Creating Project-Based Learning Experiences for University- K-12 Partnerships

Susan E. Powers and Jan DeWaters
Center for the Environment, Clarkson University
Potsdam NY 13699-5715, sep@clarkson.edu; dewater@clarkson.edu

Abstract - The development of University – K-12 partnerships to promote increased interest in and knowledge of STEM (science, technology, engineering and math) disciplines requires well-planned and implemented curricular content. The content must meet several constraints, including interest to the partner-teacher, relevance to the students to help engage them, and consistency with state and national standards. Through four years of experience, we have developed a process to create new project-based experiences that are used by college students who teach in middle school classrooms. The process involves input from partner-teachers, development of activities and lessons by college students, and oversight and refinement of the content by program administrators. The project-based learning approach is consistent with national and state standards and has been shown to improve the understanding of basic concepts, to encourage deep and creative learning, and to develop teamwork and communication skills. The essential elements of the development process for our project-based curricula are included here.

Index Terms – curriculum development, K-12 outreach, project-based learning.

INTRODUCTION

Through partnerships with the National Science Foundation, the GE Foundation, and several local school districts, faculty and students at Clarkson University have developed 3- to 10-week long project-based units for middle school students in science and/or technology classes to increase their awareness and aptitude for math, science, and engineering. The project-based approach we've used replicates our success in utilizing project-based learning to educate multidisciplinary undergraduate teams.

We are completing the program’s fourth year with active involvement of graduate and undergraduate Fellows in partnership with teachers in middle school science and technology classrooms. Projects developed and taught through this program expose students to societal impacts and mitigation of environmental problems. The project-based learning (PBL) approach, which is gaining a foothold in engineering education [1-4] looks at the “big-picture” to enhance STEM (science, technology, engineering and math) knowledge, critical thinking, and problem solving skills. In contrast to typical superficial coverage of technical topics in middle school curricula, PBL requires a depth of understanding and application [5]. Our PBL curricula mirror techniques used by practicing engineers and scientists by requiring students to tackle and solve a real-world problem. The process requires an understanding of the complex interaction among various technical, environmental, social, economic and ethical issues [6].

The relevance that project-based education provides is an important factor in impacting a broader pool of students, in terms of student ability as well as student interest levels. The PBL approach targets a wider range of student learning styles than a more traditional pedagogy involving lectures and rote learning [7,8]. Our program has operated on the hypothesis that using project based learning methods can persuade a more diverse range of young students to study STEM fields by emphasizing the usefulness of science and engineering to society [9].

A holistic or project-based learning approach to engineering and science tends to make quantitative subjects more "female friendly," by bringing relevancy and connectivity to their coursework and to the outside world. Studies have shown that many women capable of pursuing engineering careers opt for a liberal arts college instead, because they perceive it as offering a more "interesting or relevant environment,"[10] whereas their perception of “relevance” in engineering coursework is a large factor in keeping women enrolled in engineering [11]. The benefits of this approach are not limited to female students. Indeed, much of the education reform efforts of the 1980s and 1990s were aimed at bringing an integrated, hands-on approach to the teaching of math and science, to make these subjects more relevant and tangible [12-16].

PROGRAM DESCRIPTION

Clarkson University has been working with four schools in Northern New York State to develop curricula that use environmental problem solving as a means of introducing engineering problem solving skills, integrating the fundamental math, science and technology concepts required to solve these problems. We have developed two separate projects that challenge students to consider environmental impacts in their engineering decision making as they explore
The objective of this paper is to outline the approach we've used to meet these constraints to develop projects for University K-12 outreach programs. Examples from our Engineering for the Environment curriculum are used to illustrate these points.

