

Water Sampler Design Project -- Teacher's Guide

Overview

In the course of analyzing and solving problems in the everyday world, it is important for students to understand that mathematical analysis, scientific inquiry, and technological design are interconnected. In the course of solving any problem where students try to meet certain criteria within constraints, they must find they need to call on other sources of knowledge and skills. These include topics such as cost, risk, benefit, trade-offs, and aspects of critical thinking and creativity.

In this design project, teams of students are to undertake the solution to a problem proposed in the following scenario:

A mysterious fish kill has occurred in a 100-ft section of the Arquin Creek that flows through one of the glacial gorges in Hester State Park. You are part of a student research team that has been granted permission by the state to perform a preliminary investigation of the site. Your team has decided to take water samples at various depths so that you can perform chemical tests. Maximum depth of the creek within the gorge has been estimated to be 10 feet. The structure of the gorge where the fish kill has occurred limits your access to the creek. The stream is 20 feet across and is bounded on both sides by nearly vertical rock ledges that extend from a minimum of 2 feet to a maximum of 15 feet above the water's surface. You decide to build a sampling device that will allow you to retrieve water samples from the creek's edge to midstream from various locations along the rock ledges.

In the situation described, students need to respond to a specific design problem before they can engage in the rigors of science. Successful completion of the design requires them to meet criteria while addressing conflicting constraints.

A design parts kit, which the students will use to construct their specific design, is included with the project. The kit contains common laboratory equipment, office supplies, and hardware that will allow student teams to build and test a variety of devices. In addition to specific design criteria that all students must follow, a set of restrictions have been added to the scenario to create design alternatives.

The protocols of this project are based on a problem solving model developed at the Thayer School of Engineering at Dartmouth College. The steps of this model along with a diagram of the cycle can be found in **Teacher Supplement A**. Also included is a sample of how this model may be used in this project. This diagram is also included in the **Student** portion of the project. The fundamental abilities and concepts that underlie these activities include:

- ◆ Identify a problem or design an opportunity.

- ◆ Propose designs and choose between alternative solutions. Students should demonstrate thoughtful planning for a design model.
- ◆ Implement a proposed solution.
- ◆ Evaluate the solution and its consequences. Students should test any solution against the needs or criteria it was designed to meet.
- ◆ Communicate the problem, process, and solution. Students should present their results in a variety of ways, such as to other students orally, in writing, and in a variety of forms, including models, diagrams, and demonstrations.

The specific New York State MST content standards and performance indicators addresses by this project are found in **Teacher Supplement B**.

Summary of the Protocols

1. Define the problem

The first protocol is designed to lead students through the problem-solving cycle in an iterative approach that allows them to identify the general specifications of the problem along with the constraints. The first task in this protocol introduces the students to the scenario and the initial statement of the problem. Task #2 allows the students to obtain a frame of reference about water sampling. Teachers may want to add to their students research base with library research, Internet research, or additional teacher-prepared information on water monitoring and water sampling. Tasks 3 to 5 assist the students in redefining the problem in terms of the identified specifications and constraints. It is important that careful reading and data recording by the students be stressed throughout this protocol. Repeated emphasis should be made on the recording of all data in the student-team laboratory log.

2. Identify Alternative Design Solutions

This protocol gives the students the opportunity to brainstorm design ideas. It is important for the teacher to stress that all possible ideas should be considered and recorded. During this protocol students will work with materials in their parts kit. Many students will need to interact with the materials as a means of investigation but should be careful not to damage the parts. They will also need clarification on additional parts that they may or may not be able to use. Emphasis should be placed on the development of design ideas that meet the specific requirements of the problem and not on actual construction. Each team of students should generate at least two design options. **Teacher Supplement C** illustrates two different possible designs. These have been included for teacher reference only.

