explanation. ______________________

Budget and Timeline:
Mention the expected financial support to be needed with timeline for completion. ______________________

Submission 1: Investigative Proposal
SAMPLE PROPOSAL

Student Name: ______________________

Investigative Title:
The Effects of Vitamin C on the development of Aquarium snail embryo.

Causal Question(s):
What will the effects of different concentration of Vitamin C have on the development of Aquarium snail embryo?

Cause Variable:
Various concentrations of Vitamin C

Result Variable:
Faster growth of snail embryos to maturity

Prediction Of The Test:
If the concentration of Vitamin C is added than the growth of the snails be enhanced within a shorter time.

Hypothesis:
Vitamin C is an Antioxidant that protects the body against pollutants. It is essential for Collagen tissue synthesis. Recent Studies have linked to the prevention of degenerative diseases and healthy cell development by increasing the uptake of the Antioxidant Vitamin C. Normal tissue growth and repair

Type Of Investigative Procedure:
Experiment ☑ Study ❑ Innovation ❑

The Procedure requires the intentional addition of the Antioxidant Vitamin C to the snail embryos.

Steps to Investigative Procedure:
a) Several embryos in the egg sac will be obtained and place into 2 groups.
b) One set of 5 eggs will be placed into the Expt. Group with the Vitamin C.
c) The other batch of 5 eggs will be in the Control group without any Vitamin C.
d) The temperature of the water will be maintained at ……………

Possible Results and Explanation:
Positive effects will be seen under the microscope as increase development in size and weight. The Negative effects with no change or slower growth will indicate the Vitamin to inhibiting the growth. The different conc. will also …………..

Budget and Timeline:
A budget of $15 will be required to purchase the snails and vitamins.

Week 1 - 2: Observing and maintaining snails

Week 3 – 4: Testing the snails with different concentrations/ Collecting Data

Week 5 – 6: Interpreting data / Repeating Experiment for more data/time to solve problems

Week 7 –10: Assembly / preparation for presentation / more discussions with mentor

Appendix Four:
SCIENTIFIC INQUIRY RUBRIC

Scientific Inquiry Rubric

Criteria	Level 1	Level 2	Level 3	Level 4
Formulates scientific question(s)	***Formulates questions that are limited***	***Formulates questions that can be answered through research and/or experiment with considerable assistance***	***Formulates questions that can be answered through research and/or experiment with minimal assistance***	***Formulates questions that can be answered through research and/or experiment independently***
Develops a plan to answer the question(s)	Develops a faulty plan	Develops a partial plan to answer the question	Develops an appropriate plan to answer the question	Develops an appropriate and efficient plan to answer the question
Demonstrates technical skills and strategies to carry out the plan	Demonstrates technical skills and strategies to carry out the plan with limited competence	Demonstrates technical skills and strategies to carry out the plan with some competence	Demonstrates technical skills and strategies to carry out the plan with considerable competence	Demonstrates technical skills and strategies to carry out the plan with a high degree of competence
Observations	Makes few observations	Makes observations but they may be insufficient to generate ideas or irrelevant	Makes sufficient observations to generate data	Makes rich and relevant observations
Records data	Records little data	Records data but organization is lacking	Records relevant data in an organized way	Records relevant data in an organized and skillful way
Modifies plan as needed	Recognizes the need to modify the plan only when prompted	Has difficulty recognizing the need to modify the plan	Appropriately modifies the plan when necessary	Modifies the plan in insightful ways when necessary
Analyzing data	Provides limited analysis of the data	Provides some analysis of the data	Provides sufficient analysis of the data	Provides rich analysis of the data
Ability to draw conclusions	Demonstrates limited ability to draw conclusions based on their data	Demonstrates some ability to draw conclusions based on the data	Draws valid conclusions based on the data	Draws insightful conclusions based on the data
Evaluates plan	Provides limited evaluations of plan	Provides some evaluation methods of used	Provides sufficient valuation of methods used	Provides a thorough evaluation of methods used
Communicates findings	Communicates findings with limited clarity and precision	Communicates findings with moderate clarity and precision	Communicates findings effectively with considerable clarity and precision using	Communicates findings effectively and appropriately with a high degree of clarity and precision
Uses of scientific terminology and conventions	Uses scientific terminology and conventions with limited accuracy and effectiveness	Uses scientific terminology and conventions with some accuracy and effectiveness	Uses scientific terminology and conventions with considerable accuracy and effectiveness	Uses scientific terminology and conventions with a high degree of accuracy and effectiveness
Safe use of tools, equipment and materials	Demonstrates use of tools, equipment, and materials safely and correctly only with supervision	Demonstrates use of tools, equipment, and materials safely and correctly with some supervision	Demonstrates use of tools, equipment, and materials safely and correctly	Demonstrates and promotes the safe and correct use of tools, equipment, and materials