**Table 1**

<table>
<thead>
<tr>
<th>OUTLINE OF CONCEPTS AND PROJECTS INCLUDED IN THE ENVIRONMENTAL PROBLEM SOLVING CURRICULUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction to Solid Waste Problems &amp; Solutions</td>
</tr>
<tr>
<td>• Definitions and statistics about solid waste generation, including an historical perspective of the impacts technology and society have had on waste generation.</td>
</tr>
<tr>
<td>• Understanding how nature handles solid waste</td>
</tr>
<tr>
<td>• Current technological solutions: Landfills, 3-R's</td>
</tr>
<tr>
<td>• Problem solving approach</td>
</tr>
<tr>
<td>• Defining products we can make from solid waste</td>
</tr>
<tr>
<td>2. Vermicomposting for Biodegradable Wastes</td>
</tr>
<tr>
<td>• Biodegradation</td>
</tr>
<tr>
<td>• Scientific method</td>
</tr>
<tr>
<td>• Engineering a system to improve rates – Vermicomposting</td>
</tr>
<tr>
<td>• Using the Web as a research tool</td>
</tr>
<tr>
<td>• The design process – Vermicomposting bins</td>
</tr>
<tr>
<td>o Drawing</td>
</tr>
<tr>
<td>o Assembly and flow charts</td>
</tr>
<tr>
<td>o Construction</td>
</tr>
<tr>
<td>• Implementation – Technologies based on living systems – the constraints of keeping it alive</td>
</tr>
<tr>
<td>3. Non-biodegradable Wastes as Aggregates in Concrete</td>
</tr>
<tr>
<td>• Concrete basics</td>
</tr>
<tr>
<td>• Material properties</td>
</tr>
<tr>
<td>• Making Concrete &amp; Safety</td>
</tr>
<tr>
<td>• Forces &amp; Stress</td>
</tr>
<tr>
<td>• Testing for engineering decisions – Breaking cylinders</td>
</tr>
<tr>
<td>• Weighted objectives table for engineering decisions</td>
</tr>
<tr>
<td>• Concrete Product Production and Evaluation</td>
</tr>
<tr>
<td>4. Marketing Our Product</td>
</tr>
<tr>
<td>• Introduction To marketing</td>
</tr>
<tr>
<td>• Importance of communication in engineering</td>
</tr>
<tr>
<td>• Understanding the value of our products</td>
</tr>
<tr>
<td>• Developing &amp; presenting a marketing plan</td>
</tr>
</tbody>
</table>

Teaching with project-based learning requires students to tackle a problem. The PBL approach is consistent with national and state standards and has been shown to improve the understanding of basic concepts, to encourage deep and creative learning, and to develop teamwork and communication skills.

There are two ways to integrate a project into a curriculum. The problem statement can be introduced early and used as a motivator to promote the development of fundamental knowledge and comprehension as the students progress towards application and synthesis of this knowledge into their solution. Or, the project can be introduced later and used as a culminating experience that focuses on the application and synthesis of materials learned earlier. In this case, the project is typically used as an assessment tool. Student ownership of the project is closely related to their sense of the project’s relevance, which is a key mechanism for engaging their increasing their interest in STEM. Through experience with both types of projects, we believe that the former approach, introducing the problem early in the curriculum, provides a better motivator for learning because the STEM concepts are relevant to the problem at hand, at the time they are introduced.

The most important attributes we believe important in a PBL curriculum are:
- Tackles a real-world problem that is relevant and of some interest to the student
- Has clearly defined goals, milestones and criteria for successful completion
- Requires effective team interactions
- Promotes critical thinking
- Integrates prior knowledge from STEM classes
- Requires understanding and integration of new STEM concepts at appropriate content level
- Allows students choices and decisions at multiple points in the problem solving and design process and requires students to defend their choices
- Requires engineering problem solving and design approaches.
- Expect the students to communicate aspects of their project development and solution through written reports and oral or poster presentations
- Has a tangible and “real” end product that helps students value their accomplishments.

Balancing the open-ended nature of true PBL with constraints imposed by time limitations, material and supply requirements, and the discomfort of some teachers with non-traditional pedagogical approaches has been a significant challenge.
challenge in our program. In our projects, it seems that the required time for project completion increases exponentially with the number of choices the students are expected to make. When working within a limited time period, allowing the students too many choices detracts from the time they have for developing the required level of knowledge and comprehension and the time for communicating their results. On the other hand, allowing students freedom to make their own decisions is critical to their feeling of “ownership” of, and hence enthusiasm for, the project. We have addressed this hurdle through the use of a series of short-term experiments and research activities that help the students step through different phases of the overall problem solving process. Each of these steps provides the students with an opportunity to make decisions and present their findings, without letting them get too far astray from time and material constraints.

In one of our projects, students are challenged to “make something valuable from the non-biodegradable components of their waste stream.” The possibilities are very wide. For example, they could choose to create a sculpture from trash. Obviously, not all possible solutions lead the students to the science and technology discovery needed to meet their state standards. Thus, we use a range of props and verbal direction (indicating that they must construct a product in their technology class) to steer them towards the idea of making a concrete product with waste material incorporated as an aggregate. Table II summarizes some of the activities included in this unit along with the student-centered decisions.

**PROCESS FOR DEVELOPING PROJECT-BASED CURRICULA**

The identification and development of a particular project and associated student activities such as the set of projects shown in Table II requires a lengthy process involving input and iterations from several involved parties.

