EPICS: Experiencing Engineering Design
Through Community Service Projects

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ABSTRACT

In the search for ways to simulate "real" design experiences in our classrooms, the model of service learning is often overlooked within engineering. It is, however, a powerful model for learning the engineering design process. At Purdue University the EPICS - Engineering Projects in Community Service – program is doing just that. Under this program, undergraduate students in engineering earn academic credit for long-term team projects that solve technology-based problems for local community service organizations. The program currently has 20 project teams with approximately 250 students participating during the 1999 academic year.

Each EPICS project team consists of ten to fifteen students and is paired with a local community service organization that functions as its customer. Each team has a faculty or industrial adviser. The teams are interdisciplinary including students from Electrical, Computer, Mechanical, Civil, Aerospace, Industrial and Materials Engineering as well as from Computer Science, Chemistry, Sociology, Nursing, Visual Design, English and Education. The teams are vertically-integrated - each is a mix of freshman, sophomores, juniors and seniors - and a student can participate in a project for up to three and a half years. The continuity provided by this structure allows projects to last for many years. Projects of significant size and impact are thus possible.

Four projects are highlighted to illustrate the multidisciplinary aspects of the program. The projects selected illustrate mechanical, civil and electrical hardware and software design in the context of service learning. A discussion of how the program objectives align with the ABET 2000 criteria is also included.

Introduction

The importance of significant design experiences to prepare undergraduate engineering students for engineering careers has been well-documented [1,2]. These experiences should emphasize the application of the technical skills in the classroom as well as the "softer" skills such as communication, working as a team and customer interaction [3-5]. The need for such experiences has spawned many innovative approaches to senior capstone design courses [6,7] as well as design courses for underclassmen [8-11]. The most common model for these courses has

been a one semester experience intended to give the students an intense exposure to the design process.

The model that guided the creation of the Engineering Projects in Community Service (EPICS) curriculum was to involve each student for several semesters or even years on the same long-term project, so that each student would experience varying roles over the course of the project. The emphasis on long-term projects was combined with a goal of undertaking projects that would ultimately be deployed by the customer.

This led to the choice of local not-for-profit organizations as the customers.   Community service agencies face a future in which they must rely to a great extent upon technology for the delivery, coordination, accounting, and improvement of the services they provide. They often possess neither the expertise to use nor the budget to design and acquire a technological solution that is suited to their mission. They thus need the help of people with strong technical backgrounds. Moreover, the community service agencies will ultimately deploy the teams' systems -- an important final step that few commercial partners would take.

Through this service, the EPICS students learn many valuable lessons in engineering, including the role of the partner, or "customer," in defining an engineering project; the necessity of teamwork; the difficulty of managing and leading large projects; the need for skills and knowledge from many different disciplines; and the art of solving technical problems. In working with community agencies, the students are exposed to these agencies and thereby become more aware of the community needs and how their professional expertise can be used to meet those needs. This awareness of the community comes as a natural byproduct of fully understanding their customer, a critical piece of the design process.

The Structure and Phases of EPICS Projects

Each EPICS project involves a team of eight to fifteen undergraduates, one or more community service agencies, and a faculty or industry advisor. Each team is vertically-integrated, consisting of a mix of freshmen, sophomores, juniors and seniors. Each team is constituted for several years -- from initial project definition through final deployment -- with students participating for several semesters.

Students register for the course for either 1 or 2 credits depending on their load in their other courses. In the freshman and sophomore years, students are encouraged to register for 1 credit per semester while juniors and seniors are encouraged to register for 2 credits. The upper division students are expected to serve as the technical leaders on the teams and thereby take on more responsibility.

