AC 2010-921: CAPSTONE SENIOR PROJECT MENTORING AND STUDENT CREATIVITY

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Capstone Senior Project Mentoring and Student Creativity

Abstract

After the 2000 ABET accreditation changes, many Engineering Schools expanded or started capstone senior projects to meet the realization aspect of the engineering education. It is offered in several versions including one and two-semester course. The capstone project offers an integrated experience for the senior students to apply their engineering knowledge to solve a research or applied open-ended problem. The typical project includes design, build and testing phases. Beside the technical aspect, students work in teams and manage budget to meet certain time and resources constraints. Guidance is needed in all stages of the project starting from selecting the suitable project, assigning the teams, design, build, testing, and delivery. Engineering Schools use several models for guidance such as mentors, faculty advisors, acting customers etc. Balancing between guidance and allowing the students to have enough space for creativity has been a challenge.

In this work, a capstone senior project mentoring model is discussed. It includes the interaction between the components of the project: team, faculty advisor, and customer. It adds another level of mentoring where a board of faculty oversees all projects. The faculty members in this board are involved in the projects as faculty advisors, customers or for technical support. Several mentoring tools are presented such as design review meetings, public and technical presentations, written proposal, and final project document. Also tools to improve team dynamics such as weekly meetings, team leader, and team contact person are presented. The model was applied to two of capstone projects and showed success. The first one is to design and build a Mini-Baja off road vehicle for the SAE competition. The second project is to design and build an internet controlled robot. Each project has its own mentoring and management challenges beside the technical problems. Details of each project are discussed including the technical, management, mentoring and window of student creativity.

Introduction

Capstone project is a unique educational tool where at that level, senior students have developed both the technical and the management skills and they are ready to be challenged with an open-ended problem. However, guidance is still an important part of this educational environment. It completes the process by opening the right doors for the students to apply the correct planning, designing, building and testing procedure for a successful project. Dusing et al\(^1\) discussed the use of design review meetings to guide the students before major steps of the project. In this meeting, the students defend their technical decision and are challenged by a couple of faculty member who are experts in the topic being discussed. Miller and Olds\(^2\) described a multidisciplinary capstone project to enhance the engineering skills of graduates at the Colorado School of Mines. A two-semester design course was used for that purpose. Multidisciplinary design teams of students worked with a faculty advisor for an industrial client, and solved complex open-ended problems. The authors indicated that the approach has been successful and the industrial client was pleased with the quality of the final product. Although this work represents quite an old example, it definitely shows the success of using a senior project as a teaching tool. Todd et al\(^3\)
presented the results of a survey performed in the nineties about the use of capstone engineering courses. The results indicate that they are widely used to increase student awareness of soft skills and as tools to subject them to “real world” open-ended problems. Napper and Hale\textsuperscript{4} presented the use of capstone senior projects as assessment tools for engineering programs. They discussed the ABET requirement for the program outcomes and how a senior project serves as a good indicator for student ability to work in teams and use critical thinking to solve open-ended problems.

Design projects were also used as a tool to enhance the learning in undergraduate courses. For example, Mokhtar et al\textsuperscript{5} discussed the use of projects in thermo-fluid courses where the students designed and built complete systems using both experimental and CFD tools. They also showed how the design project meets the ABET realization requirements. The use of projects in a Mechanics courses showed also success as reported by Hamid and Esche et al\textsuperscript{6}. Newell et al\textsuperscript{7} used design projects for Heat Transfer courses. Mokhtar et al\textsuperscript{8} discussed the use of project-based-learning in Mechanical Engineering programs. Jones\textsuperscript{9} developed a course where undergraduate and graduate students work in teams to design thermal systems and solve real industrial problems. Having graduate students in the course allow the use of advanced tools and created an excellent educational environment for both group of students. Even in the freshman year, projects showed success to increase the students interest in engineering and improve the retention rate, Parker et al\textsuperscript{10} and Mokhtar\textsuperscript{11}.

