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Service Learning: Industrial Embedded Systems Course

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Abstract

Service learning is defined by the National Service-Learning Clearing House as "a teaching and learning strategy that integrates meaningful community service with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities." A service learning capstone project was incorporated into a senior/graduate level industrial control course. The course provides instruction on control system design commonly encountered in industry. The design of control systems incorporating programmable logic controllers and microcontrollers is covered along with accompanying laboratory work to reinforce course concepts. To integrate course concepts, practice team design skills and expose students to service learning; students were required to complete a capstone service learning project. The students worked in a large team effort to design, construct, test and deliver a Concrete Curing Box (CCB) for use in a high school STEM recruiting and enrichment program. This paper will discuss how the service learning program was constructed and integrated into the course, the objectives of the service learning component and the results of the project. The CCB will be used as a case study to illustrate service learning in action.

Overview

Every engineering program has some form of a senior, capstone design project course. The purpose of these courses is for student engineers to apply what they have learned in previous coursework toward the design of a project within specified constraints. As ABET criterion states, "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints [1]."

We've had some success in incorporating service learning activities into our capstone design course [2]. Based on this success, we elected to provide a significant, team-based, service learning design project into a senior/graduate-level Industrial Control course. Details of the course have been previously reported in the literature [3].

The specific project developed was a Concrete Curing Box (CCB) that maintains a stabilized concrete curing temperature over a period of days. The box was requested by a Civil Engineering faculty member for use in a high school summer enrichment program. Students attending the program are exposed to engineering concepts and practices with an emphasis placed on hands-on activities. The instructor for the Civil Engineering portion of the program requested construction of a CCB box to provide for controlled concrete curing over a five day curing cycle. His goal was to have students produce a number of concrete samples on the first day of class. Samples would then be tested for hardness every 24 hours. The goal was to demonstrate how the strength of concrete improves when curing parameters are controlled over a period of time.

In this paper we provide a brief review of service learning and its characteristics as described by Eyler and Giles followed by a brief description of the Industrial Controls course. As a case study, the majority of the paper is devoted to the methods used by the student design team to formulate a team design approach, design the project and ultimately to construct, test and deliver the project.

Background

In a previous ASEE paper [2], we provided a brief definition of Service Learning. It is quoted here for reader convenience and completeness. "Service learning as defined by the National Service-Learning Clearing House as “a teaching and learning strategy that integrates meaningful community service with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities [4].” While service learning programs may be quite diverse and employ students from a wide variety of age groups, there are certain common characteristics as described by Eyler and Giles. Only a brief overview of their work is provided here. The reader is highly encouraged to see [5,6]. Service learning experiences [5, 6]:

- Have a positive effect on student personal development [5, 6].
- Involve cooperative experiences and promote leadership, teamwork, citizenship, and communication skills in participating students [5, 6].
- Address complex problems in complex settings. They offer participants the opportunity to develop mature problem-solving skills [5, 6].
- Are likely to be personally meaningful to participants and enhance their social, emotional and cognitive learning and development [5, 6].”

We’ve had some success incorporating the tenets of Service Learning into capstone senior design coursework [2]. Based on this success, we elected to provide a significant, team-based, service learning design project into a senior/graduate-level Industrial Control course. The motivation was to provide students additional real world design experience, team-based project experience and serve the educational community. The Industrial Controls course was developed and improved in response to an alumni request. We reported on this course in an earlier ASEE paper. A brief summary of the course is provided here from the earlier paper.

“The Electrical and Computer Engineering Department at the University of Wyoming was contacted by one of our alumnus in the Spring of 2008 concerning development of an industrial controls course. The alumni had graduated in the early 1980’s developed a highly successful industrial control company that provided service to the chemical, mining, oil, petrochemical, gas, and automotive industries [7]. The alumnus was interested in supporting the development of a course that emphasized the design of programmable logic controller (PLC) based systems vital to a wide range of industries and to support the ongoing demand for engineers educated in industrial control concepts and applications. Further, the alumnus pledged financial support to develop a physical laboratory and the required instrumentation to stand up an industrial controls laboratory. His motivation was to honor the memory of the late Professor R. Kenneth Beach who taught in the ECE Department for 38 years and who had a profound impact on his education and professional development [8].