Each student in the EPICS Program attends a weekly two-hour meeting of his/her team in the EPICS laboratory. During this laboratory time the team will take care of administrative matters or work on their project(s). All students also attend a common one-hour lecture given each week for all EPICS students. A majority of the lectures are by guest experts, and have covered a wide range of topics related to engineering design and community service. The long term nature of the program has required some innovation to the lecture series as students may be involved in the program for up to seven semesters and do not want to hear the same lectures repeated. This has been addressed by rotating the lecture topics on a cycle of two to three years and also by creating

supplements to the lectures called skill sessions, which students can take as a substitute for lectures they have already seen. Examples of skill sessions include such topics as learning to operate a mill or lathe, developing effective surveys and sessions on multimedia software. These have been very popular and we have found that students use this as a way to gain expertise needed for their projects and also as a broadening opportunity (e.g. computer engineering students learn about a mill)

The structure of EPICS enables long-term projects. Over time, each project has five phases: Finding Project Partners, Assembling a Project Team, Project Proposal, System Design and Development, and System Deployment and Support.

Phase 1 - Finding Project Partners: Each EPICS project addresses the technology-based problems of one or more service organizations in the local community. Agencies with appropriate problems must therefore be found. Three criteria are used in matching projects to EPICS teams.

- *Significance*
- *Level of Technology*
- *Expected Duration*

Each year, the EPICS advisers and directors using these criteria select new projects. From five initial projects in Fall 1995, the program has grown to twenty projects in Spring of 2000. Once a project has been selected for the EPICS Program, the service agency that will be directly involved is designated the *Project Partner*.

Phase 2 - Assembling a Project Team: Once a project and Project Partner have been identified, a student team is organized. This is done by advertising the project in undergraduate classes, through academic advisers, call-out meetings and on the World Wide Web. Eight to fifteen students are chosen for each *Project Team*. Depending on the needs of the Project Partner, teams may reflect a single engineering discipline or may be multidisciplinary, including students Electrical, Computer, Mechanical, Civil, Aerospace, Industrial and/or Materials Engineering as well as from Computer Science, Chemistry, Sociology, Nursing, Visual Design, English and Education or other disciplines.

The team must be *vertically-integrated*: it must be a mix of freshmen, sophomores, juniors and seniors. Each student is requested to participate in the project for as many semesters as possible. The combination of a vertically-integrated team and long-term student participation ensures continuity in projects from semester to semester and year to year. Projects can thus last many years if new students, especially freshmen and sophomores, are recruited for the project as team members graduate.

Phase 3 - The Project Proposal: During the first semester of a project, the Project Team meets several times with its Project Partner and the EPICS advisers to define the project and determine its goals. During this phase the Project Team learns about the mission, needs, and priorities of the Project Partner. A key aspect of this phase is identifying projects that satisfy three criteria: the Project Partner needs them, they require engineering design, and they are a reasonable match to the team's capabilities. Also, to ensure that the students build confidence and the Project Partners see progress, the teams are encouraged to pursue a mix of long-term and short-term projects. Short-term projects generally require only one or two semesters to complete; long-term

projects take two or more years. This process of project definition culminates in a written proposal and presentation in the fourth week of the semester. The proposal is critiqued during a lab session, with detailed feedback provided in the areas of organization, content, technical approach, and writing. The proposal must be approved by the EPICS advisers and then be accepted by the Project Partner.

Phase 4 - System Design and Development: Starting from week five of the first semester of a project, the Project Team's goal is to produce a prototype of the hardware/software systems discussed in the proposal. Interaction with the Project Partner continues in order to ensure that the systems being designed and developed are as desired. The formal portion of this interaction takes the form of a written progress report and an oral presentation delivered by the Project Team to the EPICS advisers and the Project Partner at the middle and end of each semester. The progress reports must meet the same standards as the proposals.   This phase of a project lasts as many semesters as necessary for the team to complete the project to the satisfaction of the Project Partner.

Phase 5 - System Deployment and Support: The ultimate goal of each Project Team is to deliver a system to the Project Partner. After fielding a prototype, the team must train representatives of the partner in the use of the system, collect feedback, and make any reasonable changes requested by the partner. One of the hallmarks of the EPICS Program is that the systems designed and built by the students are deployed in the field, where they provide real, needed service to the community.

