Creating a Process to Design a Capstone Program that Considers Stakeholder Values

Robert H. Todd and Spencer P. Magleby
Department of Mechanical Engineering
Brigham Young University
Provo, Utah, USA

Abstract
Designing or redesigning a Capstone Program is a difficult and complicated task since these programs often embody complex relationships internal and external to the department and/or college, and can be costly in terms of funding, space and faculty time. Engineering education, and capstone programs in specific, have a number of stakeholders including students, faculty, industry and academic administrators. Identifying and meeting the needs and values of these various stakeholders is essential in developing educational programs and learning activities that are effective and sustainable. In this paper a process is developed for designing a capstone program that carefully considers the values of stakeholders. Key situational considerations are discussed for a capstone program. Stakeholders in engineering education are identified and their common values are articulated. A process for developing a Capstone course, with input from these stakeholders, is proposed and evaluated in light of stakeholder needs and wants. A case study for developing a two-semester senior design capstone course at Brigham Young University is presented.

Introduction
Capstone courses have become widely used in engineering education throughout the United States. The objectives of these courses vary, but in general they are designed to help students prepare for the practice of engineering. ABET accredited engineering programs require a capstone experience. Unlike engineering fundamental courses such as statics, thermodynamics or strength of materials, capstone courses usually involve students in synthesis or design activities and often require the building of hardware. Since engineering design tends to be interdisciplinary in nature capstone courses often require significant resources to execute. Common resource issues include funding (for hardware), space and faculty time. In addition, the

* This paper is partially based on a paper presented at the Ibero-America Summit on Engineering Education, San Jose Dos Campos, Brazil, March 2003 titled Creating a Successful Capstone Program by Considering the Needs of Stakeholders.
development of product hardware may give rise to issues of intellectual property, liability and safety for the sponsoring institution. Issues such as these inevitably draw the attention of administration requiring explanation and justification.

Many capstone courses utilize design and build projects sponsored by industry\textsuperscript{5,6}. While providing valuable interaction for students, the involvement of sponsors brings more issues to deal with along with a new group of interested parties.

We will refer to each of the interested parties and individuals as stakeholders. When considering the design and organization of a capstone program, the institution should carefully consider the values of their stakeholders along with the educational objectives that they wish to accomplish. The design of the program influences both the scope of stakeholders and which of their values (and related concerns) will be most influential. Having observed the inception, operation and evaluation of a number of capstone programs, the authors have learned that a successful capstone program design process must carefully consider stakeholder values in order to prove successful in the long term.

The objective of this paper is to present a process for designing a capstone course that considers the values of stakeholders. The paper first identifies the elements of typical programs and then the likely stakeholders. This is followed by a discussion of possible capstone program models that the authors have seen around the country. These models are comprised of various combinations of the elements described previously. A case study of the design of the BYU Program is presented along with a discussion of its history and current status in terms of stakeholder satisfaction. The paper concludes by noting some additional considerations that a program designer should keep in mind.

Miller and Olds amongst others have developed curriculum models for capstone courses\textsuperscript{7}. These models vary somewhat between disciplines, but tend to have some common elements oriented towards typical capstone program outcomes. Farr et.al.\textsuperscript{8} is typical of authors that have discussed the design and organization of a particular program. In their case they address the needs of an engineering management curriculum. Moore and Berry\textsuperscript{9} have discussed industrially-sponsored design projects and the needs of industrial stakeholders. This is also addressed by Todd et.al.\textsuperscript{10} in a previous paper.

**Elements of a Design Process for Developing Capstone Courses**

Just as any engineering design or development project can benefit from the use of a structured design process—and often capstone courses teach such a structured design process, the development of a capstone course itself can also benefit from the use of a structured design process. Such a structured process would involve similar elements to those used in developing a new machine or consumer product.

A typical design process involves the following elements or steps:

- Identify stakeholders
- Determine stakeholder needs, wants and values
- Identify concepts that will meet stakeholders needs
- Evaluate and select the best concept
- Perform overall and detailed design
- Realize the design
- Evaluate and refine the design

The first element of a design process for developing a capstone course would involve identifying the course’s stakeholders. Stakeholders are those groups of individuals or organizations that have a vested interest in the success of the course, including achievement of the course’s outcomes as well as the resources needed to successfully offer the course.

Once all of the stakeholders for such a course have been identified, the next step in the design process is to establish outcomes or functional specifications for the course based on input from the course’s various stakeholders. Ideally, just as in any product design project, these outcomes would then be prioritized and weighted, once again with input from the various stakeholder groups. Stakeholders each have their various needs and wants based on their values.