At the time of the alumnus request, the ECE Department had a modest educational program in PLC-based system design. A course had been recently developed that emphasized the control of industrial devices and processes using state-of-the-art programmable logic controllers (PLCs) and microcontrollers. Equal time was spent between PLC-based and microcontroller based control of industrial equipment and processes. In the course, students investigated control algorithm design in detail and also discussed sensors, transducers, and interfacing. Students used state-of-the-art design and troubleshooting tools to apply control theory to a series of hands on laboratory exercises.

In response to the alumnus request a team was formed to make the course, laboratory exercises and the physical laboratory a reality. The team consisted of the faculty member currently teaching the industrial controls course, a graduate student who would be developing the laboratory exercises for his graduate project, the alumnus, the department staff engineer and the department senior technician who would plan and supervise the laboratory renovation and laboratory equipment purchase [9].”

In the next section we detail the methods used by students in developing their service learning project: a Concrete Curing Box (CCB) for use in a high school STEM recruiting and enrichment program.

Methods

In this section we discuss the methods used by the student team to develop the Concrete Curing Box. The step-by-step design process employed by the student team is provided in Figure 1. It must be emphasized the students followed this approach on their own accord. The student team consisted of 14 senior/graduate-level students in the computer, electrical and mechanical engineering disciplines. Even though students had been exposed to various forms of the design process since their first freshmen orientation to engineering course, it was still gratifying to see them apply the design process without prompting toward project development. We briefly discuss each step in turn.

Establish team. The team consisted of 14 students enrolled in the Industrial Controls course. All students had either senior or graduate level standing in the electrical and/or mechanical engineering disciplines.

Elect team leader. The students elected a team leader based on popular vote. The team leader selected was known for his maturity, work ethic and demonstrated leadership skills. The primary function of the team leader was to coordinate all aspects of the project, maintain the project schedule, and maintain team cohesiveness and unity.

Establish requirements. Given a brief description of the project, the design team elected to meet with the user to discuss specific project requirements. For the following list of requirements were set:

- Maintain temperature at 150 ^{o}F +/- 5^{o}F
- Maintain temperature for up to 120 hours (5 days)
- Provide capacity for multiple (12) 6” x 12” cylinder samples
- User-friendly interface
- Easy access for serviceability
- Safe operation including:
    - Protected main power switch (protective plastic access cover),
    - Maximum temperature setting of 180 ^{o}F,
    - Automatic shutoff when heating chamber is open,
    - Automatic shutoff after 10 days of use,
    - Automatic detection of fault heat source or temperature sensor, and

    - Fused power source.
- Budget: $250
- Timeline: deliver mid-May 2012 (120 days from project start)