Sample EPICS Projects

For the Spring Semester, there are 20 EPICS teams. A description of each team can be found in a companion paper [12] and on the EPICS web site at http://epics.ecn.purdue.edu. Summaries of four representative projects with different areas of emphasis within engineering are given below.

The Homelessness Prevention Network Project (HPN)

The Homelessness Prevention Network (HPN) is an alliance of not-for-profit community service agencies in the Lafayette, IN area surrounding Purdue. Its membership currently consists of Lafayette Transitional Housing Corporation, Lincoln Center, the Community and Family Resource Center, the YWCA's Domestic Violence Intervention and Prevention Program, the Salvation Army, the Mental Health Association, Home with Hope, and the Area IV Council on Aging. Its primary goals are to generate an accurate count of homeless individuals and families and to coordinate all services provided by the agencies to each homeless client or family.

To achieve the desired level of coordination of services and sharing of client information, the HPN agencies proposed, as early as 1991, a distributed database linking them together. The obstacles to establishing such a system are raising the funds for the computers and custom software that would be required, determining how and by whom the system would be maintained, and developing the protocols governing the collection and use of the data.

When the EPICS Program was founded in 1995, the agencies requested that a HPN EPICS team be established to design, develop, deploy and support the database system they needed. The team that was created has been in operation for five years now. Over this period, the students on the team have come from a wide variety of disciplines, including Computer Engineering, Computer

Science, Electrical Engineering, Psychology and Sociology. Advisors and teaching assistants for the team have come from Electrical and Computer Engineering and Sociology.

The HPN EPICS team deployed computers and Version 1.0 of its software with the HPN agencies in the Spring of 1997. Version 4.2 was deployed in Spring 1999, with a service pack released in Fall 1999. The entire system was customized to meet the needs of the agencies. Connections between the agencies' machines and the central server are all made at night over standard telephone lines to minimize costs for the agencies. When the database is closed or is transmitted over phone lines it is encrypted according to the government-approved DES standard to ensure the security of the data. Agencies with very strict confidentiality guidelines can select when and to which other agencies the data they enter will be released. A very user-friendly intake form with all fields requested by the agencies was developed in close cooperation with them.

The HPN database in Lafayette, which currently contains data on approximately 4000 people the agencies have served, will continue to be improved over the next few years. These improvements will include continued upgrades and new features that are requested by the agencies, customized client-demographics and services-provided reports for each agency, a LAN version of the software, and enhanced yet simple to use administrative tools for the agencies.

An EPICS program was initiated at the University of Notre Dame in the Fall of 1998. It supports an HPN EPICS team that works with the agencies in the South Bend, IN area. The Purdue and ND teams have met with each other several times to plan the development of protocols to enable data on client demographics and services to be shared between the two cities. This will help determine the extent to which the homeless move between cities and provide continuity in the services they are provided. Long-term goals include a national-scale HPN project that would continuously gather data on homelessness from all cities supported by an HPN EPICS team. If this long-term goal were achieved, the result would be the first truly accurate count and characterization of the homeless and the services they require.

Wabash Center – Greenbush Industries

Wabash Center – Greenbush Industries is a non-profit organization that aims to better the lives of individuals with disabilities. The organization assists these individuals through vocational rehabilitation in an integrated environment. Greenbush Industries offers commercial subcontracting services to local business and industry. The industries contact Greenbush for functions such as the kitting of parts for washing machines, the packaging of medical tubing, or the rebuilding of food processing filters. The revenue generated from these operations provide salary to individuals who may not otherwise be employable in mainstream industry as well as subsidizing other services that the Wabash Center provides such as adult daycare services and assisted living services.

The WCGI EPICS team is in its third semester working with Greenbush Industries. The team for WCGI is a diverse group of people consisting of undergraduate students majoring in mechanical, electrical, and interdisciplinary engineering. Freshmen through seniors have worked on the team adding different perspectives and experience levels to the team. The team advisors include a Staff Mechanical Engineer with ALCOA as well as faculty from the schools of engineering at Purdue.