3. Select the best alternative

In order to select the best alternative, students must determine the advantages and disadvantages of each alternative device or alternative modifications to an existing design. This protocol allows the students to assess the merits of each alternative against the general specifications and restrictions posed by the problem. To do this, the students will create a qualitative or quantitative scale to judge each of their alternatives against the same set of criteria.

As an example, students may rank each specification for each alternative on a scale of 1 to 3 as follows:

- 1 - poor
- 2 - acceptable
- 3 - good

Using the following matrix they can then select the best alternative based on the results of the analysis.

Alternatives	Specifications							TOTAL
	cost	vertical spec.	horiz. spec.	time	sampling accuracy	safety	durability	
Bill's idea	2	2	2	2	3	3	2	16
Mary's idea	1	2	1	2	2	3	1	12
Ted's idea	3	2	3	2	2	3	3	18
Marsha's idea	2	3	1	1	3	3	1	14

Emphasis should be placed on the need to make trade-offs in selecting alternative designs and the reasoning used to make the decisions. An analysis matrix has been included in the **Student Guide**. The teacher may want to assist students in developing their scales or provide an alternative rating scale.

4. Build and test the best water sampler design

Students will construct and test their water sampler using the water sampler parts kit and any other acceptable materials that they have included in their design. Students may wish to reduce costs in their design by using items such as a rock for a weight or a tree limb as a method of extending their device horizontally.

As students assemble their sampler they will need to test it at various stages of development. Lab sinks within the room can be used as a location for students to test their devices for leaks and basic operation. Final testing can be done by sampling water from a 10 gallon pail located on the floor within the classroom. Students could stand on chairs to represent changes in height above the stream.

Students will most likely find it necessary to make modifications in their designs to overcome problems such as leaks, sampling times, and stability of structure. Emphasis such be placed on the methods developed for judging alternative choices developed in protocol #3.

5. Self-assessment of constructed water sampler

When students have completed the construction and testing of their model, it is important that they be able to assess the quality of their work. The following design rubric has been provided to complete this protocol:

Assessment Scale

- 5 - Exceeds minimum requirement**
- 4 - Satisfies minimum requirements**
- 3 - Minimum requirement questionable**
- 2 - Does not meet minimum requirement**
- 1 - no evidence for assessment**

Design Criteria	Evaluation	Wgt.	Pts
The cost of sampler is less than \$10.00	1 2 3 4 5	1 3 5	
Building time for the water sampler is less than 30 minutes	1 2 3 4 5	1 3 5	
Sampling trials can be made within 5 minutes	1 2 3 4 5	1 3 5	
The sampler can be used to obtain water samples from different depths with high precision	1 2 3 4 5	1 3 5	
The sampler can be used from shore and extend horizontally to a distance of 10 feet	1 2 3 4 5	1 3 5	
There is no mixing of water from other depths	1 2 3 4 5	1 3 5	
Your sample volume is greater than 100 ml	1 2 3 4 5	1 3 5	
Your water sampler is easy to handle and operate	1 2 3 4 5	1 3 5	
Your water sampler is capable of performing several trials without repair	1 2 3 4 5	1 3 5	
Your water sampler is safe to handle and operate	1 2 3 4 5	1 3 5	
Total:			

The rubric contains a “weighting” column that allows the teacher to apply a greater emphasis on one or more criteria or to give them all the same level of importance. For example, a weighting of “5” for the cost factor would produce a possible score of 25 points for that specification while a weighting of “3” for the volume specification would create a possible score of 15 points. The teacher may want to discuss this option with the class before they complete the self-assessment. The grade for the assessment is a percentage of the points earned compared to the total possible point total.

In addition, the teacher may want to further define the different evaluation levels, develop their own set of guidelines for each of the five levels, or provide an alternative measuring tool.

