Abstract

Our previous research has shown that multidisciplinary capstone programs can enhance development of systems engineering competencies. However, undergraduate engineering capstone projects typically focus on only one engineering discipline. One way to foster more collaboration between engineering departments and students is to partner with colleagues at other universities. Although this provides more challenges for students it also exposes them to a wider variety of peers.

Good capstone experiences involve sponsors with real needs. Finding and engaging such sponsors takes time and effort by faculty that might be better spent on other tasks. It would be easier if a global marketplace existed for multidisciplinary engineering capstone problems and projects. A marketplace would allow sponsors to propose challenging projects that require systems thinking across multiple disciplines. It would allow students to self-organize and select projects based on their backgrounds and interests. It would also allow faculty to focus on guiding student learning rather than defining challenging capstone projects and obtaining necessary resources.

This paper describes an ongoing pilot project to develop a marketplace for multidisciplinary systems engineering capstone projects. Students from six different universities have applied to projects that were posted to the marketplace website by sponsors from government and industry. Each team includes students from different disciplines and different schools. The goals of the pilot project are to determine the requirements for a global electronic marketplace and to develop guidelines for faculty, students and sponsors who would use it.

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1. Introduction

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Capstone projects play a key role in many engineering programs. Often these projects are performed by students from individual engineering disciplines. In contrast, most large industrial systems are produced by teams of engineers from many different disciplines. Thus, multidisciplinary projects are a more realistic experience for engineering students. Multidisciplinary projects are also larger in scope and team size, providing opportunities for more interesting and engaging experiences. We have conducted research on multidisciplinary projects and have found them to be effective in teaching systems engineering concepts. However, we see many barriers to the adoption of these types of projects in traditional engineering programs.

We are now conducting a pilot research project to form multidisciplinary teams of students across multiple universities using a marketplace concept. We feel that this approach has great promise in promoting multidisciplinary capstone projects at many schools.

In section 2 we describe some of our results in multidisciplinary projects conducted by individual schools. In section 3 we describe our attempts to form partnerships between schools in forming project teams. In section 4 we describe the marketplace concept as it was originally conceived at Stevens Institute of Technology. In section 5 we describe the first implementation of the marketplace. In section 6 we describe our current research with a multi-university marketplace. In section 7 we report our results so far. We report on related research in section 8, and conclude in section 9.

2. Need for multidisciplinary systems engineering projects

A two-year SERC research project initiated by our colleagues [1] demonstrated that students who worked on multidisciplinary capstone projects had increased interest and learning in basic systems engineering concepts. In the first year of the project 50 faculty from 14 schools developed systems engineering courses and multi-disciplinary systems engineering capstone experiences for more than 360 students. In most cases these course sequences included a first semester course that introduced fundamental systems engineering concepts and processes. Students were given pre- and post-course-sequence assessments of their knowledge of systems engineering concepts as defined by the Systems Planning, Research Development, and Engineering (SPRDE) Career Field/Systems Engineering (SE) and Program Systems Engineer (PSE) competency model [2]. Students showed increased understanding of systems engineering principles and processes. Engagement with mentors from industry and government was particularly effective in improving student learning outcomes.

Capstone projects are a key component in the major design sequence of an engineering curriculum. As such they demonstrate whether students have adequately mastered important topics and skills. These projects are also a source of pride and accomplishment to individual engineering departments. Student presentations and posters play a key role in marketing and recruitment of new students. Projects performed for corporate sponsors may help establish strong student recruiting ties between industry and individual academic departments. For all these reasons and many others departments are naturally hesitant to lose control of the definition and supervision of these projects.

In order to create and run a successful multidisciplinary capstone project, faculty from different academic departments must coordinate their efforts in defining the project, recruiting the students, supervising and guiding the students during the project, and assessing the students’ performance. This may result in 3 or 4 faculty members working with an individual student project. For example, work performed by civil engineering students may require guidance and assessment by a professor of civil engineering, work performed by mechanical engineering students on the same project may require guidance and assessment by a professor of mechanical engineering, and work performed by electrical engineering students on the same project may require guidance and assessment by a professor of electrical engineering.