The WCGI EPICS team works with Greenbush Industries to make the jobs of the people working for Greenbush easier. Since the employees have handicaps such as cerebral palsy, brain trauma, and amputated limbs, many have problems performing their tasks at work. The EPICS team works with these individuals to make fixtures and machines that aid in these tasks. They also look at the process to suggest more efficient manufacturing floor layouts. The students on the team face the challenge of defining the project partner's problem, making observations about the working conditions and the worker's abilities, doing preliminary design, obtaining design approval from the project partner, fabricating the design, and then finally field testing the design. The students have faced real life experiences working with their project partner. For instance, they have faced the challenge of having their design approved only to modify it once the design was installed. However, they have also seen the reward of having an individual with cerebral palsy break into a wide grin and give thumbs up when asked if a new jig was helping him in his work.

The team has already delivered two projects. The first was a fixture that aided in the placement of a clip over airline tubing. The employee who performed this job had problems assembling the clip because his hand shook. The fixture made assembly of the clip easier by guiding the tubing into the clip. The second project was a collapsible coiler reel that was a device for coiling electrical cable. The previous coiler reel was flimsy and collapsed prematurely. The new design was able to hold more weight and collapsed only when a button was pushed. The team is about to deliver a third project that is a mechanical device for tube winding. This motorized device winds pharmaceutical tubing automatically. Two additional projects are in the design phase, a fixture to assist in the placement of rubber grommets in a heat exchanger, and a clamping system and process evaluation for the rebuilding of large food processing filters.

Children's Clinic at Wabash Center (CCWC)

The Children's Clinic at Wabash Center (CCWC) is a not-for-profit organization that provides early intervention programs for disabled or developmentally delayed children and youths. Many of the young children have cerebral palsy. The Clinic works with the children and their families to provide therapies and treatments that enhance opportunities for learning and acquisition of skills. The EPICS CCWC team began in 1995 with a goal of bringing technology to bear on both therapy and play activities. The team started with students from electrical and computer engineering, but quickly expanded to include mechanical engineering students. These have remained the core disciplines on the team. Students from nursing and liberal arts have also participated, as evaluators of how the team's products are used at the Clinic.

The request to the EPICS team from the clinicians at the CCWC was to develop play environments that would achieve several objectives: provide a rich set of multisensory experiences that could be controlled by the disabled child; allow the disabled child to interact with the play environment using modalities consistent with the child's abilities; provide experience with "cause and effect" relations; allow disabled and normally abled children to play together in a cooperative way, with the disabled child in control of some aspects of the play; and be easily stored in the clinic's limited space. Although some commercial products are aimed at children with disabilities, they are typically very expensive. Also, the clinicians have found many of them too simple to engage children for long, and few that encouraged interactive play.

In its five-years of operation, the EPICS team has tackled and delivered several projects to the clinic:

- Custom software that uses a commercial large format input keyboard to allow children to activate animations of faces.
- Animated storybooks using multimedia software.
- Animations of songs and nursery rhymes that incorporate images and voices of the children in the clinic.
- A computer-based sign language tutorial for young children.
- A "pop box" that speech therapists operate by remote control to encourage correct speech.
- A custom interface and set of interchangeable handles for a commercial toy record play to allow children to activate the record player using motions that don't depend on fine motor skills.
- Two rooms of a custom multisensory electromechanical dollhouse.