Adapted from Nelson 9 Teacher Resource Binder and The Ontario Curriculum Grades 9 and 10 Science
Catherine Christie and Heather Highet, STAO 2001

Appendix Five:
YSF JUDGING FORM

Judge's Marking Sheet – Canada-Wide Science Fair

PART A: SCIENTIFIC THOUGHT – 45 %			Mark
Experiment An investigation undertaken to test a scientific hypothesis using experiments. Experimental variables, if identified, are controlled to some extent.	**Innovation** The development and evaluation of innovative devices, models or techniques or approaches in technology, engineering or computers (hardware or software).	**Study** A collection and analysis of data to reveal evidence of a fact or a situation of scientific interest. It could include a study of cause and affect relationships or theoretical investigations of scientific data.	
Level 1 (low) – Mark Range 5 to 15			
Duplication of a known experiment to confirm the hypothesis. The hypothesis is totally predictable.	Building models (devices) to duplicate existing technology.	Study of existing printed material related to the basic issue.	
Level 2 (fair) Mark Range 15 to 25			
Extend a known experiment through modification of procedures, data gathering, and application.	Make improvements to, or demonstrate new applications for existing technological systems or equipment and justify them.	Study of material collected through compilation of existing data and through personal observations. Display attempts to address a specific issue.	
Level 3 (good) Mark Range 25 to 35			
Devise and carry out an original experiment with controls. Variables identified. Some significant variables are controlled. Analysis such as graphs/simple statistics.	Design and build innovative technology or provide adaptations to existing technology that will have human benefit and/or economic applications.	Study based on observations and literary research illustrating various options for dealing with a relevant issue. Appropriate analysis (arithmetic, statistical, or graphical) of some significant variable(s).	
Level 4 (excellent) Mark Range 35 to 45			
Devise and carry out original experimental research which attempts to control or investigate most significant variables. Data analysis includes statistical analysis.	Integrate several technologies, inventions or designs and construct an innovative technological system that will have human and/or commercial benefit.	Study correlating information from a variety of significant sources which may illustrate cause and effect or original solutions to current problems through synthesis. Significant variable(s) are identified with in-depth statistical analysis of data.	

PART B: ORIGINAL CREATIVITY – 25%			
Level 1 (low) **Mark Range 5 to 10**	**Level 2 (fair)** **Mark Range 10 to 15**	**Level 3 (good)** **Mark Range 15 to 20**	**Level 4 (excellent)** **Mark Range 20 to 25**
Little imagination shown. Project design is simple with minimal student input. A textbook or magazine type project.	Some creativity shown in a project of fair to good design. Standard approach using common resources or equipment. Topic is a current or common one.	Imaginative project, Good use of available resources. Well thought out, above ordinary approach. Creativity in design and/or use of materials.	A highly original project or a novel approach. Shows resourcefulness, creativity in design. Use of equipment and/or construction of project.
Mark			

Paste Label here

PART C: DISPLAY
Maximum 20 Marks

1. Skill (Maximum 10)	Max	Mark
Necessary scientific skill shown.	3	
Exhibit was well constructed.	3	
Material prepared independently.	2	
Judge's discretion.	2	
2. Dramatic Value (Maximum 10)		
Layout logical and self-explanatory.	3	
Exhibit attractive.	3	
Clear logical enthusiastic presentation.	3	
Judge's discretion.	1	
Total Display Mark	**20**	

