# AC 2009-662: ALIGNING GOALS OF CAPSTONE DESIGN, SERVICE LEARNING, AND ADAPTED PHYSICAL ACTIVITY

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Brian Self has been an Associate Professor at Cal Poly for the last three years. Before that, he taught at the Air Force Academy for seven years. He is the ASEE Campus Rep and the Zone IV Chair. Besides his pedagogical research, Dr Self is actively involved in aerospace physiology and biomechanics research. He has worked extensively to involve undergraduates in his research, taking students to present at national and international conferences. By involving students in solving ill-defined projects and problems that don't have a "correct answer", Dr Self hopes to further advance their intellectual curiosity and problem solving skills.

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# Aligning Goals of Capstone Design, Service Learning and Adapted Physical Activity


## Abstract

Given that senior capstone design courses are critical elements in achieving important undergraduate engineering education outcomes and that universities are increasingly emphasizing a humanitarian component in institutional-level outcomes, we posit service learning pedagogy is well suited to accomplish both. In this paper, we describe the integration of service learning projects into existing senior level mechanical, computer and multidisciplinary senior design classes. These projects focus on the design, building and testing of adapted physical activity devices to allow greater inclusion of persons with disabilities in recreational activities. Adaptive physical activity projects are well-aligned with the goals of service learning and provide rich open-ended design experiences for students. This paper provides a framework for aligning capstone and service learning outcomes.


## Background

Service-learning occurs when "Students engage in community service activities with intentional academic and learning goals and opportunities for reflection that connect to their academic discipline" (Cress et al, 2005)[1]. Reflection is an integral part of learning and helps to develop critical thinking skills (Jacoby, 1996; Tsang, 2000; Tsang, 2002)[2,3,4]. The development of these critical thinking skills enables engineering undergraduates to develop a broader appreciation of and ability to deal with the constraints facing the engineering profession and the ever changing world. Global issues have been proposed as a means to precipitate change in engineering curricula (Vanasupa et al., 2006)[5]. Skills for well-rounded engineers, one could argue citizens here, have seen an increased focus recently from ABET criteria (ABET, 2000)[6] to the National Academy of Engineering (NAE, 2004).

## Capstone Course Structures

This paper focuses on three capstone design classes at California Polytechnic State University (Cal Poly) where service-based projects that involve the design, construction and testing of adaptive devices to allow greater access to recreational activities for persons with disabilities are completed by teams of engineering undergraduates. The three courses are Capstone design classes in Computer Engineering (approx 60 students and 12 projects/year), Mechanical Engineering (approx 200 students and 65 projects/year) and an Interdisciplinary class (approx 30 students and 6 projects/year) which is open to students in any of the twelve engineering disciplines at Cal poly. Typically about 50% of all projects are sponsored by industrial partners while 25% have campus sponsors including research and student club activities and 14% are service related[7].

The three courses all contain the major elements of industrial-based capstone design classes. The Computer Engineering class lasts two quarters while the Mechanical Engineering class has projects that last two or three quarters depending on scope. The interdisciplinary class lasts three quarters. All projects have external sponsors who bring "real" world problems to the classes for teams of three to six students to solve through hardware-based engineering designs. While the students work on their projects they are instructed about typical design processes that they are expected to apply in their work. The basic design process followed in all classes consists of:

- A *project definition* phase where students develop a list of requirements in conjunction with their sponsor to insure that the problem is fully understood and the users needs will be addressed in the design.
- A *conceptual design phase* where students creatively explore as many solutions to the given design task as possible.
- A *concept selection phase* where different ideas are evaluated and the best concepts are selected for detail design.
- A *detail design phase* where standard components are selected, detailed analysis occurs and drawings, schematics and software structures are created.
- A *manufacturing phase* where raw materials and standard parts are procured, custom parts produced, electronic circuits assembled and software created.
- A *testing phase* in which design requirements are verified and necessary modifications are made.

Deliverables in all courses include a *Design Requirements Document*, a *Design Report* and *Critical Design Presentation and Review* with the project sponsor, a *Final Project Report* and hardware demonstration through a tradeshow-style *Senior Design Expo*. Student workload is typically high due to the open ended nature of the projects, the amount of detail work necessary and the iterative nature of the design process. Specific learning objectives and student outcomes for each of the capstone classes come from departmental, ABET and University-wide requirements. A sample set of learning objectives from the Computer Engineering Capstone course is given below.