6. Plan a classroom presentation

Students have spent a great deal of time planning, designing and building their water sampler to meet the required specifications. It is important for them to realize that in the workplace, their project isn’t complete until they have presented their results. Their presentation should be designed to convince their audience that their device meets all the established criteria. The teacher may want to include a discussion of the attributes of a quality presentation. Students should have a copy of the assessment rubric that will be used as they prepare for their presentation. **Teacher Supplement D** represents an example of a presentation rubric that may be used. The teacher may use this rubric, modify it, or provide an alternative.

7. Presentation

Students present their results to a specific audience. It is important that students receive feedback from their peers as well as the teacher. If classroom conditions allow it, the teacher should stress the importance of utilizing the appropriate technology in communicating their ideas. The use of presentation software, such as, Powerpoint, should be encouraged. Emphasis should be placed on peer assessment. A presentation rubric should be provided to each member of the audience, including the teacher. The presentation should include a question and answer period. It is suggested that each team meet with teacher at an assigned time to review the results of the self-assessment, peer-assessment, and teacher assessment. This will supply the student with essential feedback to adequately judge the quality of their work.

Interdisciplinary Problem Solving

The focus of this design project is allow students to make the connections that the knowledge and skills of mathematics, science, and technology are used together to

make informed decisions and solve problems. This project requires that students gather and process information, generate and analyze ideas, present results, and probably most difficult of all, work effectively in teams.

The teacher should stress that there is a difference between a project work group and a project team. **Teacher Supplement E** is an overview of the characteristics of an effective team. The teacher may want to consider using this project design scenario as a vehicle for developing the concepts of quality team behaviors.

Equipment and Supplies

Protocol 1: Define the problem

Materials for Students

- Student Guide
- laboratory log

Supplies Needed by Teacher:

- copies of the Student Guide
- notebooks or steno pads to be used as laboratory logs

Protocol 2: Identify Alternative Design Solutions

Materials for Students

- Student Guide
- laboratory log
- water sampler parts kit
- commercial water sampler designs (**Student Supplement B**)
- design challenge parts list (**Student Supplement C**)
- water sampler parts catalog (**Student Supplement D**)
- cost analysis worksheet (**Student Supplement E**)

Supplies Needed by Teacher:

- water sampler parts kits for all student teams
- additional items that may be substituted

Advance Preparations:

- obtain materials and supplies that will be used in student parts kit
- additional items that may be substituted

Protocol 3: *Select the best alternative***Materials for Students**

- **Student Guide**
- laboratory log
- design rubric (**Student Supplement F**) or alternative

Supplies Needed by Teacher:

- sample matrixes for alternative evaluation

Protocol 4: *Build and test the best water sampler design***Materials for Students**

- **Student Guide**
- laboratory log
- water sampler parts kit
- additional items that may be added to design

Supplies Needed by Teacher:

- water sampler parts kits for all student teams
- additional items that may be substituted
- 10 gallon pail for device testing

Advance Preparations:

- determine classroom layout to test water sampler devices

Protocol 5: *Self-assessment of constructed water sampler***Materials for Students**

- **Student Guide**
- laboratory log
- constructed water sampler
- water sampler assessment rubric (**Student Supplement G**) or an alternative.

Supplies Needed by Teacher:

- copies of design rubric

Advance Preparations:

- preparation of a design rubric
- “weighting” values for design criteria

Protocol 6: Plan a classroom presentation**Materials for Students**

- **Student Guide**
- laboratory log
- constructed water sampler
- presentation assessment rubric (**Student Supplement H**) or alternative

Supplies Needed by Teacher:

- copies of presentation rubric
- material and supplies needed for presentations

Advance Preparations:

- preparation of a presentation rubric
- equipment needed for student presentations

Protocol 7: Presentation**Materials for Students**

- all presentation materials
- constructed water sampler
- presentation rubric

Supplies Needed by Teacher:

- copies of presentation rubric
- AV equipment needed for student presentations

Assessment Items

Authentic Assessment Items

1. This design and construction problem could be applied to other problems associated with monitoring water in streams, lakes, and ponds. For example, specific monitoring situations may require the construction of equipment to collect stream bank runoff, measure turbidity, and/or monitor maximum or minimum water levels.
2. Students could use this design rubric as a tool to make decisions on a variety of problems other than design questions. For instance, in deciding what brand of athletic shoes to buy or what college to apply to, students need to determine general specifications and select alternatives.