Some of the various stakeholders for capstone courses include the following:
- Students
- Faculty
- Department and College Staff
- Industry Sponsors (if sponsored projects are used)
- Employers
- University administration
- Alumni
- ABET Accreditors
- Other

Another important step in the design process is to establish design constraints—including resource constraints, based on input from stakeholders. These constraints can be significant and taking the time to understand various stakeholders’ needs, wants and values can have a significant impact on the successful development and long-term operation of a capstone course.

The next step in the design process is to identify capstone concepts that will meet stakeholder needs. Certainly one way to identify possible capstone course concepts is to review the literature describing capstone courses that has already been developed. Additional concepts can also be devised from combining existing concepts as well as adding novel new portions, etc. Since engineering capstone courses tend to be more interdisciplinary in nature and also exist today in a variety of disciplines other than engineering, a large collection of ideas can be gleaned from various other disciplines.
Once a variety of concepts have been identified, the next step in the design process is to evaluate and select the concept/s that will best meet the desired outcomes and constraints established by the stakeholders. As in any design project there are usually several alternatives that can succeed and will be successful. Carefully identifying those concepts that will be supported by the faculty, staff and administration who will need to become champions for the course is also critical for its success.

One of the most time consuming parts of the design process for a capstone course, is the overall and detailed design phase. Once a concept has been selected, all of the learning activities for the course need to be designed and documented. In this phase, a wide variety of design questions need to be posed—and answered, to enable each learning activity to meet the outcomes that are to be achieved by the students taking the course. This phase also involves developing all of the documentation for the course, much the same as detailed engineering drawings, bills of material and manufacturing process plans are developed for a manufactured product.

Some of the typical documentation for a capstone course includes a detailed syllabus, selection or development of a textbook, descriptions of any deliverables or reports to be submitted by the students, detailed lesson plans, lab activities, quizzes and/or examinations, grading criteria and a host of other items such as project sponsor agreement letters, policy statements concerning intellectual property, liability, and etc.

Once the design has been completed, including its documentation, the design can begin to be realized and the course taught. As in any product development process, each step is iterative in nature and improvements are found as the design is tested and implemented. In any design process there are always feedback loops enabling improvement to be achieved. This is especially important in an educational effort as comprehensive and complex as a capstone course.

**Identifying Stakeholders and Their Values**

One of the most important steps in the development of a new product is to identify the potential product’s stakeholders. Stakeholders include customers and users of the product, as well as others that may be affected by the product. The next step is to carefully determine and analyze stakeholder needs, wants, desires and values. Learning how to do this well and to delight stakeholders is critical in the success of any product.

These same principles also apply in the design of a complex educational program. In the case of a capstone course we have identified five key stakeholders, drawn from the list above, that are interested in the operation, objectives and results of the program. These stakeholders are students, faculty, industry, academic administrators and what we call “latent” stakeholders. The values held by these stakeholders is next discussed in the context of their interaction with a typical array of Capstone programs.

**Students**
Students are the lifeblood of any educational program and should be the primary stakeholder of any education entity. Recognizing student’s needs, wants and values and then carefully considering these in the design of a program has a great impact on the long-term success of the program. As most educators know, what students value and what they need do not always match. This can be especially true for a capstone experience as student’s expectations and anxieties are generally high.

In our experience students in a capstone program want relevance and are interested in learning how to do things that will enable them to be successful in an engineering career. They are also interested in learning things that will be of value to their prospective employers and will be seen as such on their resumes.

Engineering students have heavy demands on their time and as a result have limited time to invest in activities that they see as irrelevant to their interests. They also value flexibility concerning when they will need to spend time on school work and predictability in how they should spend their time to achieve good grades. We have also found that engineering students find fulfillment in fabricating hardware to test their ideas, although this may be very intimidating to them if they have not had successful experiences doing it previously. Related to this, they are very interested in learning activities that build their self confidence, particularly activities that will build confidence in their ability to perform in the engineering profession.

Since money is often tight for students, they are interested in building and testing hardware to prove out their ideas using someone else’s money rather than their own. If students are required to use their own funds for test hardware and prototypes they will generally begin designing for low-cost (that is, they make design choices based on what is available to them) instead of making decisions that would be economically sound in an actual development environment.

Probably one of the most important things they value in their learning activities is the opportunity to work with other students on a team where everybody works. Many students have been on teams previously where some on the team may have not pulled their fair share of the load and the whole team suffered as a result. Students are interested in being part of a successful team where the members of the team work synergistically with one another to achieve success on their project.