If multidisciplinary projects were the same size as traditional capstone projects, say 3-5 students, the faculty overhead would be too large to justify the expense. A better strategy is to combine sub-teams of students, where each sub-team is about the size of a traditional capstone team. This results in a larger overall team, which has its own advantages and disadvantages. A larger team can accomplish more, producing more interesting and effective products. Coordinating a larger team is harder, increasing the probability that some students will lose touch or become frustrated. We have found that graduate student teaching assistants can be particularly effective in helping coordinate larger teams and in mentoring students on individual tasks.

3. Challenges and benefits of partnerships between schools
As we contemplated scaling up our efforts to deploy multidisciplinary capstone projects we realized that a potential barrier to adoption was lack of experience with systems engineering. Accordingly, in the second year of our project we encouraged experienced schools (that is, schools with mature systems engineering programs) to partner with less-experienced schools (for example, schools with no systems engineering or no engineering programs at all) in forming capstone project teams. We continued our assessments of students before and after their course sequences and confirmed our earlier results about increased student understanding of systems engineering concepts. In this second year we collaborated with 52 faculty and more than 340 students from 15 different schools.

The partnerships that were formed all involved some personal connection between faculty members at the partnering schools. For example, faculty from two different schools who were already collaborating with one another in research might work together to form a joint student team. In other cases existing collaborations helped introduce potential partners to one another. In a few cases faculty contacted potential partners at institutions where they already had some connections, but not in the departments where they ultimately found their partners. While these types of personal relationships can be very helpful in creating links, we realized that they probably would not scale up to larger efforts to deploy multidisciplinary capstone projects.

Different models of team organization were used in the partnerships we observed. In some cases each school had its own sub-team that worked on its own component or piece of the project. On one project the student sub-teams were composed of students from more than one campus. On another project a sub-team from one school provided a service (quality assurance) to the sub-team from the other school. One partnership included three schools, while the rest were all pairs of schools. One partnership was formed between faculty only: faculty from one school observed and reviewed the project conducted by the faculty and students at the other school. All of these models seem to be valid and useful.

Partnering between schools provides several benefits:

- students at schools that could not otherwise conduct multidisciplinary projects are able to participate on those types of projects
- students are exposed to a wider diversity of teammates
- a greater variety of student skills and abilities is available when forming teams

However, such partnerships introduce new challenges:

- students at different schools may have different academic calendars, causing delays at startup or forcing early completion for some students
- students may be too far away to meet face-to-face, and must learn how to communicate effectively via teleconferencing
- students at different schools may have different weekly schedules or be in different time-zones, making it more difficult to find times when they can work together

All of these challenges make the projects more realistic, as modern engineering practice often includes partnering with colleagues in remote locations. Nevertheless, greater challenges imply greater risks, often mitigated by increased faculty supervision and guidance.

Most faculty who participated in these multi-school partnerships reported that they enjoyed the experience but felt that they worked harder than they did on "normal" capstone projects. Again, this did not bode well for scaling up to larger efforts. We needed to find a way to create and support projects that did not add an extra tax on scarce faculty resources.

4. Marketplace concept

The idea for the Senior Design Marketplace at Stevens Institute of Technology came out of observations over the years advising and coordinating the capstone design class for the undergraduate Engineering Management (EM) program.

- There were logistical problems involved with matching students and projects, which often led to team issues and lack of motivation.
There were students that brought their own project ideas and/or project sponsors, but they lacked a proper channel to get the word out and recruit team members.

Most senior design projects took place in a vacuum where the breadth and depth of projects undertaken would not be exposed to the community before the last week of the spring semester at the annual Senior Design Exposition.

Many of the students (and the faculty) would have liked to work on interdisciplinary projects. This would only happen ad-hoc and mostly through personal networks.