References

EPA. 1997. Volunteer Stream Monitoring: A Methods Manual, 126-133.

New York State Education Department. 1996. Learning Standards for Mathematics, Science, and Technology, 1-65.

Strumpf Associates. 1997. Integrating SCANS Skills and Competencies across the Curriculum. Center for Strategic Change, Washington, DC.

Thayer School of Engineering. 1993. "Engineering Concepts in the High School Classroom." Dartmouth College, Part 1.

Credits

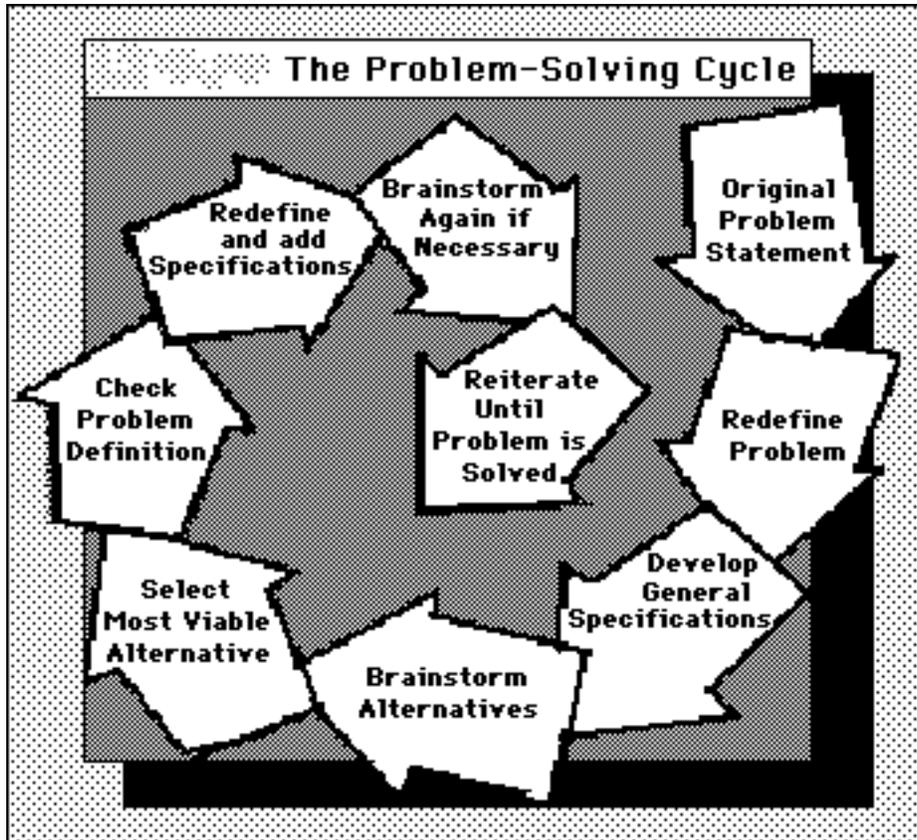
This exercise was written by Harry Canning, teacher at Newark Valley High School and participant in Cornell's Environmental Inquiry Project, 111 Rice Hall, Cornell University, Ithaca, NY 14853.

Please let us know if you have any suggested changes in this protocol. We'd also appreciate feedback on what kinds of investigations your students carried out. Please send your comments to EnvInquiry@cornell.edu or call (607) 255-9943.

Teacher Supplement A

Water Sampling Design Problem-Solving Cycle

The problem-solving cycle** is an iterative approach that involves brainstorming, constructing matrices, analyzing and testing until the optimal solution is reached. It is important that all steps be done in order.