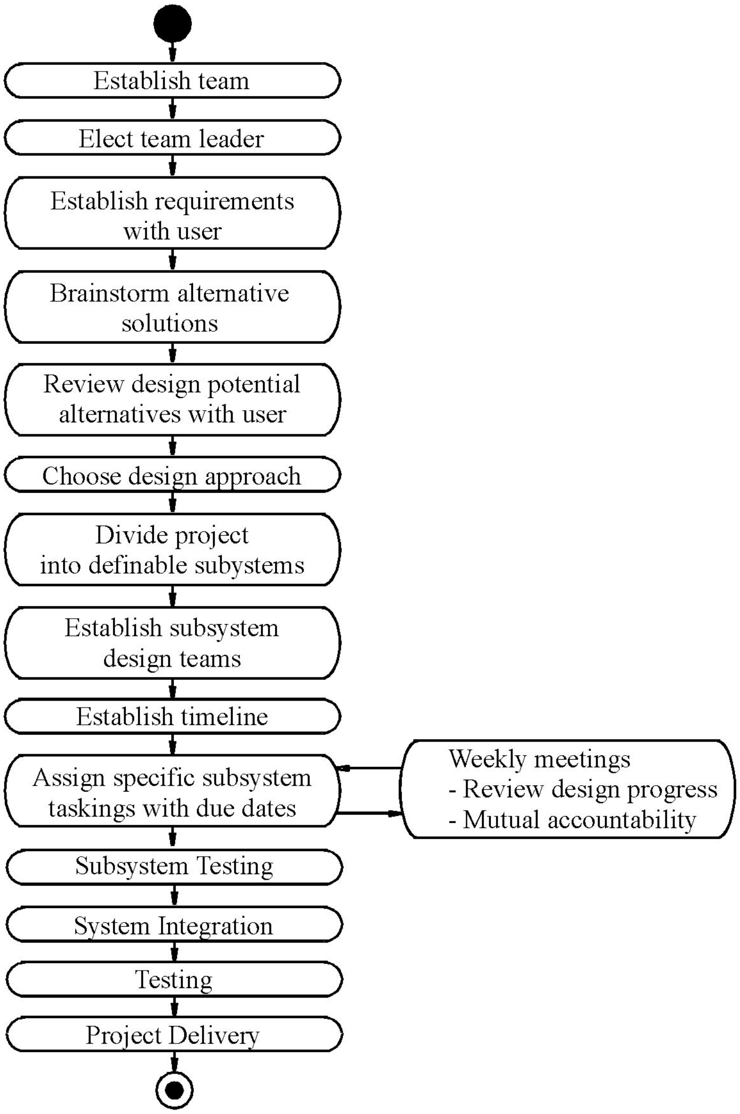


Figure 1. Team design process.

Brainstorm alternative solutions. With a list of requirements in hand, the student team had a brainstorming session to discuss possible design alternatives. Different alternatives included adapting an off-the-shelf product to meet design requirements and designing a product from the ground up. Several brainstorming sessions were held to arrive at a final design alternative. Between the brainstorming sessions the team leader assigned team members specific areas to research and report back to the group.

Review alternatives with user. The design team invited the user to another meeting to review and receive feedback on potential design alternatives.

Choose design approach. To arrive at a final design approach, the team evaluated each alternative against the established requirements. The team leader emphasized the importance of the team to agree and support the alternative once chosen. After considerable productive interaction, the team collectively arrived at a final design alternative.

Divide project into subsystems. With a design alternative selected, the team via a group discussion subdivided the project into definable subsystems. Team members then volunteered for a subsystem team of their choice. The team structure is provided in Figure 2.

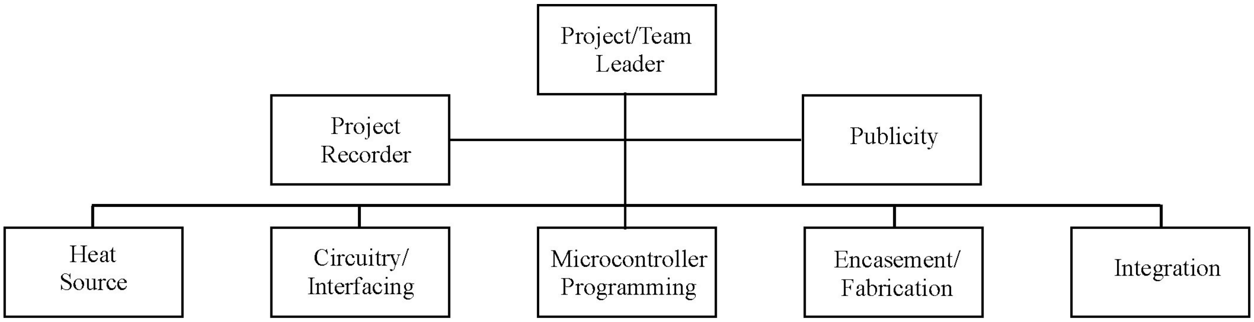


Figure 2. Design team structure

Establish timeline. The team leader with individual team member assistance established a timeline to complete the project in a timely manner.