1. *Articulate design specifications and criteria by which they are to be measured.*
2. *Design and defend a solution to a real-world problem.*
3. *Verify that a design implementation to solve a real-world problem satisfies all specified project requirements, such as marketing, engineering, and constraints.*
4. *Evaluate the effectiveness of one's own team and other teams' designs.*
5. *Effectively contribute one's own disciplinary knowledge on a team as well as locate and evaluate new information.*
6. *Contribute to effective project management (e.g., through the use of Gantt charts).*
7. *Effectively communicate with others in a team, fulfilling one's individual role in the project and in interfacing with customers.*
8. *Employ principles of effective communication.*
9. *Employ ethical practices in all aspects of the design process.*
10. *Reflect on aspects of design and the design process.*

Content and experiences in Capstone design courses are required by each degree program to ensure students demonstrate certain abilities as outlined in the Criterion 3 of the ABET a-k outcomes. Additionally, many requirements of Criterion 4 are addressed by the Capstone courses. For example, the Mechanical Engineering program relies in some part on the capstone design course to provide students with instruction, application, and feedback with respect to criteria a-d, g, i and k. For other outcomes, students may receive experience depending on the nature of their project. The following list of ABET criteria are generally satisfied through the capstone courses. Details on assessment of the Mechanical Engineering capstone class can be found in (Widmann)[7]:

*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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.*
*d) an ability to function on multi-disciplinary teams.*
*g) the ability to communicate effectively.*
*i) a recognition of the need for, and an ability to engage in life-long learning*

Finally, on top of the individual engineering programs and ABET expectations, the University has adopted learning objectives for all its students that are often addressed or assessed by engineering curriculum in capstone courses. These objectives state that all Cal Poly graduates should be able to:

- *Think critically and creatively*
- *Communicate effectively*
- *Demonstrate expertise in a scholarly discipline and understand that discipline in relation to the larger world of the arts, sciences, and technology*
- *Work productively as individuals and in groups*
- *Use their knowledge and skills to make a positive contribution to society*
- *Make reasoned decisions based on an understanding of ethics, a respect for diversity, and an awareness of issues related to sustainability*
- *Engage in lifelong learning*

It is clearly essential that the projects undertaken in a capstone course allow for the attainment of this large number of difficult and diverse outcomes. It is appropriate to examine the elements of successful capstone projects. Given the typical capstone course goal of students understanding and successfully applying the engineering design process, a successful capstone project must allow the students to fully explore each phase of the design process as outlined above. A short list of requirements for successful capstone projects based on these primary objectives includes:

- *Enough ambiguity to allow sufficient exploration by the students in the project definition phase.*
- *Sufficiently open ended so as not to include an obvious or historical solution. This way the students must fully participate in the creative concept generation and selection phase.*
- *Appropriate scope to provide students with a design and manufacturing challenge that is within their capabilities, is discipline appropriate and can be manufactured using campus and/or sponsor resources.*
- *Sufficiently motivates students to claim ownership and invest time in the project.*
- *Forces progress towards the many desired student outcomes of the course.*

**Capstone Service-Learning Project Descriptions**

During the past year, 11 teams including a total of 38 engineering students finished or are in the process of designing and building service-based capstone design projects whose goals are to increase recreational access to persons with a variety of disabilities. Short descriptions of each project follows:

*Adjustable Sit Ski, completed June 2008*
Student Team: Four Mechanical Engineering students in consultation with the United States Paralympic Ski Team.

The Adjustable Sit Ski project was initiated after Jon Kreamelmeyer, Coach of the US Paralympic Ski Team, inquired about the possibility of developing a modular sit ski for persons with varying degrees of paraplegia. The modular design improves upon existing sit skis by helping athletes adjust the ski to their optimal body position for maximum power output as well as potentially increasing access to the sport by recreational skiers. The modular design could help ensure that rental shops have appropriate equipment on hand for those athletes wanting to try Nordic (cross country) sit skiing. The Sit ski is shown in various positions in Figure 1 below.

