Introducing Environmental Problem Solving as a Means of Increasing Interest in Science and Engineering

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Summary

A project-based program was implemented last fall to increase the interest and knowledge of middle school students in science, math and technology through the solution of an environmental problem that is relevant to their local school community. Nine Clarkson students developed curricula for 7th and 8th grade science and technology classes. Clarkson students then worked with the middle school students throughout the year to reduce the solid waste generated from their school cafeteria through composting. The solution to this problem provided a vehicle to teach fundamental science and math content as well as the process of doing science and solving problems.

Overview and Objectives

Through Clarkson's *Project-Based Learning Partnerships*, new curricula for middle school science and technology classes have been developed to expose middle school students to the societal impacts and mitigation of environmental problems. The concept of *project-based* learning incorporates a "big-picture" approach to enhancing science, math and technology knowledge, critical thinking, and problem solving skills. Project-based learning requires students to understand a problem, with all of the fundamental science, societal, ethical and other constraints, prior to assessing and implementing a solution.

The goal of Clarkson's *Project-Based Learning Partnership* program is to provide training to K-12 fellows who can then enhance the teaching of science and technology classes in area school districts. Because of this primary goal, the K-12 student will have an increased interest and appreciation for these subjects and improved critical thinking skills. The following objectives were defined to achieve its goals:

- Train graduate and advanced undergraduate student fellows in teaching and communication skills, and project-based learning approaches;
- Prepare college students to deliver science, math and technology concepts by effectively using hands-on activities in the classroom;
- Engage K-12 students via active learning through project-based learning as a means to enhance their interest and competency in science, math and technology concepts;
- Work in collaboration with area schoolteachers and administrators to establish these curricula in to meet local needs;

Clarkson has used our highly qualified graduate and advanced undergraduate students to bring relevancy, attractiveness, and interrelationships of science, mathematics, engineering, and technology education to middle school classrooms. Clarkson students in the first year of this partnership program were trained during the summer of 2000 and entered the classroom in the fall of 2000. They interacted with students and teachers at three local school districts in 7th and 8th grade science and technology classes. The partnership program currently focuses on the issue of solid waste disposal at the schools. The use of composting as an effective means of transforming this waste product into a valuable product illustrates the solution of an environmental problem as well as the relevance of the life and physical science curricula taught at the middle school level. Additional details about this program are available at http://www.clarkson.edu/k12.

Background

Experiential and interdisciplinary learning techniques are just gaining a foothold in science education [1-4]. Trends in teaching with problem-based learning (PBL) concepts require students to tackle a problem: "Here's a broken toaster, fix it," rather than listen to a lecture on the conduction of electricity through a resistor [5]. Whereas PBL approaches often tackle discrete problems that can be addressed in a few class sections, the extension of this concept to *project* based learning incorporates a much "bigger-picture" approach to enhancing an understanding of science content, critical thinking, and problem solving skills. Project-based learning requires students to understand a problem, with all of the fundamental science, societal, ethical and other constraints, prior to assessing and implementing a solution [6].

Interdisciplinary team-based projects and project-based learning have also been shown to improve the understanding of basic concepts and to encourage deep learning, creativity, and a broader knowledge base, as well as developing team work and communication skills. Opportunities to simultaneously learn and apply theory to practice improve student performance and motivation [1].

*Perry's Model of Intellectual Development is concerned first with how students move from a *dualistic* (right vs. wrong) view of the universe to a more *relativistic* view (incorporating complex thinking), and second, how students develop commitments within this relativistic world. For more information, see (Perry, 1970[10]).

The goal of the holistic project-based curricula developed through this program is to prepare students to embark on a career in which their success is conditional on life-long learning, critical thinking and decision making, teamwork, leadership, and commitment [2]. Our approach targets a wider range of student learning styles than a more traditional approach involving lectures and rote learning. In fact, according to Perry's Model of Intellectual Development* as applied to science and engineering education, the most powerful learning is enabled by coursework that is less structured and provides a diversity of learning tasks. Team-based projects and case studies are recommended [7]. Solving problems in the classroom can be used to illustrate the relevance of student's science coursework to the "outside" world. This has been shown to be especially important in attracting young women to these fields [8]. The curricula presented here incorporate communication, social, environmental, and other people-related needs into science and technology learning activities. Emphasizing the usefulness that science and engineering has for improving peoples' lives can persuade a wider range of young students to study these fields [9].