Subsystem tasking. Each subsystem team had the autonomy and responsibility to meet the requirements for their specific subsystem. Weekly large group meetings were held to report on subsystem development progress, discuss subsystem integration issues, and provide for mutual accountability on overall project progress. As a result of the meetings additional tasks were assigned to keep the project on schedule.

Subsystem testing. Each subsystem team was accountable to complete the design and testing of their assigned subsystem.

System integration. With subsystems complete, the integration team was responsible for integration the subsystems into a final system and testing the overall product.

Testing. With the entire system integrated a battery of tests were accomplished to insure product requirements were met.

Project Delivery. The project was delivered to the user for use in the STEM summer enhancement course.

In the next section we describe how the methods were used to successfully complete the Concrete Curing Box (CCB) project.

Results

From project assignment until semester completion, the student team had approximately 120 calendar days to complete the project. Based on their systematic approach to the project, the project was successfully completed. In this section we detail the Concrete Curing Box (CCB) that resulted from the design effort. The results have been divided into four areas: the CCB circuit, the CCB control algorithm, the CBB user interface and the overall integrated design.

CCB circuit. The CCB circuit interface diagram is provided in Figure 3. At its most fundamental level, the purpose of the circuit is to maintain the CCB at the desired temperature using two 50W AC heater elements. As shown in the diagram, there are four hardware debounced switches to allow the user to increase the desired temperature or time, decrease these values, display system status or reset the system. There is also a sensor to determine if the CCB lid is ajar or off. The system will not heat when the lid is not properly in place. The control circuit also monitors the temperature within the CCB at eight different locations using LM34 temperature sensors. Imbalances between the measurements indicate a potential heating element failure or a faulty temperature sensor. These faults are reported on the liquid crystal display (LCD). The control circuit also controls the two 50W AC heater elements through solid state relays. Overall system control is maintained by an Atmel ATmega164. This processor is an 8-bit microcontroller equipped with 16k bytes of flash programmable memory.

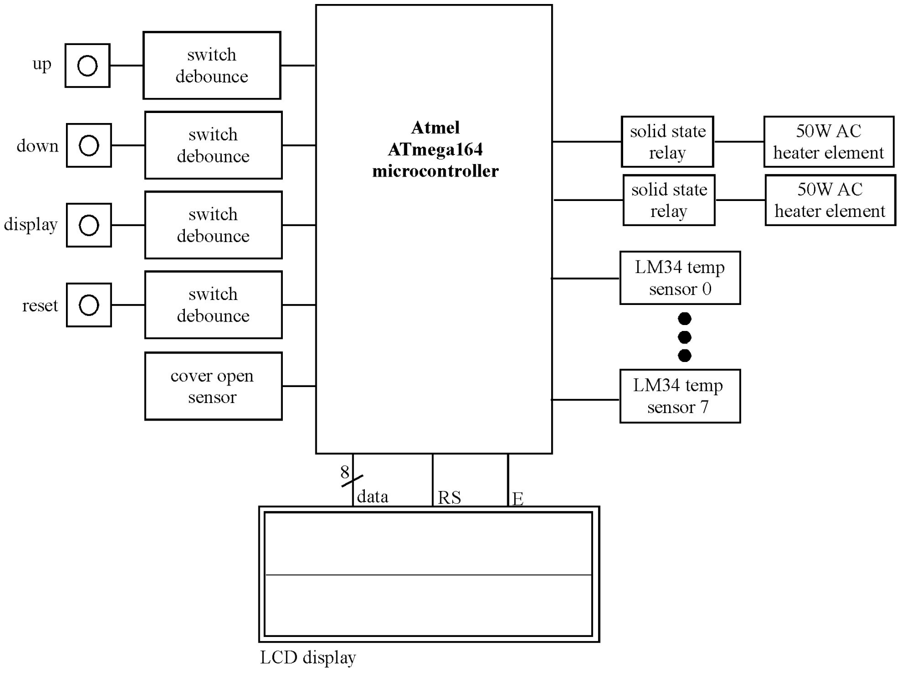


Figure 3. Concrete Curing Box (CCB) interface diagram.