1. State the Problem

Enter the creative problem-solving cycle with a statement of a problem that pertains to a specific topic. It may take any of these forms:

an open-ended question

an existing condition in need of change

a kit of materials provided to design and build something

a research proposal for a student project

Teachers are encouraged to select age-appropriate topics for their students, keeping in mind their particular enthusiasms and environments. Think of yourself, the teacher, as a customer with a problem in need of a solution. Small groups of students become team problem solvers.

2. Redefine the Problem

The problem solvers should assume that the initial problem comes to them reflecting the bias of their customer and also his/her preconceived notion(s) of a desired solution. Therefore, the problem solvers must question the customer and redefine the problem in a "cleaner" form.

The new problem statement is less ambiguous; it is open-ended and not constrained by the customer's preconceived solution.

3. Identify Constraints and Set General Specifications

Once the problem solvers have a clear understanding of the customer and his/her needs, brainstorming will help generate a list of specifications that will establish the constraints the solution must meet. Some constraints (moral, legal, ethical) may apply to any problem, not just this one.

The first time through the cycle, the specifications will be general in nature. For optimal effectiveness, each should be defined, quantified and justified.

4. Identify Alternative Solutions

Brainstorm possible solutions to the problem using established specifications and constraints. Brainstorming is a free flow of ideas without criticism, since this would hinder tapping into the group's innate creativity. A long list assures the problem solvers that another solution can be found should a first or second choice fail.

5. Select the Most Viable Alternative

In order to identify those advantages which will have the most favorable impact on this client's energy costs, we must weigh the advantages and disadvantages of each alternative. To do this, we create a matrix by examining the brainstormed list of alternatives, categorizing them according to broad similarities. (In this case, all alternatives are either new energy sources, changes in efficiency, or lowering of energy losses.) A qualitative or quantitative scale should be established to judge the merits of each alternative against each specification. The matrix analysis yields a pool of alternative solutions that may be ranked from most to least desirable. The best alternative is selected based on the results of this analysis.

In constructing and analyzing the matrix, problem solvers may have engage in some experimentation. They certainly will have to do market and technical research, either in the library or by telephoning outside sources such as companies and trade associations.

6. Redefine the Problem

The highest-ranking alternative is re-evaluated by redefining the problem as necessary.

7. Refine and Add Specifications

Brainstorm to develop refined specifications for the alternative selected. In this second iteration, the specifications should be more specifically defined, quantified and justified relative to the alternative solution which has been chosen.

8. Brainstorm Alternatives

Using the refined and more-focused specifications, additional appropriate alternatives should be generated.

9. Reiterate Until the Problem Is Solved

The redefined problem now is to determine the best method to insulate thematic and the windows. So, a new set of specifications is developed.

10. Select the Most Viable Alternative

Establish a new matrix based on the new specifications and alternatives. Analyze the alternatives and re-rank from the best to the least desirable.

** Based on the Dartmouth/Thayer approach to engineering problem solving.

Teacher Supplement A1

Water Sampling Design Problem-Solving Cycle - Sample

1. State the Problem

Students are given the following problem:

“Build and test a device for retrieving water samples from the rock ledges along a creek. Samples will be taken at various depths from the sides of the creek to midstream. “

This problem is based on a scenario of a mysterious fish kill within a stream. Students will be given a kit of materials from which they will design and build a water sampling device.

2. Redefine the Problem

As students read the scenario and examine the kit of materials, questions for the teacher will arise. As they obtain more information, the student teams will most likely revise the problem.

An example of a new version of the problem may be:

“Build and test a device for retrieving water samples from a height of 2-15 feet and a horizontal distance of 1 - 10 feet using only the materials found in the student design kit.”