PART D: PROJECT SUMMARY
Maximum 10 Marks

1. Information	Max	Mark
Is all the required information provided?	3	
Is the information in the specified format?	1	
Is information presented clearly with continuity?	2	
Summary accurately reflects the project.	2	
2. Presentation		
Neatness, grammar, spelling in the report.	2	
Total Project Summary Mark	**10**	

Total Marks		
Part A: Scientific Thought (from page 1).	45	
Part B: Original Creativity (from page 1).	25	
Part C: Display.	20	
Part D: Project Summary.	10	
Total Mark awarded to this exhibit.	**100**	

FEEDBACK FOR THE EXHIBITOR(S)

Strengths ______________________________

____

____

Recommendations ______________________________

____

____

Judge's Name (Please Print!) **Judge's Signature**

Use this form to give a mark to each exhibit, and to assist you in ranking the exhibits assigned to you. This mark will not be used in subsequent rounds of judging. **Return this form to the Chair of your Judging Team.**

Appendix Six:
MENTORING FORM

Contribution From a Recognized Institution

Youth Science Foundation Canada

Canada-Wide Science Fair – Contribution From a Recognized Institution

The Science Fair participant(s) that you have generously agreed to help has/have chosen to develop one of three types of project: **Experiment, Study or Innovation**. Please note that this project is subject to the *Policy, Procedures and Guidelines* of the Youth Science Foundation Canada and any applicable federal, provincial, or municipal legislation. You may wish to request a copy of the YSF rules governing projects from the participant(s) or visit the official Youth Science Foundation Canada site at www.ysf.ca. The Youth Science Foundation Canada wishes to thank you for your help and encouragement.

PARTICIPANT(S) & PROJECT:	
Participant's Name (1)	Participant's Name (2)
Title of Project	
Project Type (Check only one): ____ Experiment ____ Study ____ Innovation	

RECOGNIZED INSTITUTION:	
Name and address of institution that contributed to this project:	Name(s) and qualifications of supervisor(s):

INSTITUTION'S CONTRIBUTION:
Please summarize the ways in which your institution contributed to the completion of this project:
Based on your knowledge of this project's field of study, does this project verify, replicate, or present existing scientific knowledge? How is this project innovative? Did the original idea come from the participant or a member of your institution?:

EXPERIMENTAL PROJECTS ONLY:	
Did the project require the use of hazardous biological materials (bacterial pathogens, viruses, DNA, etc.)?	____ Yes ____ No
If hazardous biological materials were used, please indicate whether they were handled under the supervision of qualified personnel in a facility equipped to handle such materials.	____ Yes ____ No
Did the project involve the use of laboratory animals?	____ Yes ____ No
If animals were used, please specify whether they were vertebrate or invertebrate animals.	____ Vertebrate ____ Invertebrate
If animals were used, please indicate whether they were handled under the supervision of an ethics committee that complies with the rules and standards of the Canadian Council on Laboratory Animal Care?	____ Yes ____ No

DISPLAY, ORAL PRESENTATION & WRITTEN REPORT:	
Have you discussed the content of the project's display and oral presentation with the participant(s)?	____ Yes ____ No
If yes, do the display, oral presentation, and written report accurately reflect the original contribution of the participant(s) and clearly identify the contribution of your institution and its personnel?	____ Yes ____ No
Have you read the written report of the project prepared by the participant(s)?	____ Yes ____ No
If yes, does this report accurately reflect the original contribution of the participant(s) and clearly identify the contribution of your institution and its personnel, in addition to including a complete list of relevant references?	____ Yes ____ No
If yes, does this report include a complete list of relevant references?	____ Yes ____ No

AUTHORIZATION TO PRESENT RESULTS:	
Is/are the participant(s) authorized to present these research results in public?	____ Yes ____ No

COMMENTS:

SIGNATURE OF SUPERVISOR OR REPRESENTATIVE OF RECOGNIZED INSTITUTION:		
Name and position (Please print):	Signature:	Date:

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