The exhibits at the Senior Design Exposition would often reveal the lost potential in many projects due to the fact that only one engineering discipline had worked on them.

The idea of a marketplace instead of a simple, central repository of available projects was inspired by the rising tide of “social”, mass-collaboration, crowd-sourcing, and on-line matching services of all kinds. The vision was a venue where faculty and departments could recruit students for their project ideas, where students could recruit faculty advisors for their project ideas, and where students could self-organize in interdisciplinary teams around projects of their shared interests.

The project was posted as a potential Senior Design project for the EM class of 2012. The team that took on the challenge conducted a survey among all seniors at Stevens early in the fall semester while capstone project selection process was still fresh in their minds. The survey results to a large extent confirmed the observations above. The more freedom the students had in selecting project, the happier they were about the selection process. 73% of the students would have liked to work on an interdisciplinary project whereas 45% of the projects had more than one discipline represented, and of those less then 1/3 had more than 2 disciplines. Finally, 70% of the students responded that they were interested or very interested in a central marketplace of potential projects [3].

The team released a prototype of the marketplace for initial testing by the EM junior class in the last half of the spring semester. This allowed the team to expose critical bugs and fill the marketplace with data so they could demonstrate an improved version on Senior Design Expo Day. Both students and faculty enthusiastically received the concept, and the Department of Mechanical Engineering as well as the EM program decided to try it out for the fall semester. Detailed feedback is not yet available, but over the summer the Marketplace successfully matched 174 students and 16 advisors with 56 projects, and everyone involved on the faculty side would like to see the concept further developed for use in the spring of 2013.

5. Building the first marketplace at Stevens

5.1. Design Goals and Inspirations

The SeniorD Marketplace was designed with simplicity and usability in mind. Its goal in design was to facilitate and encourage student and faculty collaboration and to make sharing ideas and forming project teams around those ideas a creative and enjoyable experience. The system would be used university-wide and would be housing a very large collection of student and faculty profiles as well as all of the ideas and projects generated by the user base. Hence, the site would need to be highly navigable and the massive amount of content would need to be organized and presented in such a way that was not “cluttered”, and could easily be filtered and configured to a target audience or by the user.

The initial design of the prototype system stemmed from a collection of inspirations from various project-sourcing and social-networking platforms that are already in existence on the public Internet. Many of the features included in the prototype system are a combination of what the design team deemed “best in class” or “best practice” features of the major project-sourcing sites and the most popular and up-trending features included in major social networking sites such as Facebook or Twitter. The table below summarizes some of these “best in class” features from both the project-sourcing and social-networking spaces that enabled the prototype system design to become the unique social project-sourcing hybrid that it is. Features marked with an asterisk were not included in the scope of the prototype system, but were instead added to a list of “future desired features”.

Table 1. Features and their sources
The website’s navigation focused on creating a “web of connectivity” among its pages, users, and projects. The prototype site was designed in such a way that from any project page, a user may access its participating members’ profiles simply by clicking on their image. Likewise, the user may then link to any project that participant is working on through their profile page…and so on. The goal was to minimize the amount of effort and time it takes a user to navigate from one page to the next via a web that connects all users and projects together in the background based on relationships.

### 5.2. Moderation and Governance

While the SeniorD Marketplace put a lot of emphasis on enabling student-driven projects, the design team realized the need for some sort of moderation model to oversee the generation of ideas and their evolution into full capstone projects. To govern and oversee the capstone process, the Marketplace would take advantage of a role and permissions system that only allows users with “advisor” privileges to promote project “ideas” to the “project” level. While any user in the system can submit an idea for a project, only once a project is “approved” by a user at the advisor level can students begin to form teams around the idea as a capstone project. There are a number of other processes related to project member management that are also governed using the permission system. The inclusion of such a workflow system is to ensure project and process integrity while still enabling students themselves to drive the capstone project selection process.