Finally, students are most motivated to learn and then perform if they feel an obligation to a person (or persons) that is not a faculty member. This is especially true if this outside entity acknowledges their efforts and praises them. Sometimes a contest can take the place of a person or project sponsor.

Faculty
We have found that engineering faculty members seek affirmation that what they do in their stewardship is important in the eyes of their peers and their academic administration. As a result, they pursue academic products that they can “count” and are rewarded in their evaluation criteria. Individual institutions can have a great influence on faculty values by what they choose
to reward. It is difficult to sustain any program that does not align in some way with the reward system for faculty.

Faculty obviously value good learning experiences for their students. This would include receiving high student evaluations for their courses and for them as instructors. In addition, they are interested in the educational and career successes of their students. Praise of peers and administration for specific teaching efforts is clearly a motivating factor.

Often faculty are interested in learning new things themselves – especially if it will contribute to their research programs. They are interested in sources of funding for their students and for their research. Many faculty are also interested in an association with industry for consulting, a source for good student projects, feedback on their educational programs and contacts that will be of help to them and their students.

Faculty are also interested in control of the curriculum content they are expected to teach their students and the methods they will use to help their students learn. They generally value independence in selecting how they will use their time. Most faculty value the things that they themselves have learned and feel an obligation to pass these things on to their students. This focus on a particular area of expertise can sometimes lead faculty to resist teaching of material that may fall outside of this area.

Industry
One of the principal needs and wants of industry from schools is access to a pool of good graduates that they can choose new employees from. Certainly the most valuable asset and lifeblood of any industrial enterprise are its employees. Companies look to good engineering programs from academia to supply their needs for new hires that will bring success to their enterprise. For many enterprises the skills learned in a Capstone program are highly valued and may be the distinguishing factor in choosing to hire a particular student.

Industry may look to academia for help with their products and processes and makes judgments about the quality of academic programs based on their own past experiences in academia and how useful those experiences are to their current assignments and roles in industry. Often managers from industry are interested in access to the engineering and research capabilities found in academia and the creative thinking that can be found there. In particular, they are interested in new ideas they can use now.

Industry personnel are also interested in supporting their alma-mater—particularly when that support overlaps perceived company needs. Companies may also depend on academia to help them in their goal of having their employees learn new skills after graduation. This can occur as support for graduate programs for their employees—on or off campus, televised or closed circuit courses, short courses and/or a variety of other activities.
Academic Administration
The academic administration of any university is a very important stakeholder in deciding which educational programs will be pursued, the program’s educational objectives, how resources will be allocated and how the program and faculty will be evaluated and rewarded. This is especially true for capstone programs which can be very high-profile within any given program.

The administration of a university is interested in being perceived as supportive of industry and the community that the institution serves. In the case of engineering as a discipline, the administration is also interested in insuring and bolstering the reputation of their engineering programs through favorable external reviews and evaluations of the work of the faculty as well as of their alumni. One metric used by many institutions as a method of external review is the amount of external funding that is received for support of their faculty and their research interests.

As in any enterprise, academic administrators are also interested in limiting the liability of their programs and in the efficient use of their resources including physical facilities. Space utilization is often a critical metric in academia for determining program cost and efficiency. Good public relations is another key aspect of value to academic administrators.

Latent Stakeholders
There are a number of additional stakeholders and needs at each institution and often all of these stakeholders and their respective needs do not emerge until a program becomes operational. Being sensitive and open to the expressed and sometimes unexpressed needs of additional stakeholders is important for the success of an educational program. In addition, the needs and values of existing stakeholders may change over time which may necessitate changes in any given program. There are always benefits to be gained from seeking out and carefully considering the needs, desires and values of stakeholders interested in a given educational program and we can always learn from their input.
Table 1: Comparison of the values and other interests of stakeholders in the design of a Capstone program