3. Identify Constraints and Set General Specifications

Once the team has a better understanding of the problem, brainstorming will help generate a list of specifications that will establish the constraints the designed device must meet. Some constraints may include:

- *cost*
- *vertical requirements of sampling*
- *horizontal requirements of sampling*
- *time for samplings*
- *accuracy of sampling*
- *safety*
- *device durability*

4. Identify Alternative Solutions

Based on the materials in the kit and established specifications and constraints, students will brainstorm different ideas for constructing their sampling device. The kit includes materials

that should allow teams to build a variety of devices. A list of all possibilities should be created that should include sketches of the proposed alternatives.

5. Select the Most Viable Alternative

In order to select the best alternative, the students must determine the advantages and disadvantages of each alternative device. To do this, the students will create a matrix by examining the brainstormed list of alternatives, categorizing them according to the previously determined specifications. A qualitative or quantitative scale should be established to judge the merits of each alternative against each specification. The matrix analysis yields a pool of alternative solutions that may be ranked from most to least desirable. The best alternative is selected based on the results of this analysis.

As an example, students may rank each specification for each alternative on a scale of 1 to 3 as follows:

- 1 - poor
- 2 - acceptable
- 3 - good

Using the following matrix they can then select the best alternative based on the results of the analysis.

Alternatives	Specifications							TOTAL
	cost	vertica 1 spec.	horiz. spec.	time	accuracy	safety	durability	
Bill's idea	2	2	2	2	3	3	2	16
Mary's idea	1	2	1	2	2	3	1	12
Ted's idea	3	2	3	2	2	3	3	18
Marsha's idea	2	3	1	1	3	3	1	14

6. Redefine the Problem

Students will want to redefine the problem in terms of how their particular design will be used to sample the water.

7. Refine and Add Specifications

As students construct and test their device, they will need to refine, eliminate, or add specifications based on their particular device.

8. Brainstorm Alternatives -

Using the refined and more-focused specifications, choices in design modifications may need to be made. Students should make a list of possible alternatives.

9. Select the best alternative

If there are several alternatives, they should again develop a matrix to select the best alternative .

10. Reiterate until the device is complete.

Teacher Supplement B

<p style="text-align: center;">Content Standards & Performance Indicators for Water Sampler Design Challenge</p>

Standard 1: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

1. The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Students:

- elaborate on basic scientific and personal explanations of natural phenomena, and develop extended visual models and mathematical formulation to represent their thinking.
- work toward reconciling competing explanations; clarifying points of agreement and disagreement.
- coordinate explanations at different levels of scale, points of focus, and degrees of complexity and specificity and recognize the need for such alternative representations of the natural world.

2. Abstraction and symbolic representation are used to communicate mathematically.

Students:

- apply algebraic and geometric concepts and skills to the solution of problems.

3. Engineering design is an iterative process involving modeling and optimization finding the best solution within given constraints which is used to develop technological solutions within given constraints.

Students:

- initiate and carry out a thorough investigation of an unfamiliar situation and identify needs and opportunities for technological invention or innovation

Standard 5: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

1. Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints.

Students:

- initiate and carry out a thorough investigation of an unfamiliar situation and identify needs and opportunities for technological invention or innovation.

- generate creative solution ideas, break ideas into the significant functional elements, and explore possible refinements; predict possible outcomes; choose the optimal solution to the problem, clearly documenting ideas against design criteria and constraints; and explain how human values, economics, ergonomics, and environmental considerations have influenced the solution.
 - coordinate explanations at different levels of scale, points of focus, and degrees of complexity and specificity and recognize the need for such alternative representations of the natural world.
2. Technological systems are designed to achieve specific results and produce outputs, such as products, structures, services, energy , or other systems.

Students:

- explain why making tradeoffs among characteristics, such as safety, function, cost, ease of operation, and environmental impact, is necessary when selecting systems for specific purposes.

Standard 6: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

1. In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs.

Students:

- use optimization techniques to determine optimum solutions to problems that can be solved using quantitative methods.
- analyze subjective decision making problems to explain trade-offs that can be made to arrive at the best solution.