### 5.3. Choice of Design Tools

The SeniorD Marketplace prototype was designed using a suite of HTML, PHP, and MySQL development tools. The dynamic nature of the content (much like Facebook or any of the sourcing sites) calls for a robust database engine and middleware. The PHP-MySQL combination is widely available and highly supported. When designing a system for supportability and maintainability, selecting such a suite of technologies is important. It allows for laying out a solid prototype framework for the system so that it can be easily shared, understood, and supported by others interested in developing and taking the prototype to a marketable level.

### 6. Marketplace for multi-school projects

Having observed the success of the marketplace concept at Stevens, we considered using the same approach for projects involving multiple schools. We envisioned a version of the marketplace where:

- sponsors would propose projects through a central website
- students would apply for participation on projects through the same website
- sponsors would select students for project teams, perhaps with some assistance from faculty
- students would have some freedom to define and direct their projects to meet their common interests and abilities

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<th>Project-Sourcing</th>
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All of these actions could take place with little or no faculty involvement. The only problem with this strategy is that it ignores an important purpose of capstone projects, namely their role within engineering curricula. Each student would need to find someone at their school to approve their participation (that is, give them credit for their work) and then to provide any needed guidance and assessment of their work. Additionally, until they became experienced with this process, sponsors would need assistance in creating realistic project proposals and in selecting appropriate students. Similarly, students might need some assistance in using the marketplace.

We decided to embark on a pilot project to test the marketplace concept with a few sponsors, schools and students. We provided some faculty assistance to sponsors in writing proposals and in forming teams. We also provided one faculty advisor to each project to make sure that students got the guidance they needed. That advisor would work with other faculty, as needed, in assessing student performance. At the end of the pilot the team of project faculty advisors will write a set of guidelines to be used in future versions of the marketplace.

7. Experience to date

We modified the software system developed for the Stevens SeniorD Marketplace to allow student participation from multiple schools. Although we did not have time to enable all of the functionality we had hoped for, we were able to post project proposals and allow students to post their interests and abilities. We collected 9 project proposals from sponsors and posted them on the website. All of the projects were good multidisciplinary systems engineering projects.

As of this date the student projects are about halfway through their academic year. There are 3 projects:

- Humanitarian Assistance and Disaster Relief project involving students from the University of Alabama in Huntsville and from Stevens Institute of Technology
- NASA satellite component involving students from Southern Methodist University and from the University of Hawaii at Manoa
- Immersive Training System project involving students from Missouri University of Science and Technology and from the University of Hawaii at Manoa

The marketplace website was useful in helping students find potential projects to join, but we did not use it to form the teams. Instead we negotiated individually with faculty at each of the participating schools. If we had started our effort earlier we might have been able to use the marketplace website more effectively for team creation.

8. Related research

This is not the first attempt to conduct capstone engineering projects across multiple schools. Early work in this area [4][5] concentrated on bringing together students from different schools who shared the same engineering discipline. A recent workshop on globally distributed teams reported on several such efforts in software engineering [6][7][8][9]. Since software projects usually do not include physical artifacts to be created and shared between teams they are easier to conduct across multiple sites. Recently there has been an interest in moving traditional engineering tasks toward cloud-based tools, which also enables collaboration across multiple sites [10].

Our pilot project is unique in emphasizing student input and direction in creating projects. One of our capstone projects includes mechanical engineering students at the University of Alabama in Huntsville working with engineering management and naval engineering students at Stevens Institute of Technology. The students met virtually to discuss their relative competencies and narrow their project focus. After negotiation with their sponsor they prepared their project plans. This type of specialization to meet individual student needs is a significant advantage of the marketplace concept.

9. Conclusion

Multidisciplinary capstone projects present challenges to supervising faculty that often inhibit their creation. The same is true of multi-university projects. A marketplace for projects offers an alternative approach to project creation and supervision. Students must assume more responsibility for identifying, defining and participating on capstone projects in this model. We hope that the rewards will encourage students to continue using this model, and we are working on ways to reduce the sponsor and faculty overhead.
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References