<table>
<thead>
<tr>
<th>Students</th>
<th>Faculty</th>
<th>Industry</th>
<th>Administrators</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Values</strong></td>
<td>Efficiency in use of time</td>
<td>Production of academic products</td>
<td>Effectiveness of new graduates</td>
<td>Reputation of the institution</td>
</tr>
<tr>
<td></td>
<td>Skills that will help make them successful</td>
<td>Recognition of performance and achievement by peers</td>
<td>Curriculum applied to their industry</td>
<td>Productivity of faculty</td>
</tr>
<tr>
<td></td>
<td>Items to put on resumes</td>
<td>Efficient teaching</td>
<td>Opportunities to influence education</td>
<td>Efficient use of resources</td>
</tr>
<tr>
<td></td>
<td>Relevance of their work</td>
<td>Productive use of their expertise</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Want to Avoid</strong></td>
<td>Unpredictable classroom situations</td>
<td>Extensive preparation for courses</td>
<td>Regular time commitments outside of their work</td>
<td>Liability of all types</td>
</tr>
<tr>
<td></td>
<td>Conflicts between classes</td>
<td>Unpredictable classroom situations</td>
<td></td>
<td>Ineffective use of space</td>
</tr>
<tr>
<td></td>
<td>Poor team situations</td>
<td></td>
<td></td>
<td>Unhappy students and parents</td>
</tr>
<tr>
<td><strong>Constraints</strong></td>
<td>Discretionary funds available for projects</td>
<td>Time</td>
<td>Time to interact with educational programs</td>
<td>Budgets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compromising proprietary information</td>
<td>Legislatures or Boards</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conceptual Models for Capstone Programs

A fairly wide variety of possible concepts exists for how a capstone course might be organized, taught and administered. One of the first design decisions for a project course of this type is to decide whether or not one student team will be assigned to each individual project or if multiple teams will be assigned to compete with one another by working on the same project. Of course, there are advantages and disadvantages to each of these alternatives that should be considered. In addition, a decision needs to be made concerning how large each project team will be.

Another important decision that needs to be made is to what extent the program will seek funding from its industrial project sponsors. Funding provides many advantages, including an increased sense of ownership on the part of the sponsor for the success of the team, and also an increased sense of responsibility on the part of the students. When the students know that a sponsoring company is paying for the project, this provides a sense of realism, motivation and urgency in the minds of the student team members. Funding can also enable the team to purchase hardware for the project which increases the learning value of the project for the team.

Projects may be recruited from local, regional or national industry. Projects sponsored by local industry may have some advantages in that communication and interaction with the project sponsor by the team can be easier where less distance is involved. Nevertheless projects sponsored by industry located some distance from the school can be very successful if a commitment for good communication exists between the project sponsor and the student team.

Having student teams that are well mentored through the design process by a faculty coach can be a real advantage to student learning. If coaches are to be used for each team, training of the coaches for their role as mentors can be important and can have a significant effect on the success of the teams.

Another alternative for coached teams is whether or not the coaches will come from the regular faculty of the university or be part-time faculty who are practicing engineers from industry. A combination of these two alternatives can also be pursued.

We have seen programs that are very structured in nature and those that are not structured. By structured we mean that a design methodology is taught to the student teams and the teams are expected to use this methodology in accomplishing their project. In addition, design reviews and deliverables which document the progress of the project by the student team are required and evaluated so that the team can receive helpful feedback on how others see they are doing on their project. Another issue is whether or not instruction will be provided for the students or if they will be left on their own to accomplish the project without formal classroom instruction.

A number of factors may be considered when deciding whether or not the course will be one semester in length, or two. For example, projects may be more comprehensive and larger in scope if the course duration is two semesters in length versus one. In addition, a two semester
course may foster an opportunity for the student team to more likely be involved in both design and fabrication activities which usually provides a more comprehensive learning experience for the students.

Another issue that needs to be decided on is whether or not students will have a choice in the projects they are assigned to work on. If the projects are sponsored by industry, generally they have been arranged for ahead of the start of the course. Depending on the size of the class, having the students “choose” their projects and/or their team may not be practical. If students do have some choice in the project they work on they may have greater motivation than if they are assigned arbitrarily. Some compromise between these two extremes may be achieved by giving students an opportunity to complete an information sheet as they sign up for the course, which describes their interests and capabilities. Students may also be given a personality test such as the Hermann Brain Dominance or Myers Briggs tests as input for forming the project teams. Interest, capability and personality tests can also provide data that may be of help in insuring success of the teams.

BYU Case Study
As noted in the introduction section of this paper, Brigham Young University has conducted a Capstone course with projects provided by industrial sponsors since 1990. BYU’s educational objectives for this course have been established, at least in part, with input from its various stakeholders.

Some of the basic characteristics of BYU’s program, which have evolved over time with input from its various stakeholders are discussed in the following sections.

