CREATING PROJECT-BASED LEARNING EXPERIENCES FOR UNIVERSITY- K-12 PARTNERSHIPS

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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 includes input from partner-teachers, a lot of activity and lesson development 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 team-work and communication skills. The essential elements of the development process for our project-based curricula are included here.*

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

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 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. Through this program, projects have been developed and taught to expose students to the 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. PBL requires a depth of understanding and application in comparison with typical superficial coverage of technical topics in middle school curricula [5]. Our PBL curricula mirror techniques used by practicing engineers and scientists by requiring students to tackle and solve a real-world problem involving an understanding of the complex interaction among various technical, environmental, social, economic and ethical issues [6].

The relevance that project-based education provides is also important for broader impacts. The PBL approach targets a wider range of student learning styles than a more traditional pedagogy involving lectures and rote learning [7,8]. 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,"[9] whereas their perception of "relevance" in engineering coursework is a large factor in keeping women enrolled in engineering [10]. 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 [11].

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. 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 uses environmental problem solving as a means of introducing engineering problem solving skills and 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 consider ways to integrate materials from solid waste streams into a valuable

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product (Table 1). Depending on the school, one or the other or both projects are taught as part of an integrated curriculum. This has included teaching components of the overall curriculum in both science and technology classes at middle school levels.

There are various levels at which "true" problem-based learning (e.g., [17]) can be integrated into classroom activities. Based on the direction and choices of our partner teachers, we utilize a directed approach that steers the students towards a solution that ensures consistency with the teacher's needs and our preparation. The identification of suitable projects and integration into a curricular unit requires that we understand and work within the constraints imposed by state and national educational standards, teacher and school district desires, and our own philosophies related to use PBL and environmental problem solving to increase the diversity of students who become more interested in STEM disciplines. 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.

ATTRIBUTES OF A SUCCESSFUL PROJECT-BASED CURRICULUM

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 fundamental knowledge and comprehension as the students build 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 can be used as an assessment tool. Through experience with both types of projects, we believe that the former provides a better motivator for learning.

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
- Allows students choices and decisions at multiple points in the problem solving and design process and requires students to defend their choices
- Expects students to follow engineering problem solving and design approaches.
- Expects 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.

TABLE I
OUTLINE OF CONCEPTS AND PROJECTS INCLUDED IN THE ENVIRONMENTAL PROBLEM SOLVING CURRICULUM

1. Introduction to Solid Waste Problems & Solutions
   - Definitions and statistics about solid waste generation, including an historical perspective of the impacts technology and society have had on waste generation.
   - Understanding how nature handles solid waste
   - Current technological solutions: Landfills, 3-R's
   - Problem solving approach
   - Defining products we can make from solid waste

2. Vermicomposting for Biodegradable Wastes
   - Biodegradation
   - Scientific method
   - Engineering a system to improve rates – Vermicomposting
   - Using the Web as a research tool
   - The design process – Vermicomposting bins
     - Drawing
     - Assembly and flow charts
     - Construction
   - Implementation – Technologies based on living systems – the constraints of keeping it alive

3. Non-biodegradable Wastes as Aggregates in Concrete
   - Concrete basics
   - Material properties
   - Making Concrete & Safety
   - Forces & Stress
   - Testing for engineering decisions – Breaking cylinders
   - Weighted objectives table for engineering decisions
   - Concrete Product Production and Evaluation

4. Marketing Our Product
   - Introduction To marketing
   - Importance of communication in engineering
   - Understanding the value of our products
   - Developing & presenting a marketing plan

Balancing the open-ended nature of true PBL with constraints imposed by time, material and supply requirements, and some teacher's comfort with traditional pedagogical approaches has been a significant 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. Too many choices detract from the time the students have for developing the required level of knowledge and comprehension and the time for communicating their results. We have addressed this hurdle through the use of a series of short-term experiments and research activities that help the students step through 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. But not all possible solutions lead the students to the science and technology discovery they need to meet their state standards. Thus, we use a range of props and verbal direction that they need to build this product in their technology class in order to steer them towards a concrete product with waste material 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

Although the end-point of our development process is the specific project and associated activities (e.g., Table II), a lengthy process is required to lead to the identification and development of a particular project such as this.