Real world problem solving involves an understanding of the complex interaction among various fundamental sciences, environmental, social, economic and ethical issues as well as computationally based analysis and design. Teaching students to think in a manner that would encompass these issues is needed at all levels of education. Therefore, the holistic approach we use in the classroom address projects that mirror the problem-solving techniques used by practicing engineers and scientists. These include:

- Problem identification and understanding
- Identifying alternatives to solve the problem
- Feasibility assessment leading to a proposed solution
- Implementation of the solution
- Evaluation of the success of the solution

Basic professional skills - oral and written communication skills, teaming skills, research (gathering information) skills, drawing conclusion, and decision making process are also necessary components of the project-based curriculum. The solution of this problem provides a vehicle for teaching fundamental science, math and technology classes in a relevant manner.

Several university-K-12 partnership programs that seek to promote science, math and technology education provide hands-on activities. A few of these programs use activities designed specifically to facilitate an understanding of the influence that these subjects have on the environment and community. However, the inclusion of a holistic, project-based learning approach to engineering problem solving is a unique and innovative aspect of the partnership program developed here. Middle school students are challenged to understand critical issues associated with the problem and then find and implement an acceptable solution.

The types of skills covered in the *Project-Based Learning Partnership Program* are directly related to the applicable educational standards in New York State [11]. The New York State Learning Standards for Mathematics, Science, and Technology include: 1) Analysis, Inquiry, and Design; 2) Information Systems; 3) Mathematics; 4) Science; 5) Technology; 6) Interconnectedness of Common Themes; and 7) Interdisciplinary Problem Solving [24]. Our program is especially strong in addressing the "extended process skills" (Standards 1,2,6 and 7).

Curriculum Development

Project-based curricula that emphasize environmental problem solving skills have been developed for 7th and 8th grade science and technology classes. In New York State, the 7th grade science class focuses on life sciences while the 8th grade curriculum focuses on physical science. The development of the curricula required many compromises. Our program emphasized the *process* of doing science, whereas the textbook and the majority of the state science exam require knowledge of specific science content. Thus, it was critically important that our program fits the needs and covers content required within the state mandated core curricula. The science curricula are composed of a series of units that were taught between September and April. The technology unit was a stand-alone 3-4 week unit. In each curriculum, we took a problem solving approach. For the middle school level, we broke the problem solving approach into four basic steps as illustrated in Figure 1:

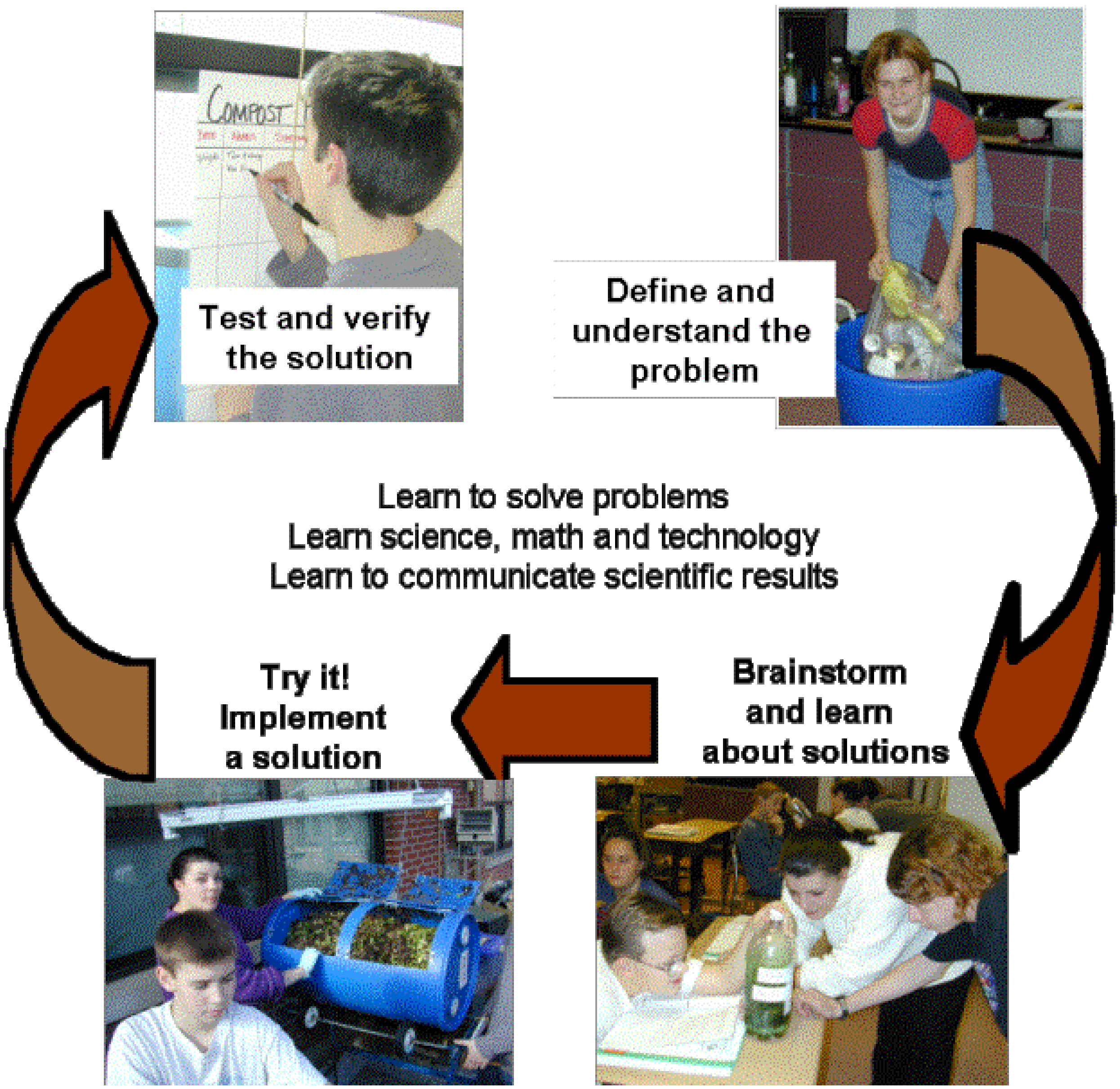

Figure 1: Year-long problem solving process used in the Clarkson Project-Based Learning Partnership Program

At the beginning of the year, the students were posed with a problem statement: Too much solid waste generated in the school cafeteria is sent to a landfill. Wording of the problem we posed was critical in order to guide the students in the direction we wanted to go. Composting became an obvious solution, providing the students not only with an understanding that they can reduce solid waste, but also providing a topic that can be integrated into their required core curriculum. Over the course of the year, the students learned about solid waste, the science of composting, built and used compost bins, tested the quality of the compost they generated, and planted a tree using their final product. Throughout the year, the lessons focused both on solving the problem and on learning the math, science and technology required to solve this problem. Although we found that true problem based learning was difficult with this age group, inquiry-based lessons and other active learning modes were used whenever appropriate. The teachers' needs, NYS standards, 7^{th} and 8^{th} grade textbooks, and new NYS 8^{th} grade science exam were all used as guides and constraints for the development of each lesson.

Tables 1 and 2 summarize the curricula developed in each of the science classes, and Table 3 summarizes the technology curriculum. Most of the activities in the science curricula are not original. The unique aspect of our program was combining them in a manner that they collectively were used to investigate and solve an environmental problem that was relevant to the middle school student. The integration of this project into both the science and technology classes proved to be valuable. This overlap provided an opportunity for reinforcing concepts that were taught as well as illustrating the very necessary interconnections between these subjects. Math concepts were included in both curricula to further introduce the notion that math is indeed useful and relevant to science, technology, and the solution of environmental problems.

The curricula are still evolving. Most notably, we are currently transforming the 8^{th} grade science and technology program to make concrete with a waste material as an aggregate. This will better overlap with the physical science content required at this grade level. These students will make concrete benches in technology class to increase the connection between science and technology. The use of a waste material as a useful product will be a continuing waste reuse theme for the students who made compost from food waste last year. The refinement of these curricula during another year of teaching will be necessary before unit and lesson plans will be ready for dissemination.