The main challenge with the design projects is the balance between guidance and creativity. It is the nature of the students to take short cuts and jump to conclusions without a thorough analysis of the options. The advisor rule is to provide the students with design and management tools and allow them to try on their own and learn from the process. Several models of guidance are used by the Engineering Schools for capstone senior projects. Estell et al\textsuperscript{12} used a business model to run a senior capstone two-semester project. In their model, projects are announced to the students during the junior year and they have the chance to choose between them. By the end of the junior year teams, are selected and faculty advisors start working with the students. By the end of the first semester of the senior year each team is required to write a project proposal that includes the project feasibility, its implementation plan, and the scope of the work to be accomplished. The proposal is reviewed by Project Review Board (PRB) who are a group of faculty including the faculty advisor and each team is required to give a presentation. If the project is approved by PRB, the team starts the building and testing during the second semester. A second round of review by PRB is done during the mid-semester to evaluate the progress of the project. In this model, the faculty advisor is support by the PRB to best evaluate and support the capstone projects and ensure its success without losing the educational value of the design process.

Soda et al\textsuperscript{13} described the use of students from Engineering Management major as managers for the teams who are from other engineering majors during the capstone project. The student-student interaction created, as indicated by the authors, a healthy educational environment and showed significant enhancement in the design experience for both group of students. Faculty advisor rule is still active in the project guidance process in both the technical and the management aspects. This model supports the idea of allowing student-student mentoring as an added layer in the project supporting structure.
Presented a performance evaluation model that can be used to assess the design capstone projects. They report four areas for evaluation: (1) personal capacity, (2) team processes, (3) solution requirements, and (4) solution assets. They showed the importance of designing skills and how a capstone project can successfully be used to develop these skills. They indicated that both the student learning and the solution of the problem grow in parallel as the students are challenged repeatedly, think creatively and develop solutions. The discussion presented in their work highlights the importance of student creativity as part of the project.

It is clear that the capstone senior project is a great educational tool. Student creativity is a natural product of the project with the right amount of guidance using one or multi layer of supervision. In the following section, the outline of the model used in the present work is presented follow by two examples for capstone senior projects.

Mentoring philosophy

A senior project team needs help in two main areas: technical and management support. The bridge between the theory and practice is not fully developed even in the senior year and technical support is needed throughout the project. Being an open-ended project, one faculty member will not be able to provide all the needed technical support for the team as the project may have components outside his area of expertise. The management part includes project planning, team dynamics, communication with the customer and budget. Figure 1 shows an outline of the mentoring philosophy used in this work. This setting provides the team with several levels of technical and management mentoring. The Faculty Advisor (FA) is the first level of mentoring who is involved with the team on a daily basis. The second layer of support is the Faculty Advisor Board (FAB) who is a group of faculty covering several areas of engineering. Two elements are used to help with the team dynamics: team leader and team contact.

Faculty Advisor Board (FAB): The first job of the FAB is to choose the projects and assign the students and the faculty advisor to each team. They evaluate the technical difficulty and select a group of students that have the needed technical background for each project. The interpersonal skills and leadership for each senior project team are also reviewed by FAB. Then an FA is assigned to each team whose technical expertise matches the project. During the two semesters of the project, FAB provides the needed technical support and coordinates the management of the projects. The members of the FAB also act as judges for the presentations, written reports and technical meetings. They have a good chance to interact with the teams and they contribute to the final grades of the students. FAB provides a support for the FA for disciplinary actions. Each student can receive up to three written warnings from the FAB based on the FA request before he/she or she is removed from the course. It is a tool to allow the FA to control the performance of the team members. Having the FAB involved in this process supports the FA and ensures the transparency.
Faculty Advisor (FA): The FA is the one responsible for the educational process and the development of the students’ skills throughout the project. He/she mentors the performance of each student in the team and balance the amount of work shared by the members. He/she also provides the technical support for the project and directs the students to the possible solutions for the problems. He/she works with the customer to maintain the level of the project within the students’ capabilities and sometimes interferes to add or eliminate tasks to keep the project doable. Having a major role in the grade and with the warning system described before, he/she has enough authority to keep the students working in the project.

Team leader: Team dynamics is another challenge. Not all students have the same technical and management level and sometimes weaker students tend to hide behind the good ones. The team leader is a good tool to increase the mentoring. He/she is selected by the FA with the team agreement and is given lighter technical load to allow for more management role. He/she keeps track of the action items and reports back to the FA in a weekly progress report. The team leader also acts as an easy contact between the FA and the team. The end of the first semester is a suitable time to start the team leader job where all the research and design phases are complete and the building and testing stages are starting.