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 project 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 through 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].

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

Activity	Directed Aspects	Self-directed components
Research –"Determine the components and ratios of components necessary for mixing concrete"	Suggested web sites General types of information required	Specific detailed information collected and reported
Identify and categorize properties of aggregates	Example aggregates provided Material properties defined (ductile, elastic,etc.)	Additional aggregates identified and provided by students for future testing
Make and break concrete cylinders to determine strength and density	Recipes and aggregates for known successful concrete mixtures Safety procedures Testing methods Excel to be used for calculations and graphing	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
Weighted objectives table to evaluate aggregates	Concept and process of using weighted objectives table	Choice of criteria and weighting used for evaluation
Production of concrete product	Choices of molds provided (for financial reasons. Students could have more say in this choice if molds not already purchased) Amounts of aggregates available defined	Which product to choose (sometimes a class choice, typically stepping stones or bench) Aggregate selection and concrete recipe

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 to 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. Thus, the PBL partnership that we provide can focus on some of the process oriented standards and 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, thus providing clear direction regarding the scope and depth of what we should consider covering in our PBL curricula. For example, under 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 fit their interests and needs the best. We have limited ourselves to one new topical area in a given year. We are also 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 description 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 used for learning objectives. The "SMART" approach requires objectives that are:

- **S**pecific
- **M**easurable
- **A**ttainable
- **R**ealistic
- **T**ime-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 range over 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 to move them from isolated activities we do in K-12 classrooms to 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 – only on a smaller scale than 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 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 a 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.

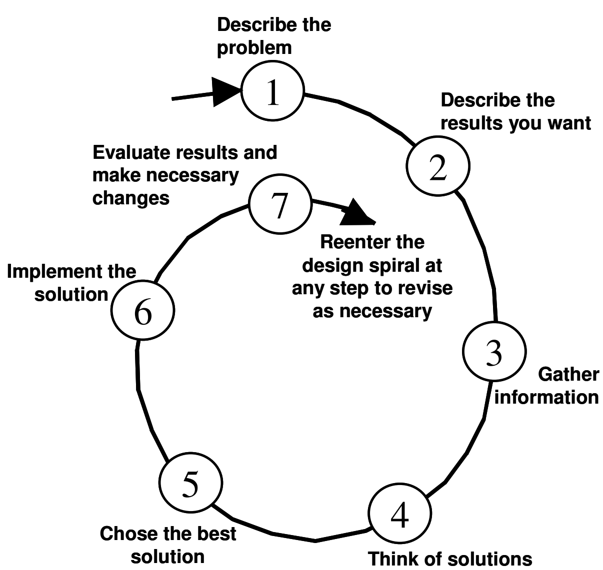

FIGURE 1
AN ITERATIVE APPROACH TO ENGINEERING PROBLEM SOLVING (ADAPTED FROM [25])

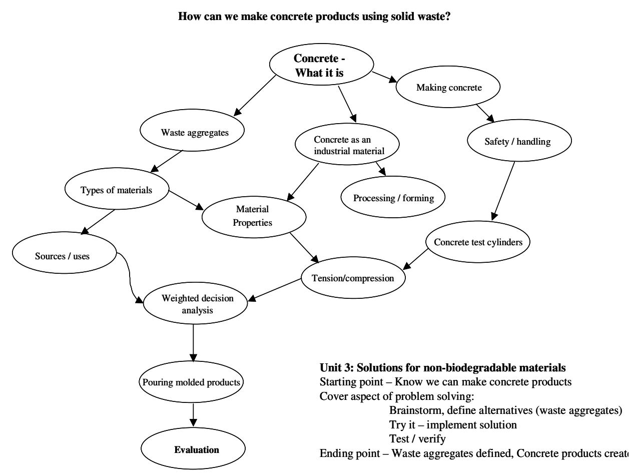

FIGURE 2
CONCEPT MAP SHOWING THE INTERRELATIONSHIPS AMONG MATERIALS PRESENTED IN THE UNIT ON WASTE AGGREGATES IN CONCRETE PRODUCTS

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 often found with programs that focus on a series of isolated activities that do not offer the relevance and context that a PBL approach provides.

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