Table 1: Seventh grade science curriculum

UNIT 1 – Introduction to solid waste and the problem solving method

- Develop teamwork skills
- Learn an approach to solving problems
- Investigate trash generation at the school
- Understand the flow of solid waste through the community and its ultimate destination
- Examine alternative reduce/recycle options for solid waste

UNITS 2/3 - Microorganisms and biodegradation

- Learn and apply the scientific method
- Build mini-bioreactors to test hypotheses regarding the biodegradability of waste materials
- Design experiments and build larger scale bioreactors to observe food decomposition and the biodiversity of food webs within this biological system

Unit 3a: Communication of Concepts

- Posters made for each aspect of the project
- Open house for classes, parents, community

UNIT 4 – Vermicomposting

- Learn about and observe food degradation by worms.
- Observe worm's digestive system and how soil is produced.
- Measure worm length and apply statistics
- Observe worm response to stimuli to understand habitat

UNIT 5 – Composting as a Solution to Food Waste Problem

- Learn what CAN and CANNOT go into the compost pile
- Trip to cafeteria to assess materials for composting
- Measurements – height, weight, density, volume of wastes
- Fill and rotate bins that they built in technology class

Unit 6 – Wrap up

- Open and inspect compost bins
- View micro and macro organisms
- Use compost (classroom plants, tree or shrub for school etc.)
- Review of yearlong problem solving approach

Table 2: Eighth Grade Science Curriculum

Unit 1: Understanding the Problem of Solid Waste

- •Develop teamwork skills
- •Learn an approach to solving problems and scientific inquiry
- •Investigate trash generation at the school
- •Understand the flow of solid waste through the school
- •Visit waste transfer station to understand ultimate disposal of wastes

Unit 2: Understanding the Properties of Solid Waste

- •Understand and measure mass, volume, density, bulk density, moisture content
- •Make observations and measurements of physical characteristics of the categories of trash
- •Model the flow of trash in their school and community
- •Make paper to understand recycling

Unit 3: Communication of Concepts

- •Posters made for each aspect of the project
- •Open house for classes, parents, community

Unit 4: Compost Management

- •Understand the basic biodegradation and element cycling in compost
- •Research alternatives for best composting
- •Develop a management strategy for filling and testing compost bins built in technology classes

Unit 5: Energy and Chemistry

- •Guest "Chemical Magician" to illustrate importance and careers in chemistry
- •Properties of water affect food and composting (polarity, pH)
- •Elements and compounds of importance in food and compost (N, P)
- •Energy conservation and conversion in food and compost
- •Making and understanding how thermometers work
- •Development of a plan to test the quality of compost

Unit 6: Verify our solution

- •Test moisture content, and temperature of operating compost bins
- •Test chemical composition and pH of compost
- •Use compost on school grounds

Table 3: Technology Curricula

Unit: Compost bin design and construction

- •Learn an approach to solving problems
- •Application of problem solving to compost bin construction
- •Define what is known/unknown about compost bin construction
- •Learn variables that affect composting
- •Investigate qualities of commercially available compost bins
- •Determine appropriate size for compost bins through measurement
- •Brainstorm alternatives for compost bin design
- •Choose best design for compost bin
- •Develop orthographic drawings of bins
- •Develop list of materials required for bin construction
- •Construct compost bin using suitable power tools
- •Evaluate the effectiveness of the bins and suggest modifications

Scientific inquiry, a basic skill for middle school science was integrated throughout the year. Significant improvement was observed in the student's ability to apply the standard scientific method. Figure 2 illustrates an example of incorporating the scientific method into an experiment to understand both biodegradation and the specific conditions needed for composting.

Scientific question:

What conditions do we need for making compost?