CCB LCD user interface. A close up view of the LCD user interface is provided in Figure 4. The CCB user interface displays the current CCB internal temperature, desired temperature, fault status and the amount of time the CCB has been in operation.

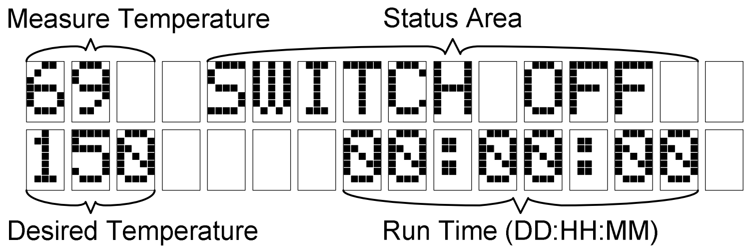


Figure 4. CCB LCD user interface.

<u>CCB control algorithm</u>. The control algorithm was written in C using the ICC AVR ImageCraft compiler [10]. A UML activity diagram for the control algorithm is provided in Figure 5. After initializing microcontroller subsystems, the desired temperature is set for 150 °F. The algorithm then enters a continuous loop to update the display, monitor external switches and then assert the heater elements. The loop also checks to see if the heater has been on for more than ten days and if the temperature is within bounds.

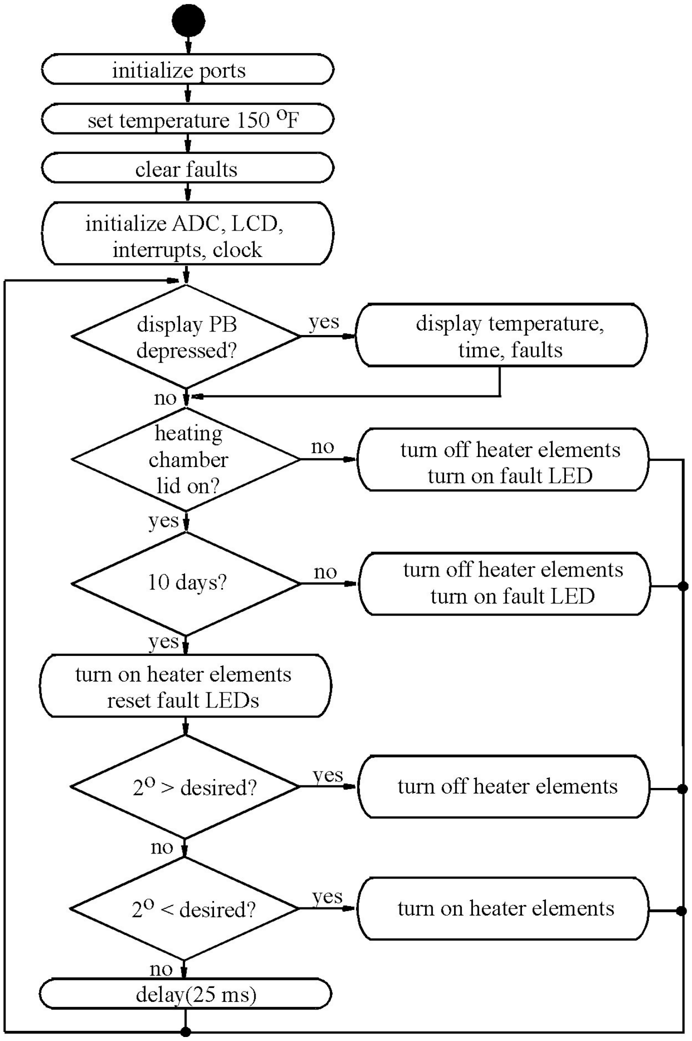
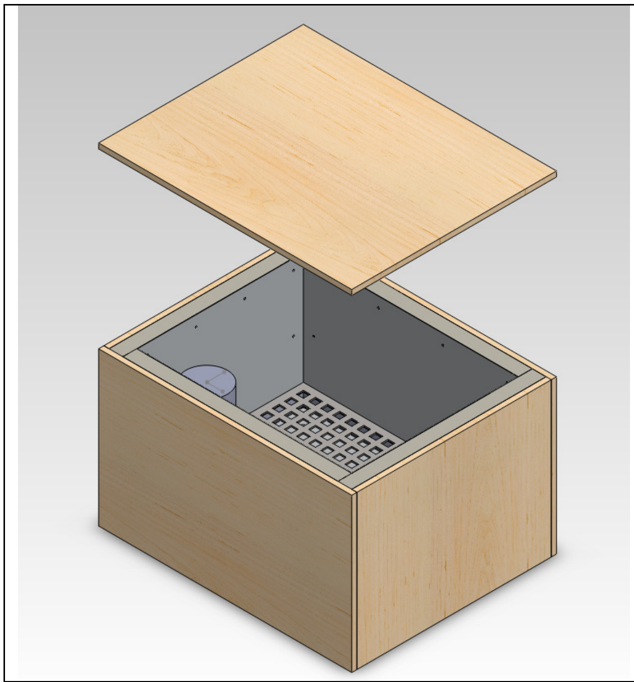
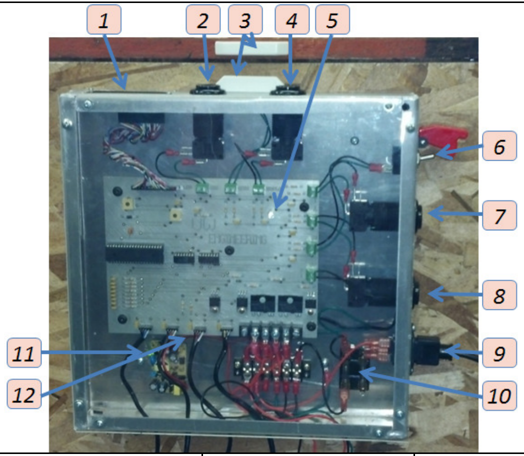