The dollhouse provides an example of an extended, ambitious project that has integrated EE design, computer interfacing and programming, and mechanical design. The project was initiated at the request of the Clinic's therapists. Several preliminary designs were explored before the idea of a modular, room-by-room construction was adopted. The first system was a kitchen with electronically controlled refrigerator door, lights, and kitchen sounds that a child activates selectively with a large, easy-to-use wired or wireless touch pad. The second-generation system, a bathroom, included electronically controlled toilet lid, swimming/singing rubber duck, lights, and sounds, and added a simple speech recognition interface. The third system, a bedroom, is in progress, and includes a ceiling-mounted rotating mobile, a cupboard with two doors that open, phone and radio sounds, lights, and (at the request of the clinicians) a vibrating bed, so that the children can feel the motion. In addition to the touch-pad and speech interfaces, it will include a custom "finger sensor" interface that activates the bedroom devices when a child successfully inserts a finger into a hole that detects the insertion with infrared emitters and sensors. This new interface is to encourage children to develop their fine motor skills and practice pointing motions.

Each room is a custom plastic box approximately 24" x 10" x 16", with the electronics and motors and housed in a "subfloor" under the room itself. The kitchen and bathroom are currently in use at the clinic, serving several functions. They are used as a part of therapy sessions in which the clinician uses the placement of the touch-pad to encourage specific motions; in cooperative play involving disabled and normally abled children; and as a reward for good progress, since the children like playing with the rooms. In each new room, one of the key design decisions has been considering what aspects of the implementation to adopt from the previous design, which aspects of the system could be improved by modifying the design, and which aspects must be completely new because of new functionality or requirements. The project is expected to continue for several semesters into the future, with the focus of the next generation systems turning to size: the Clinic has requested smaller designs, about the size of a lunch box, so that therapists can easily take dollhouse rooms on home visits.

Constructed Wetlands (CW)

Purdue University operates a large agricultural facility about 10 miles north of West Lafayette, Indiana. In addition to intensive farming activities there are confined feeding operations for dairy cattle, hogs, chickens and an aquaculture center for raising fish. Storage lagoons are used to collect all of the wastes from these operations and the lagoon contents are applied to the farmland by spray irrigation during the portions of the year when the crops are off the land. This commonly used practice can have the effect of increasing the levels of nitrogen, phosphorus, and other chemicals in both the surface runoff and the groundwater.

The CW EPICS team was formed in the Fall of 1998 to provide engineering support for a faculty member from the Department of Forestry and Natural Resources who serves as the primary project partner and contact for the project. For this Fall Semester, the team has been comprised of students majoring in Environmental, Civil, Interdisciplinary, Mechanical, and Electrical Engineering as well as Environmental Chemistry. The team is vertically-integrated involving freshmen through seniors. The students work together to form project teams while reporting progress to the main group. The team's advisors include faculty from Civil and Electrical Engineering as well as two industrial advisors, a chemical engineer and an environmental lawyer.

The goal of the project is to build and operate a constructed wetland that treats the agricultural runoff entering Indian Creek. The team participates in the process of planning, designing, constructing and operating the wetland. The team quickly discovered that the devil is in the details, and that constructing and operating a wetland is a complex process requiring an array of tasks to be completed. The team designed the wetland cells and piping layout, and the pump installations. A contractor was hired to excavate the site and to install the large piping and boxes. The students also conducted the cut and fill calculations and worked with a wetlands nursery to determine the type and quantity of plants required.

The four wetland cells have been excavated and the pumps installed and wired to assure flow through the wetland. About 9000 plants were placed by the students as they quoted Spring 1999 Semester report:

> *"On May 1, the team and friends met at the site to plant the wetland plants and install the supports for the weir box. This proved to be a great success as all the plants delivered were in place within seven hours. All of this was accomplished on a beautiful sunny day, with great teamwork and an occasional mud fight."*

Flow measurement and sampling equipment are currently being designed and installed. When the physical facilities are completed, the project will move into an analysis and modeling phase. Data will be collected to prepare water, nutrient and pesticide mass balances. The four cells are arranged into two parallel trains so that the effect of different loading levels can be evaluated. At present, little design information exists for constructing wetlands to treat this type of wastewater, and the long range objectives for the project are to develop predictive models for pollutant removal performance, engineering design criteria, and good construction and operating cost information.