Team contact: For industrial sponsored project it is very important to assign a team contact person who is responsible for coordinating meetings and exchange documents with the customer. He/she needs to have good interpersonal skills.

Customer: The customer is the representative of the sponsor and he/she provides the initial technical problem. It is important to keep him/her in contact with the team throughout the project specially before major design decisions. If the customer technical background it not enough, a faculty member could play this role with the coordination with the actual customer.
Mentoring tools

Several tools can be used to provide the students with the needed technical help and to keep the project on track. From the educational point of view, these tools help the students to develop soft skills as they work on the project. Figure 2 shows a summary of the mentoring tools used in the projects.

**Weekly meetings:** Two meetings are needed each week. One of them is between the team members to review the individual assignments and plan the coming tasks. The other meeting is to report the project progress to the FA. As part of the FA meeting, each student is required to report his/her weekly accomplishment in specific tasks and the number of hours spent on the project for this week and the plans of the coming week. Also in this meeting the team leader reports the project progress and treasurer reports the budget. During both meetings all team members take turns in coordinating the meeting and taking minutes.

**Norms and expectations:** It is a good practice for the team to develop its own rules in terms of team dynamics and expectation. Discussing these items between the team members sets the standard from the beginning of the semester and helps in avoiding conflicts later on.

**Goals and objectives:** Each team is asked to develop goals and objectives at the beginning of the project. They help to keep the team focused and clarify the priorities of the project. It is another educational tool to help the students to develop planning skills.

**Scope presentation:** It is the first public presentation for the team. It is scheduled one month after the beginning of the semester to give the students enough time to contact the customer and collect enough information regarding the project. The objective of the presentation is to evaluate the students understanding of the assigned tasks and measure if they have an initial vision of the
solution. It also forces the team to collect information about the project and explore solutions. From the customer point of view, it is an initial contract with the team for the expected product of the project. The scope presentation is also a good opportunity where FAB can provide the team with technical and management information.

**Project proposal:** By the end of the first semester, each team is required to write a detailed document describing the project, the solutions and the acceptance criteria for the final product. They should also include a detailed timeline for the project. At this stage of the project the team is almost done with the research and design phases. It is also another chance to get input from the FAB and from the customer for his expectation of the final product.

**Update presentation:** At the beginning of the second semester each team is required to give a second public presentation to show the progress of the project and review the plans to finish it. As a third event on the project after the scope presentation and the project proposal, the team should be in a good status. It also serves as another opportunity for the customer to give input to the project.

**Design review meetings:** It is required for each team to hold a technical meeting with members from the FAB, the FA and the customer before each major decision. They have to provide a handout to the invited persons forty eight hours before the meeting. In the meeting each team member should participate and the team has to prove that the selected design is the optimum solution for the problem using tools such as Pugh analysis and decision matrix. One of the team members acts as the coordinator of the meeting and minutes are taken and distributed to everybody twenty four hours after the meeting. This is a critical event in the project where both technical and management skills are taught to the students.

**Final documentation:** For industrial sponsored project, final documentation is a main part of the final product. The team and the customer decide the level of details in this document. Sometimes the document acts as a user manual for the designed product.

**Final presentation:** At the end of the second semester, the final presentation is given. It is less technical and the audiences include FAB, faculty members, customers and community members. The objective is to give the students an opportunity to present their work on another technical level.

**Peer evaluation:** Each student is required to complete a peer evaluation form for each team member including him/herself at the end of each semester. The evaluation includes both the technical contribution and the amount of effort. The objective of this process is to train the students to do professional evaluation and to add another tool of self-monitoring for the team.

The mentoring tools listed above are mix between written documents, oral presentations, management meetings, and technical meetings. In addition to help the students to stay on track, these tools create a good training environment to develop soft skills needed for engineers. They are distributed throughout the two semesters to give the students a line of guidance.
Two examples of capstone projects will be discussed in the following sections. The method explained above is applied to them with some changes based on the nature of the project.

**Project 1: Mini Baja vehicle**

The Society of Mechanical Engineering (SAE) organizes a design competition for off-road vehicles each year (Mini Baja). Each team is given the same engine, a set of rules for general vehicle dimensions, and a list of minimum safety requirements. The technical challenge is to design and build a light, fast and strong off-road vehicle and compete in an international race. The competition includes a design report, budget report, technical inspection and several racing events including acceleration, maneuverability, and durability. In other words the designed vehicle is well tested for nearly all aspects of design.