Figure 5. CCB UML Activity Diagram.

<u>Integrated design</u>. The integrated CCB design is shown in Figure 6. Pictured in Figure 6 (left) is the CCB heating chamber. The chamber is constructed of 1" particle board but has an aluminum interior liner. The heating elements and temperature sensors are mounted to the floor of the chamber. A heating rack is mounted 1" above the CCB floor. The rack protects the elements and sensors and also provides a stable platform for the concrete samples. Pictured in Figure 6 (right) is the CCB control panel that provides user interface and system integration.





1. LCD	5. Status indicator	9. Power cord
2. Reset button	6. Control switch	10. Fuse
3. Proximity sensor	7. Up button	11. 5 VDC status indicator
4. Display	8. Down button	12. Temperature

Figure 6. Overall design. (left) heating chamber and (right) control panel.

Discussion

A number of metrics may be applied to determine if the project was successful. These include measurements of service learning, development of enhanced leadership and team-design skills and success of the actual project. We discuss each in turn.

<u>Service learning</u>. Earlier in the paper, the tenets of service learning as described by Eyler and Giles were provided. Did this project achieve these tenets?

- Have a positive effect on student personal development [5, 6]? Yes. The student team completed a complicated project on a short schedule. Their primary motivation for devoting so much time to the project was to help the instructor improve high school STEM recruiting and enrichment program. During the course of the project the students developed a close relationship with the instructor and wanted to see the project through to completion.
- Involve cooperative experiences and promote leadership, teamwork, citizenship, and communication skills in participating students [5, 6]? Yes. As mentioned throughout the paper the students took a cooperative team approach to designing and completing the project. Furthermore, many students had an opportunity to apply leadership skills and leading the overall team and various subsystem teams. Also, students were required to give weekly oral

updates on subsystem design tasks. This provided mutual accountability among team members.

- Address complex problems in complex settings. They offer participants the opportunity to develop mature problem-solving skills [5, 6]? Yes. This was a very complex project requiring a varied skill set to complete. Students applied the engineering design process that had learned in earlier coursework to great success. No one student had the capability or background to complete the entire project. The students required the joint expertise of all team members to successfully complete the project.
- Likely to be personally meaningful to participants and enhance their social, emotional and cognitive learning and development [5, 6]?" As previously mentioned, the students became personally invested in the project. Their primary motivation for devoting so much time to the project was to help the instructor improve high school STEM recruiting and enrichment program.