Standard 7: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

1. Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

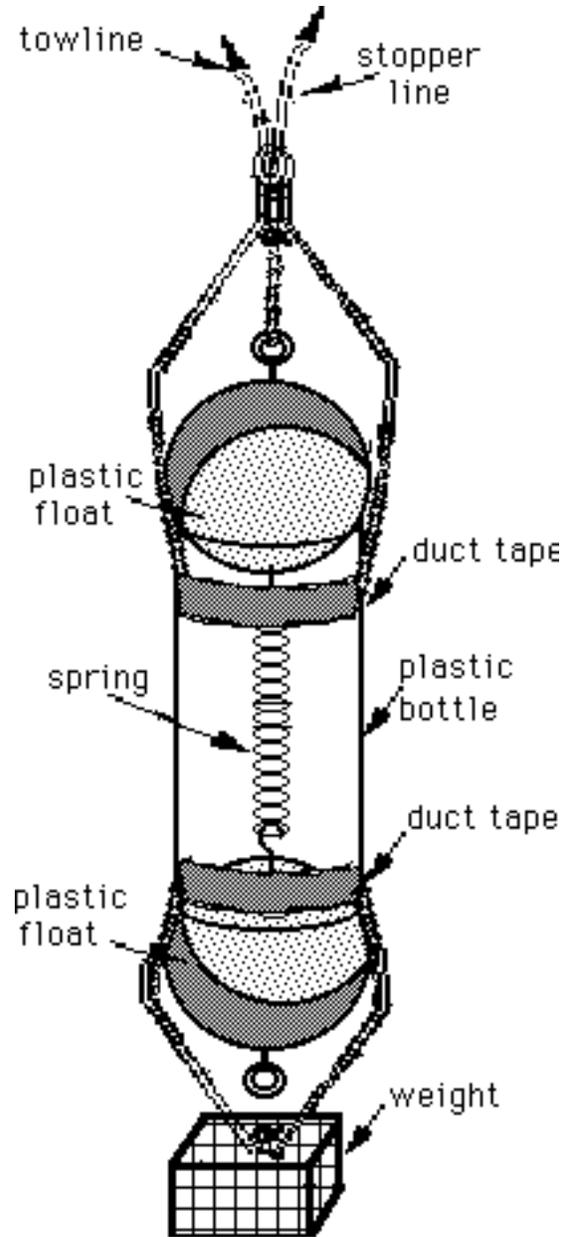
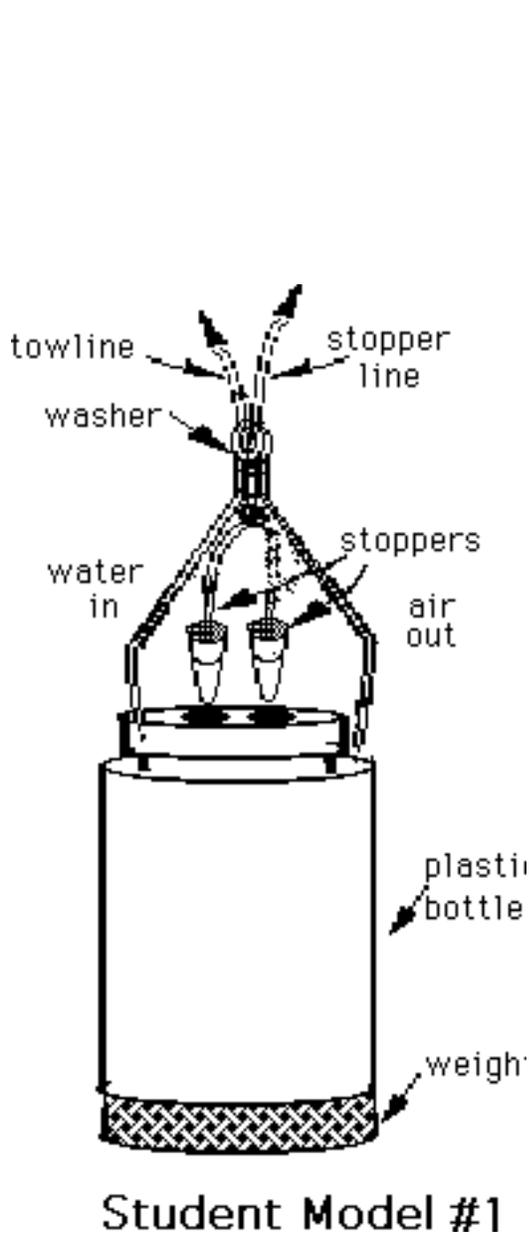
Students participate in an extended, culminating mathematics, science, and technology project. The project would require students to:

- work effectively
- gather and process information
- generate and analyze ideas

- observe common themes
- realize ideas
- present results

Teacher Supplement C

Sample Student Water Sampler Designs



Teacher Supplement D**Water Sampler Presentation Rubric**Presenters: _____

Assessed by: _____

Date: _____

Assessment Scale

- 5 - Exceeds minimum requirement**
4 - Satisfies minimum requirements
3 - Minimum requirement questionable
2 - Does not meet minimum requirement
1 - no evidence for assessment

Presentation Criteria	Evaluation	Wgt.	Pts
The cost of sampler is less than \$10.00	1 2 3 4 5	1 3 5	
Building time for the water sampler is less than 30 minutes	1 2 3 4 5	1 3 5	
Sampling trials can be made within 5 minutes	1 2 3 4 5	1 3 5	
The sampler can be used to obtain water samples from different depths with high precision	1 2 3 4 5	1 3 5	
The sampler can be used from shore and extend horizontally to a distance of 10 feet	1 2 3 4 5	1 3 5	
There is no mixing of water from other depths	1 2 3 4 5	1 3 5	
Your sample volume is greater than 100 ml	1 2 3 4 5	1 3 5	
Your water sampler is easy to handle and operate	1 2 3 4 5	1 3 5	
Your water sampler is capable of performing several trials without repair	1 2 3 4 5	1 3 5	
Your water sampler is safe to handle and operate	1 2 3 4 5	1 3 5	
Overall quality of presentation	1 2 3 4 5	1 3 5	

Overall quality of the presentation	1	2	3	4	5	1	3	5	
TOTAL									

Teacher Supplement E

****Characteristics of an Effective Team**

- The atmosphere tends to be informal, comfortable, and relaxed
- There is a lot of discussion in which virtually everyone participates, but it remains pertinent to the task of the group
- The task or objective of the group is well understood and accepted by the members. There will have been free discussion of the objective at some point until it was formulated in such a way that the members of the group could commit themselves to it.
- The members listen to each other. Every idea is given a hearing. People do not appear to be afraid of being foolish by putting forth a creative thought even if it seems fairly extreme.
- There is disagreement. Disagreements are not suppressed or overridden by premature group action. The reasons are carefully examined, and the group seeks to resolve them rather than to dominate the dissenter.
- Most decisions are reached by a kind of consensus in which it is clear that everyone is in general agreement and willing to go along. Formal voting is at a minimum; the group does not accept a simple majority as a proper basis for action.
- Criticism is frequent, frank, and relatively comfortable. There is little evidence of personal attack, either openly or in a hidden fashion.
- People are free in expressing their feelings as well as their ideas both on the problem and on the group's operations.
- When action is taken, clear assignments are made and accepted.
- The leader of the group does not dominate it, nor on the contrary does the group unduly defer to the leader. In fact, leadership shifts from time to time depending upon the circumstances. There is little evidence of a struggle for power as the group operates. The issue is not who controls but how to get the job done.
- The group is conscious of its own operations.

**** INTEGRATING SCANS SKILLS AND COMPETENCIES ACROSS CURRICULA**