Since the project is mechanical in nature, a team of mechanical and manufacturing major students were selected. The project was divided into three main phases: design, build and testing as shown in Figure 3.

![Figure 3: The layout of the Mini Baja capstone project](image)

**Vehicle design:** During the design phase (first semester), the team was divided into two sub-teams with a faculty advisor and a faculty member acting as customer for each sub-team. The first sub-team was responsible for the structural part of the vehicle and the second sub-team was responsible for the power train. Each sub-team operated as a separate team with a team leader.
and completed the first part of the mentoring tasks presented in Figure 2. In addition to the duties listed in the previous section, each sub-team had a student responsible for coordinating with the other sub-team and a student responsible for the SAE rules. Each sub-team had three weekly meetings. The first meeting was for the sub-team to coordinate the tasks, the second meeting was with FA to report the project progress, and the third meeting was a general team meeting for both sub-teams to discuss the overall progress of the project. Separate design review meetings were held for each sub-team to make decision for their major tasks and the other sub-team was invited to attend and give input. Figure 4 shows a 3D view of the frame and the suspension system and an FEA analysis of the frame.

![Figure 4: A 3D view of the frame and suspension system and an FEA analysis of the frame.](image)

**Building phase:** In the second semester, the team was re-organized again into two main task groups: machine shop and office. A leader was assigned to each group. The job of each leader is to prepare the work schedule for all the team members and follow up on the tasks. They also report the project progress to the FA’s on weekly bases. The office managed all the administrative work in terms of competition registration, order parts, budget and writing reports. The machine shop focused on the building. All the students in the team had the chance to work in both groups. Having two leaders helped in keeping the project on track. Figure 5 shows a photo taken during the building process.

![Figure 5: Photo taken during the building process.](image)

**Testing phase:** After the vehicle was built, around mid-semester, the team was asked to prepare a detailed testing plan for the vehicle and it was approved in a design review meeting by FA’s, customers and FAB. At this phase, the team worked as one unit with one team leader who controlled the testing schedule. The testing results were used to tune up the vehicle and sometimes redesign parts. Figure 6 shows a photo during of the vehicle testing.

![Figure 6: Photo during vehicle testing.](image)

The mentoring of this project was a real challenge because of the large team size and the need to change the structure of the team during each phase of the project. From the educational point of view, the project was a very rich environment for both technical and the management aspects. The team leaders and the rest of the students had to work closely to finish the tasks on time. The FA’s and the customers had to put more time to follow up with the team leaders. The project had
a lot of areas of creativity and the students were repeatedly challenged. All the phases of the project were designed by the students and the role of the faculty members were to approve the decisions and sometimes suggest alternative options.

Figure 5 Frame welding.

Figure 6 A photo during the vehicle testing.
Project 2: Internet controlled robot

In this project, the students were asked to design and build an internet controlled robot. Based on the size of the project and the skills needed, a small team of students was assigned: one Mechanical Engineering (ME), one Electrical Engineering (EE) and one Computer Engineering (CE) student. Figure 7 shows the layout of the project. The system consists of a robot arm that interacts with a set of blocks on a table inside a work cell located in the engineering laboratory in the School of Engineering. Through the internet, a user can send orders to the robot and see it live using a set of web cameras installed inside the work cell. The objective of the project is to develop a recruiting tool to attract prospective students to engineering.

![Diagram of internet controlled robot](image)

Figure 7 Layout of the internet controlled robot capstone project.

The project was funded by the school of engineering and a faculty advisor was assigned and another faculty member acted as a customer. The main tasks of the project were to research similar systems, design and build the work cell, programming the controllers, and design the website. The project followed the flow chart shown in Figure 2

**Research phase:** Each student was asked to collect information about the project based on his or her area. The ME student explored the different designs for the work cell and the interaction table based on the working envelope of the robotic arm. The controller was the job of the EE students. The website design and the server was the task of the CE student.

**Design and build phase:** By the end of the first semester, design was completed and approved in a design review meeting. This included the work cell, the controller the server. Most of the parts were ordered during the break between the two semesters. The building took place during the second semester. A couple of design review meetings were held to approve the details of the interaction table and the website design later in the semester. Figure 8 shows a photo of the robotic arm and the interaction table. Figure 9 shows the designed work cell and a photo of the actual work cell. The designed website is shown in Figure 10.