Hypothesis:

Moisture, temperature and aeration are important variables that will affect the extent of decay

EXPERIMENTAL DESIGN

Methods:

Build soda bottle bioreactors
Add compost and food material
Observe extent of decay of food items

Variables:

moisture content
air access
temperature

Control:

sterile soil

OBSERVATIONS

- Too much water or no air holes resulted in STINKY compost and little food decay.
- Food did not decay much under cold temperatures
- All bioreactors with compost had some decay
- Control bioreactors did not show any evidence of decay

CONCLUSIONS

- Biodegradation always occurs to some extent when microorganisms are present
- Some moisture, a lot of air, and warm temperatures are needed for best compost

Figure 2: Example illustrating the application of the scientific method into the solid waste reduction project

Implementation of the Program

The development of this *Project-Based Learning Partnership Program* has been made possible through a grant from the National Science Foundation through their GK-12 program. These initial funds provide stipends for the students to develop and teach the curricula, supplies for carrying out the hands-on activities, and the salary of two part-time employees to carry out the administrative aspects of running the program.

The program was planned during the 1999-2000 school year and brought into the classroom in September 2000. The planning process was critical for communication between the program administrators and teachers so that we could devise curricula that meet both of our goals – something that we continue to work to improve. Clarkson students were recruited in the spring of 2000 and 2001 and receive training during the summer prior to their first contact with the middle school students.

Clarkson students worked with middle school students at three school districts in the 2000-2001 school year. The students included 5 undergraduates and 4 graduate students, comprised of engineering (ChE, CEE, MAE, ECE) and science (chemistry, environmental science) and technical communications majors. The multidisciplinary group provided a wide range of expertise for developing and teaching the curricula. We worked primarily with the Colton-Pierrepont Central and Parishville-Hopkinton Central school districts. Both of these districts are small, with the entire K-12 school district under one roof. They are rural, predominantly agricultural communities. Each of these school districts had two sections of each of the classes we worked with. Clarkson students worked in pairs and were generally assigned to two sections of one class. They taught approximately two times per week when both university and K-12 school districts were in session. They also presented a two-week intensive unit to the seventh grade science classes at Potsdam Central School in the spring 2001. Thirteen Clarkson students will teach during the 2001-2002 school year.

During the time the pairs of fellows were in their respective classrooms, they delivered the curricula outlined in Tables 1 though 3. They also had opportunity to interact with the students at a close enough level to mentor students, although this was not a formal component of our program. The fellows' time in the classroom was supplemented by a variety of special events, including:

- Field trip to the local transfer station (8th grade, Colton)
- Slide presentation with discussion of Fellows' college majors and intended professions (Potsdam)
- Open house to show science-fair type posters to parents (Parishville and Colton)
- End of year assemblies to review work, receive awards and certificates, and plant a tree with compost (Parishville and Colton)
- Field trip to Clarkson to see a Chemistry Magic Show and tour freshman physics and biology labs (Parishville and Colton)
- Presentation about composting science by Steven Van der Mark, Cornell Cooperative Extension Service (8th grade, Parishville and Colton)

Training

The Clarkson students are trained for their classroom experiences during the summer before they enter the classroom. Classes are taught by the director of the program and guest speakers. A text covering science instruction in middle schools [12] proved to be a very valuable resource for this class. The students receive three credits for the class and create and analyze one unit that they will teach in the classroom. It is expected that the students have the necessary background in science and technology to teach themselves the content and environmental relevance of the problem they need to understand. Lecture/workshops included:

- Team work
- Components of an effective class and teacher
- Project planning and management

- Problem solving process
- Inquiry based learning, deductive/inductive learning
- Creating unit/lesson plan, defining learning objectives
- Incorporating mentoring into program
- 8th grade science exam and NYS standards – how to incorporate this into our curricula
- Assessment techniques

Journals are used to encourage the fellows to reflect on their learning and own educational experiences. An evaluation of the program by both Clarkson students and their partner teachers indicated that this training was appropriate for the students to enter the classroom as professional scientists and engineers. Their classroom interaction skills improved throughout the year.

Outcomes Assessment

A formal outcomes assessment program is being lead by Dr. Timothy Schwob at the State University of New York, Potsdam College. At this point, the assessment has focused on the teachers and students, not the middle grade students. Anecdotal evidence from parents, however, suggests that the program has increased the students' interest in their science and technology classes. They are also interested in composting and currently arguing over who gets to take the compost bins home for use. A more intensive assessment of the students' attitudes and knowledge base will be conducted next year using journal assignments and development of portfolios.

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