Project success. Prior to delivering the CCB, it underwent extensive testing to insure all requirements were met. As an example, one test examined the capability for the CCB to maintain a set temperature over a multi-day period. It maintained the temperature within +/-1 ^{o}F. Furthermore, the project was delivered on time to be used high school STEM recruiting and enrichment program. During the course students conducted concrete hardness tests on number of concrete samples. Here are the results received from the course instructor:

"We cast cylinders during the afternoon of Monday, June 18. We used the recipe from Cretex, a maker of prestressed bridge beams…To heat the cylinders, we used the box that your class constructed. We left the cylinders in the heated box from Monday afternoon through Friday afternoon. The heat drives the reaction and speeds up the curing process. Type III cement is ground much finer than Type I or Type II cement. The finer grind (which costs more to produce) allows the water to penetrate the cement quicker which speeds up the reaction. The strength we obtain in one day normally takes three to four weeks.

We obtained the following breaks [11]:"

Table 1. Concrete sample break points

Day one	162,000 lb	5,730 psi
Day three	172,000 lb	6,080 psi
Day five	199,400 lb	7,050 psi

For those familiar with accreditation requirements, the ABET implications are quite dramatic. In "Criteria for Accrediting Engineering Programs," Criterion 5 -- Curriculum states "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints [1]." This criterion further defines design as "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 the engineering sciences are applied to convert resources optimally to meet these stated needs [1]." In addition, Criterion 3. Student Outcomes describe what "students are expected to know and be able to do by the time of graduation [1]." Participation in a service learning based projects allow students exposure to a number of these student outcomes including [quoted directly from [1]]:

- “(a) an ability to apply knowledge of mathematics, science, and engineering
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (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
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice [1,3].”

Conclusions

Based on the success of this pilot project, additional service learning projects will be incorporated into the course. Due to the dramatic need for students with industrial control expertise, our constituents have requested this course be offered annually. Also, a follow on course in process control is under development as a follow on to the industrial controls course. Both of these initiatives are underway and will be reported during future ASEE Conferences.

Any material discussed in this paper is available by contacting Dr. Steve Barrett at steveb@uwyo.edu.

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References

[1] "Criteria for Accrediting Engineering Programs – Effective for Evaluations During the 2013-2014 Accreditation Cycle." ABET, Inc. October 27, 2012.
[2] S.F. Barrett, J.R. Anderson, S.A. Morton, S. Root-Elledge, "Service Learning: Assistive Technology Undergraduate Design Projects," American Society for Engineering Educators 2012 Annual Conference, June 2012.
[3] A. Purdy, S.F. Barrett and C.H.G. Wright, "Hands on Programmable Logic Controller (PLC) Laboratory for an Industrial Controls Course," Computers in Education Journal, Volume 2, Number 4, October – December 2011, pp. 28-36.
[4] "National Service-Learning Clearinghouse – America's Most Comprehensive Service-Learning Resource." Internet: http://www.servicelearning.org
[5] Eyler & Giles, Where's the Learning in Service-Learning?, 1999: Complete reference.
[6] Eyler & Giles. Complete reference.
[7] Infinity Power and Controls, www.infinitypwr.com
[8] T. Page, "Alumni – Investing in the Future," University of Wyoming College of Engineering and Applied Science Foresight, Volume 35, No.2, Spring-Summer 2010, pp. 3-4.
[9] A. Purdy and S.F. Barrett, "Hands on Programmable Logic Controller (PLC) Laboratory for an Industrial Controls Course," American Society for Engineering Educators 2010 Annual Conference.
[10] ImageCraft C – Embedded Systems C Development Tools, www.imagecraft.com
[11] ESP Concrete, Mark Rehwaldt, e-mail dated June 3, 2012, 6:34 A.M.