EPICS and ABET EC 2000

EPICS offers many opportunities to address the Program Outcomes required for ABET accredited programs under EC 2000, Criterion 3 [13], which states that engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context

(i) a recognition of the need for, and an ability to engage in, life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The very nature of EPICS projects provides many opportunities for students to demonstrate that they have achieved these outcomes. Central to all EPICS projects are outcomes (c) and (d). In their role as engineering consultants, the teams must design a system, component, and/or a process to meet the needs of their project partners (c). The EPICS teams are always multi-disciplinary in composition (d), either involving students from different disciplines (not only within engineering, but also outside engineering) or students within the same discipline who have different areas of specialization within the discipline. The composition of most EPICS teams utilizes both of these definitions, though to different degrees, depending on the specific nature of the team's projects. Each Semester, the composition of the teams is changed to reflect the evolving needs of the specific projects.

The opportunity to apply engineering design within a multi-disciplinary context is therefore a key feature of the EPICS program. A definition of engineering design provided by ABET and used in [14] is:

Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the

establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.

The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternate solutions, feasibility considerations, and detailed system descriptions. Further, it is essential to include a variety of realistic constrains such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

While this definition is not explicitly a part of EC 2000, it is clear that many of the Criterion 3 program outcomes and, as we shall see later, Criterion 4 relate directly to this definition. EPICS offers the opportunity to employ a broad range of the elements of the engineering design process that are particular outcomes enumerated in Criterion 3.

Specifically, EPICS teams must work with their project partners to identify engineering problems, establish project objectives and formulate design criteria (e), apply their knowledge of science, mathematics, and to achieve their objectives (a), design and conduct experiments to test their solutions (b), and employ many of the techniques, skills, and tools of modern engineering practice in the course of completing their projects (k).

In addition, since these projects are solutions to real world problems that are ultimately implemented for use by the project partners, they must be economically viable solutions that are safe, reliable, and aesthetically acceptable - issues that relate to professional and ethical responsibility (f). Projects and their impact must be understood and be acceptable in a societal context (h), which can only be accomplished though a knowledge of the pertinent contemporary issues (j). While teams employ skills and knowledge already acquired, projects typically require researching additional subjects in depth and learning and applying new skills (i). Further, effective communication (g) is essential to the success of the projects - between team members, with the project partner and team advisors, and to the general public. This communication takes the form of interpersonal communication, project proposals, progress reports, laboratory notebooks, oral presentations, and other forms of documentation such as user's manuals.

From the above, it is not surprising that EPICS is ideally suited to fulfill the requirements of EC 2000 Criterion 4, in that it provides *a major design experience based on the knowledge and skills acquired in earlier coursework and incorporates engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.* The School of Electrical and Computer Engineering at Purdue University offers EPICS as an option to students for fulfilling their Senior Design requirement. While students at all levels, from freshman to seniors, may elect to enroll in EPICS, only students who have completed a core set of courses (through the junior level) are eligible to take EPICS for Senior Design credit. In addition, two successive Semesters with the same team are necessary of satisfaction of the Senior Design requirement.

Conclusion

The Engineering Projects in Community Service (EPICS) Program has added a new dimension to the educational design experience for engineering undergraduates at Purdue University. It represents the first program at Purdue that formally integrates service-learning into the engineering curriculum. It has proven successful in the several areas of engineering design including Electrical, Computer, Mechanical and Civil Engineering. Key features of the program include vertically-integrated, multidisciplinary teams and multi-year participation. From the academic side, this structure provides students with the opportunity to be involved in all phases of the design process, from project definition through deployment, on projects that are large in scale. Moreover, the structure encourages an extended service-learning experience, with emphasis on providing a model of how engineers can use their technical skills to benefit the community while learning engineering design. On the community side, the EPICS structure fosters a long-term relationship between project teams and the community service agency partners, and enables ambitious projects that can have a significant impact. The student experience in the EPICS program is very well suited to meet the ABET EC 2000 requirements related to design experiences.

Further information about the Engineering Projects in Community Service Program is available at: http://epics.ecn.purdue.edu/

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