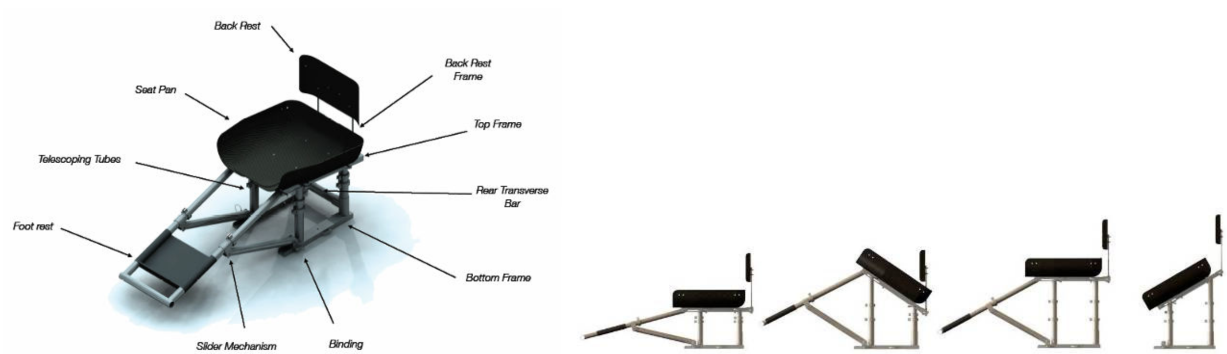


**Figure 1. Adjustable Sit Ski for athletes with Paraplegia**

*SoloQuad Kayak Conversion Control System, completed June 2008*
Student Team: Four Computer Engineering students in consultation with two Kinesiology students.

The project goal was to give independent control over a kayak to someone with high-level quadriplegia. The project began by adding outriggers, an electric motor and a joystick to the kayak. The current group of students designed and built a control system to allow the user motor control as well as steering control using a sip and puff control. The user was able to independently navigate a local estuary as seen in Figure 2.


**Figure 2. Solo-Quad Kayak for paddlers with high level Quadriplegia**

*The Universal Play Frame (UPF) Mark V, completed June 2008*
Student Team: Four Mechanical Engineering students in consultation with one Kinesiology student.

The UPF Mark V is designed to be a fully adjustable, sturdy frame that can easily and quickly attach to any wheelchair. The UPF concept is a basic frame that can connect to any participant's wheel chair. The frame then provides a foundation on which a variety of attachments can be fixed allowing users to participate in activities such as disc golf, bowling, tee-ball, soccer and golf. The most important design feature of the UPF Mark V was its universal wheelchair compatibility. It is currently in use at the Friday Club on the Cal Poly campus. The Friday Club is a group of athletes with moderate to severe physical and cognitive disabilities who meet in the Student Recreation Center to participate in adaptive physical recreation. The frame interfaces with various adapted devices also designed and built as service-based senior projects. The UPF Mark V along with the Frisbee® golf attachment can be seen in Figure 3.

**Figure 3. UPF Mark V, Frisbee® Launcher Mark II and Launcher in use.**

*UPF Attachment: The Frisbee® Launcher Mark II, completed June 2008*
Student Team: Three Mechanical Engineering students in consultation with one Kinesiology student.

The Frisbee® Mark II is a specialty sports attachment designed for the UPF V; it represents a significant refinement of the first prototype (Frisbee® Mk. I, completed June 2007). The launcher attaches to the UPF and is designed to allow people with partial quadriplegia to throw Frisbees® and play disc golf. The Mk. II affords the user greater control over the Frisbee® as it is launched and provides much higher levels of safety for both the user and their assistants. This project was completed as part of the Mechanical Engineering Capstone Course and is in regular use by the Friday Club.

*UPF V Attachment: Rock n' Bowler, Completed June 2008*
Student Team: Three Mechanical Engineering students in consultation with one Kinesiology student.

The Rock n' Bowler is a specialty sports attachment designed for UPF V. The Rock n' Bowler is intended for someone who uses a motorized wheelchair and allows them to participate in 10-pin bowling at a local bowling alley (see Figure 4). This device is a "high-end" attachment for the UPF, giving the user a great deal of control over the spin and placement of the ball. The Rock n' Bowler is designed to give the user a feeling of inclusiveness when participating in the sport of bowling. The most unique feature of the Rock n' Bowler is the powered spinning rail system that can be used to add spin to the ball. As the ball rolls down the ramp, it comes in contact with two rails spinning in the same direction that "hook" the ball.