The essential elements of the development process for our project-based curricula include:

- Exploration with teachers of the topical areas around which a project-based experience can be developed;
- Identification of the Concepts that can be covered in such a unit based on pertinent standards and students’ textbooks;
- Development of Learning Objectives that reflect the concepts and provide a basis for assessment;
- Literature review and experimentation to develop hands-on Activities and projects to achieve the learning objectives that promote creativity, inquiry and critical thinking skills;
- Creation of a concept map to help logically integrate the activities into an outline and set of cohesive lessons;
- Mapping of lesson content to appropriate national and state standards; and,
- Brainstorming to identify relevant and real-world problems that can be tackled and solved using the knowledge acquired in the set of activities and lessons.

This process is necessarily iterative in nature. The material included below has been culled and refined from two excellent sources that are recommended for further reading [18,19].

**Topics and Key Concepts**

Teachers and school districts are under increasing pressure to integrate state and national standards into every lesson they teach. There is little opportunity to stray beyond these constraints. Thus, the development of curricular material for any University – K-12 partnership program must understand and integrate these standards as much as possible. State MST standards (e.g., [20]) are sometimes more stringent and detailed than the national counterparts [21,22,23]. Many PBL projects, such as the one highlighted in Tables I and II, for example, contribute most extensively to what New York State defines as the “extended process skills,” which include:

- Standard 1 – Analysis, Inquiry and design
- Standard 2 – Information systems
- Standard 6 – Interconnectedness: common themes
- Standard 7 – Interdisciplinary problem solving

NYS Standards 3, 4, and 5 correspond to math, science and technology content. These “content” standards are often the primary focus of many classes that are taught with more traditional pedagogical approaches. By focusing on the some of the process oriented standards, the PBL partnership that we provide can contribute substantially to the overall learning needs in the classroom.

The NYS standards are broken into key ideas and performance indicators for elementary, intermediate and high school levels, thereby providing clear direction regarding the scope and depth of what we should consider covering in our PBL curricula. Consider, for example, standard 1, related to scientific inquiry. Key idea 1: “the central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing creative process,” is correlated to a performance indicator: “students should be able to independently formulate a hypothesis.” Thus, many of our inquiry-based activities focus on the skills and process required to formulate a hypothesis.

The topical areas of coverage within our curricula were chosen in concert with our partner teachers. Based on our objectives related to using environmentally based topics to engage a wider range of students, we have proposed topics to teachers, who then discuss options and provide feedback on what would best fit their interests and needs. We have limited ourselves to one new topical area in a given year. We are currently piloting a unit on sustainable energy and have requests for units on water quality and treatment.

The overlap between performance indicators defined by standards and ideas about a topical area are used to define the Key Concepts for the unit. These concepts describe the essential ideas students must understand and apply. For the concrete project, an example key concept is stated as – “Measuring material properties can help an engineer decide which material is best. In our case, the compressive strength of concrete is most important.”
Learning Objectives

Learning objectives are clear, concise descriptions of what the learner should be able to do, know, or believe at the end of the defined period of time [19]. A project management approach to defining objectives [24] can also be applied to learning objectives. The “SMART” approach requires objectives that are:

- **Specific**
- **Measurable**
- **Attainable**
- **Realistic**
- **Time-limited**

The focus on a “measurable” objective is required to maintain a close connection between learning objectives and student assessment. Verbs such as “understand” are not suitable for learning objectives; they are neither specific nor measurable. A learning objective such as: “At the end of this unit, students will be able to describe how the strength of concrete is tested,” utilizes a more specific and measurable action verb.

Given the nature and goals of PBL, we expect that learning objectives should encompass the entire range of Bloom’s taxonomy of learning (knowledge, comprehension, application, analysis, and synthesis). These higher order thinking skills are necessary to meet the extended process skill standards.

It is critically important to identify key concepts and learning objectives before planning specific curricular activities. It is from these concepts that we know what must be covered and in what depth. They are also the most critical elements that provide a basis for student assessment.

**Activity and Project Development**

As University-educators, we often begin to think about K-12 outreach first through the activities we imagine bringing into K-12 classrooms. While some thought about activities is appropriate, we must be careful to make sure that the concepts and objectives are defined before activities are developed extensively. As discussed above, we’ve found that tackling PBL through a set of clearly defined activities is a reasonable approach to complete an open-ended problem given the time and resource constraints in most classrooms. The activities must fit these needs and must flow together in a logical manner so that they are transformed, from isolated activities we do in K-12 classrooms, into a cohesive curriculum that helps our partner teachers and school districts meet their own educational priorities.

There are a wide variety of resources that help us develop a series of activities within a topical area that meet the needs defined by the concepts and objectives. We have held workshops with partner teachers to brainstorm about possible activities and associated project definitions required to tie the activities together in a PBL curriculum. Teachers are especially knowledgeable about the realistic expectations we can expect of their students and the time frame that different activities will take. Once general ideas are defined, there is a wealth of potential projects available through Internet resources that can help to initiate project development. We have relied especially heavily on state and federal government agencies (e.g., U.S. EPA, and DOE), many of which have special resources for students and teachers. Our graduate and undergraduate Fellows have done the bulk of this searching and playing with activities to find and adapt materials that specifically meet the concepts and learning objectives defined for our curricula.