Having a team of three students was not a challenge to manage. The real challenge was putting three students from different discipline to work together. Each one of them had his/her own area
and tended to isolate him/herself and work alone without coordinating with the others. To overcome that, for all oral presentations and technical meetings, it was required that each one of them could explain any part of the work being presented. Also for any task, one of them is leading and the other two are supporting. For example one student designed the website while the other two tested it and gave back input for the content. This method helped to improve the team dynamics however due to the nature of some tasks sometimes only one of them has the knowledge to complete the work alone.

Figure 8 A photo of the robotic arm and the interaction table.

Figure 9 The designed work cell.
Further discussions

All Engineering Schools see the value in the capstone senior project, however its teaching load is a significant task. In this section, the evaluation of the teaching load including the actual weekly hours and the official teaching load is discussed. Following that an assessment data are presented to show the student perspective for the capstone senior project experience.

**Teaching load:** Table 1 shows a summary of the main project activities and the actual hours a faculty needs to put in his weekly schedule. Usually each faculty plays more than one role in the projects. For example the author was an FA for a team and a customer for another project during the same academic year. Besides that, other teams may seek technical help from the faculty. In average, from the author’s experience, a faculty is expected to put about three hours for the senior projects every week. This time also include the review of written material such as project proposal, acceptance criteria, and final documentation.

The official teaching load is a challenge for the administration where the load is not well defined. The usual load for the presented model is an equivalence of a 3-credit hour course. For some faculty who are more involved, this load can be increased. A coordinator with a separate teaching load is needed to run the FAB and manage the project activities. Compared to other senior project models, the teaching load is slightly high. The leaning outcomes and the student benefit through several venues of interaction between the students and the faculty, in the author’s opinion, worth that extra mile.

Figure 10 A view of the developed website.
Table 1 Summary of the project activities and teaching loads

<table>
<thead>
<tr>
<th>Project Activity</th>
<th>Teaching load</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA team meeting</td>
<td>1 hr/week, (2 meetings toward the end of the second semester)</td>
</tr>
<tr>
<td>FAB meeting</td>
<td>1 hr/week</td>
</tr>
<tr>
<td>Design review</td>
<td>3 hr (at least 3 during the two semesters)</td>
</tr>
<tr>
<td>Scope presentation</td>
<td>4 hr (once)</td>
</tr>
<tr>
<td>Update presentation</td>
<td>4 hr (once)</td>
</tr>
<tr>
<td>Final presentation</td>
<td>6 hr (once)</td>
</tr>
</tbody>
</table>

**Assessment data:** To evaluate the presented model, the senior students were asked to complete an exit survey before graduation. It includes several items to assess the learning environment and the program outcome objectives. Below is a list of the survey areas that are relevant to the capstone senior project experience.

1. Apply mathematics and science to solve engineering problems.
2. Use engineering skills, techniques and modern tools to solve problems in the engineering profession.
3. Identify, formulate, and solve engineering problems.
4. Design and conduct experiments, as well as to analyze and interpret data.
5. Design a system, component, or process to meet desired needs.
6. Function on multi-disciplinary teams.
7. Understand the impact of engineering solutions in a global and societal context.
8. Understand professional and ethical responsibility.
9. Communicate effectively.
10. Recognition of the need for, and an ability to engage in life-long learning.
11. Knowledge of contemporary issues.

Figure 11 shows the results of the student survey. The students gave a high score for all items. The students were asked to put a score for their level of confidence in each of the presented areas. It is important to notes that most of these skills are introduced in all the levels of the engineering program starting from the freshman to the senior year; however the senior project reinforces and expands these skills significantly. In other words, the presented survey results reflect the success of the senior project model from the student perspective.

**Conclusions**

A model for mentoring capstone senior projects was discussed with two examples. The focus was to outline several tools to provide technical support to the senior teams during the phases of the project and help them to stay on track. A multi level supervision including a student-student managing was used. The two examples discussed included large and small team sizes of multi-discipline team of students. Both cases were two-semester projects. The model showed success in completing the projects and to provide the educational environment with a good balance between the guidance and student creativity. It is worth to mention that more faculty time was needed in the model to participate in the project activity however the educational benefit was much more.
Figure 11 Student feedback results.

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Bibliography