**Figure 4. The Rock-n-Bowler in use at the Mustang Lanes bowling alley and the UPF Golf Mark II Concept**

*UPF V Attachment: Golf Mark II, to be completed in June 2009*
Student Team: Three Mechanical Engineering students in consultation with two Kinesiology students.

The UPF Golf Mark II, is an attachment designed to give athletes with partial quadriplegia the opportunity to engage in pitch and putt golfing (see concept in Figure 4). The device will allow users to store energy in a spring that can be released to drive a golf ball up to 60 feet. The device allows the use of standard clubs which can be interchanged to allow both pitching and putting. Additionally the device can be set up for "right handed" or "left-handed" shots.

*UPF V Attachment: Soccer Mark II, to be completed in June 2009*
Student Team: Three Mechanical Engineering Students in consultation with two Kinesiology students.

The UPF Soccer Mark II is an attachment designed to give athletes with partial quadriplegia the opportunity to drive a soccer ball towards a goal (this is not the same as "power soccer" described later). The device will allow users to store energy in a spring that can be released to drive a soccer ball, similar to a kicking action by an able-bodied individual.

*UPF V Attachment: T-Ball Mark II, to be completed in June 2009*
Student Team: Three Mechanical Engineering Students in consultation with two Kinesiology students.

The UPF T-Ball Mark II, is an attachment designed to give athletes with partial quadriplegia the opportunity to play T-ball. The device will allow persons with partial quadriplegia store energy and then release it into a swinging bat which will bit a baseball. Afterwards the user can "run" the bases in their wheelchair. This device is a needed improvement over an earlier design for both robustness and inclusiveness.

*Motorized Wheelchair Paintball Adaptation, Foam Wars: to be completed in June 2009*
Student Team: Interdisciplinary Engineering student team which consists of one Mechanical Engineer, one Computer Scientist, one Aeronautical Engineer, two Biomedical Engineers and one Materials Engineer in consultation with three Kinesiology students.

The "Foam Wars" concept is an adapted version of paintball for persons with partial quadriplegia who use motorized wheelchairs. The system consists of a set of frames that fully enclose motorized wheelchairs and provide controls for shooting foam balls at targets located on other frames. A computer system keeps track of scoring and will provide visual and audible feedback for successful shots. Persons with manual wheelchairs or persons without disabilities can also participate by attaching the enclosures to any wheelchair. The system is designed to provide an equalized challenge for persons with or without various disabilities.

*Power Soccer Wheelchair Attachment: to be completed in June 2009*
Student Team: Three Mechanical Engineering students consultation with two Kinesiology students.

"Power Soccer" refers to a version of motorized wheelchair soccer and is supported by various organizations worldwide. The games are played by as many as eight players in motorized wheelchairs with rules similar to soccer. The students are designing a robust and universal attachment for wheelchairs to protect the user as well as provide the surfaces for controlling the soccer ball for a local Power Soccer team.

*Hand and Foot Power Cycle: to be completed in December 2009*
Student Team: Four Mechanical Engineering students working in consultation with a local adaptive technology engineer at Central Coast Adaptive Technology.

A Hand and Foot Powered Cycle will give greater access to the sport of cycling to persons with disabilities. The cycle will allow foot, hand or combined foot/hand power. The cycle is intended for a client who has limited use of their legs, but would benefit from exercise of both arms and legs. Another possible application would be for spinal cord injury rehabilitation.

**Assessment of Learning and Attitudes**

A variety of tools are being used to assess the student outcomes in terms of the course goals as well as student attitudes about persons with disabilities. The assessment of capstone design learning outcomes is accomplished through traditional means such as the quality of technical reports and presentations. Also of interest is how the assistive technology context affects student development as conscious citizens. Specifically we are interested in how engineering students view those with disabilities and how the service learning experience might change that. An instrument, the Attitudes Survey on People with Disabilities is being administered to capstone design students before and after their involvement in the projects mentioned above. The students working on industrial based projects provide a control group. It is expected that student attitudes toward people with disabilities will improve more for those who work on the Adapted Physical Activity projects than those who do not. Preliminary results indicate that students identify a positive emotional benefit for working on projects to aid persons with disabilities. More data will be available at the completion of this academic year.