Attributes that each individual activity must meet are similar to those defined above for the entire project-based curricula. They must require critical thinking, inquiry, communication, and must allow for student choice and decisions – on a smaller scale than what is expected for the entire curriculum.

**Integration into a Cohesive Unit**

The series of activities must be tied together with a modest amount of instruction-oriented lessons to meet the objectives defined for the unit. Following a standard problem solving method, such as defined in a middle school textbook (Figure 1) [25], is one way to ensure that lessons flow and help the

---

**TABLE II**

**FLOW OF ACTIVITIES THAT LEAD TO SUCCESSFUL PROJECT COMPLETION – CONCRETE PRODUCTS FROM WASTE MATERIALS**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Directed Aspects</th>
<th>Self-directed Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research – “Determine the components and ratios of components necessary for mixing concrete”</td>
<td>Suggested web sites General types of information required</td>
<td>Specific detailed information collected and reported</td>
</tr>
<tr>
<td>Identify and categorize properties of aggregates</td>
<td>Example aggregates provided Material properties defined (ductile, elastic, etc.)</td>
<td>Additional aggregates identified and provided by students for future testing</td>
</tr>
<tr>
<td>Make and break concrete cylinders to determine strength and density</td>
<td>Recipes and aggregates for known successful concrete mixtures Safety procedures Testing methods Excel to be used for calculations and graphing</td>
<td>Students expected to define and test own recipes (variable ratio of components or aggregates) in addition to provided recipes Means of presenting data determined by students</td>
</tr>
<tr>
<td>Weighted objectives table to evaluate aggregates</td>
<td>Concept and process of using weighted objectives table</td>
<td>Choice of criteria and weighting used for evaluation</td>
</tr>
<tr>
<td>Production of concrete product</td>
<td>Choices of molds provided (for financial reasons. Students could have more say in this choice if molds not already purchased)</td>
<td>Which product to choose (sometimes a class choice, typically stepping stones or bench) What to do with product (donate to school; sell for donation to charity)</td>
</tr>
</tbody>
</table>

---

**Notes:**

- **Table II:** Flow of activities that lead to successful project completion – Concrete products from waste materials.
- **Learning Objectives:** The focus on a “measurable” objective is required to maintain a close connection between learning objectives and student assessment.
- **Activity and Project Development:** As University-educators, we often begin to think about K-12 outreach first through the activities we imagine bringing into K-12 classrooms. While some thought about activities is appropriate, we must be careful to make sure that the concepts and objectives are defined before activities are developed extensively. As discussed above, we’ve found that tackling PBL through a set of clearly defined activities is a reasonable approach to complete an open-ended problem given the time and resource constraints in most classrooms. The activities must fit these needs and must flow together in a logical manner so that they are transformed, from isolated activities we do in K-12 classrooms, into a cohesive curriculum that helps our partner teachers and school districts meet their own educational priorities.
- **Integration into a Cohesive Unit:** The series of activities must be tied together with a modest amount of instruction-oriented lessons to meet the objectives defined for the unit. Following a standard problem solving method, such as defined in a middle school textbook (Figure 1) [25], is one way to ensure that lessons flow and help the

---

0-7803-8552-7/04/$20.00 © 2004 IEEE 34th ASEE/IEEE Frontiers in Education Conference F3D-21
students through the problem solving process. Two general curriculum development tools can assist in the creation of a curricular unit: the unit plan and a concept map (Figure 2). The concept map is similar in objective to an outline, but provides a more visual picture of the components, including all of the interconnections, that are difficult to show in a standard linear outline.

The concept map is an integral component within the overall unit plan. This plan also includes an overview of the material and its importance to set the stage for instruction, key concepts, learning objectives, a table matching these objectives to suitable state or national standards, a day-by-day plan of activities required to meet the objectives and a plan for assessing student learning. The completed unit plan is an effective tool for communicating plans and the value of the PBL experience with teachers and school districts. Unit plans for our curricula are available at http://www.clarkson.edu/k-12.

SUMMARY

An on-going program that brings environmental problem-solving curricula to middle school students has been designed to help students understand the breadth of activities in scientific and engineering careers. The program utilizes a project-based pedagogical approach to engage the students while meeting the constraints of state and national MST learning standards. Extensive planning is required to develop this type of outreach program in a manner that is well-received by schools and provides greater depth than is often found with programs that employ a series of isolated activities that do not offer the relevance and context that a PBL approach provides.