Another measure being taking is the degree to which the students find their projects motivational. It has been stated by others that students find service-related projects provide higher levels of motivation[9]. While anecdotally this appears true, we are attempting the measure students' motivation through surveys. Results should be available by June 2009.

For the community members who use the Adapted Physical Activity (APA) projects, surveys are being developed to assess the successfulness of the project. These are design to measure:

- The user rejection rate for those devices designed for specific individuals
- Ease of use of the device
- Interest in using the device again
- Effect of participation in APA Session/use of device on perceived ability for physical activity
- Interest in additional physical activity
- An evaluation of the individual's interactions with students working on their project

The last part of our assessment plan involves assessing design team knowledge. This is being done with the Transferable Integrated Design Engineering Education (TIDEE) Design Team Knowledge Assessment[11]. The purpose of this component is to assess students' knowledge of the engineering design process, teamwork, and design communication.

## Discussion

It is evident that service-based design projects that improve the lives of people with disabilities can provide a platform for attainment of the diverse set of learning objectives and student outcomes expected of capstone design classes. It is our intent to compare how students might benefit to a greater or lesser extent based on whether their project is an adapted physical recreation project versus more traditional industrial projects. If we first examine the typical design process content of a capstone course, as outlined previously, the nature of service-based projects may be more suited for pedagogical purposes than many industrially sponsored projects. As noted by Brackin and Gibson,[9] service-based capstone design projects that benefit persons with disabilities often are less well-defined than industry-based projects. This forces students to work hard at the *problem definition phase*, presumably giving them more experience with this traditionally difficult phase. This also allows the students to be the technical experts on the project and not defer to the expertise of their industrial sponsors. One possible side benefit would be to give the students greater confidence in their engineering abilities. Often with industry projects, the sponsor comes fully prepared with technical requirements so that the students experience with developing their own is diminished. In the next phase, *conceptual design*, the service-based projects often have no commercially available references and the students must start from a "blank" sheet of paper to generate ideas. In the authors' experience certain product development and test and manufacturing "fixture" type industrially sponsored projects can also provide a rich opportunity for conceptual design: however, many industrial projects can deteriorate into a more or less sizing problem when the industrial sponsor has a preconceived solution or extensive experience with similar devices. That is not to say they are the "wrong" solutions, it is only that the sponsor has already spent considerable effort in eliminating other possibilities. The students on these projects often have a diminished experience with the *Concept Selection* phase since there is little to left to be decided and may be left wondering why they are forced to go through a seemingly pointless exercise. For the remainder of the project phases, the experience can be similar especially if the instructors have appropriately scoped the projects for significant technical content before project initiation.

In terms of the ABET requirements addressed by the capstone classes, it is clear that given the correct advising, the students should be able to attain each objective whether they are working on an adapted physical recreation project or an industrially sponsored project. The key is in the technical scoping of the project. As can be seen in the list of projects above, significant technical content is necessary simply due to the difficulty in designing these devices. It is possible that objectives c) and i) may be obtained to a greater extent with the service-based projects. These projects force the students to think about social, ethical, health and safety issues and also force the students to work harder at project definition. Finally in reviewing the list of Cal Poly university learning objectives it would seem that service-based projects would give students a better opportunity to "*Use their knowledge and skills to make a positive contribution to society",* give the students a greater *"respect for diversity"* and force them to practice skills of life-long learning. Lastly the service-based approach can anecdotally be seen as providing higher motivation as students see their project making a "real" difference in the lives of others.

## Conclusions

This paper details the common learning outcomes associated with engineering capstone design classes at Cal Poly and how service-based design projects to provide equipment for adaptive physical recreation can best meet those objectives and generate the desired student outcomes. As evident from the project descriptions, these projects provide a serious technical challenge to the students where the use of a structured design process is essential for project completion and success. This should reinforce the need for the student to understand and use the recommended design processes and design tools often to a greater extent than some industrially sponsored projects. Unique to the projects is the fact that often the students may gain greater confidence in their engineering skills as they become the technical experts as opposed to relying on the expertise of their industrial sponsors. The project can also provide extra motivation for the students as they view their roles as engineers working for the good of society. Further assessments are being made to quantify the effects on student outcomes through survey tools.

## Acknowledgements

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