Course Objectives
Students taking this course will be able to:

- **Teamwork Skills**
  - Understand & use effective team processes
  - Function effectively as a team member
  - Assist team to make good decisions
  - Accept & effectively carry out assignments
  - Direct effective meetings & guide team

- **Oral Written Communications Skills**
  - Give an effective presentation
  - Develop effective, well written, concise reports

- **Project Scheduling & Planning**
  - Identify important milestones
  - Effectively use project management software
  - Track actual progress relative to planned progress

- **Analysis & Experimentation**
  - Perform analysis appropriate for the project
  - Choose analytical strategies
Conduct experiments to answer design questions

- **Detailed Part & Process Design**
  - Create part and assembly models on a CAD system
  - Create part & assembly drawings
  - Create a manufacturing process plan for a part

- **Hardware Testing**
  - Select appropriate prototypes
  - Plan appropriate tests for prototypes
  - Conduct, report and analyze test results

---

**Course Structure and Team Size**

We have chosen to have one student team assigned per sponsored project. This approach has been chosen to reduce the liaison effort with the sponsoring company that would otherwise be required if multiple teams worked on the same project. We also believe that this approach tends to foster greater ownership on the part of the student team when they know that their team is responsible for the success of the project.

We have formed our teams to be sized, typically, between 4 and 7 students with as much diversity as possible among the team members. We believe this diversity helps provide a more realistic learning experience for the students and enables them to have an opportunity to learn team process skills under the direction of the faculty coach more effectively.

**Project Information**

We consider our project sponsor funding to be moderate. This cost is based on the cost of running the educational program including the cost of providing full or part-time faculty to mentor each team through the design process applied to the team’s specific project. About 40% of this cost goes to pay for the coaching of the teams.

In addition, we have a full-time secretary and also a staff professional who assists in helping the faculty recruit projects from industry. This staff member also manages the budget for the program. Each team has a budgeted amount for the cost of hardware which also includes local travel, supplies, printing and telephone costs. If additional monies are needed for completion of the project hardware beyond this budgeted amount, the team prepares a proposal and submits it to the project sponsor for approval. If the sponsor approves the specifics of the proposal the team moves forward with the additional spending. The university has waived any additional overhead costs for the program because they consider the course to be an educational program and not a research program.

Our industrial project sponsors are found both locally and nationally. About half of our yearly 30 to 32 projects come from industrial sponsors that are within approximately a 100 mile radius of the university.

**Faculty Load Considerations**

The faculty load associated with coaching a project team over the two-semester period is...
equivalent to teaching one class for one semester. For example, if the full teaching load for a
faculty member were two classes each semester, for a total of four classes for the academic year,
coaching one Capstone project over two semesters (the duration of the project and its associated
course) would take the place of one of the four classes of a full faculty load. Typically coaching
a team of students takes a faculty member about 4-6 clock hours per week.

Course Content and Structure
We use a structured design process. We have one lecture each week throughout the two
semesters in which we present the design process, including additional topics such as intellectual
property, engineering ethics, engineering economics, conflict resolution, industrial design, team
processes and other related topics. We seek outstanding outside speakers to address the students
on these and related topics throughout the two semesters. In addition, we have 5 written
deliverables that document the status of the project. These deliverables are due throughout the
course of the two semesters. Each deliverable is evaluated by different coaches of other student
team projects and the evaluation is rotated among the coaches so that each team has a different
coach evaluate each of their deliverables. We believe this feedback diversity can be a valuable
asset to the team’s learning.

We also have a number of informal and formal design reviews of the team’s design work
throughout the two semesters. At the end of each semester a formal presentation is given by
each student team to their industrial sponsors. We also have some ‘lab’ sessions, especially
during the first semester, with about one sixth of the total number of teams present. These
smaller ‘workshop’ sessions are held in a classroom with moveable tables and chairs so the
teams can sit together during the session. Emphasis in these sessions is placed on learning how
to apply the design process, taught in the large lecture sessions, to each of the student teams. In
these sessions the teams also have an opportunity to see how the other teams are applying this
design process to their particular project and as a result, learn from each other’s projects.

Although we assign students to their projects, we do ask students to complete a biographical
information sheet noting their capabilities and interests. We also give each student the Hermann
Brain Dominance test and have used the results of this test to assist us in creating as much
diversity as possible in forming the teams.

All intellectual property that may be created by the student teams and their faculty mentors is
owned by the industrial sponsors. We have found that this policy enables us to recruit better
projects with the desired educational value and which are consistent with our established project
criteria and in larger numbers.

Alumni Feedback
Feedback from our alumni have been very positive about the course and its usefulness in
preparing them for their careers as practicing engineers. Table 1 shows the ranking of this
course by alumni in relation to other courses taken by the students during their undergraduate
degree. Note that the course received the highest rating of all of the courses offered by the
department itself. Technical Writing is offered as a service course to our students by the English Department.

**Table 1.** Average of all Alumni Responses to the Question, *In your career, how useful have the following courses been to you?* 1=Not Useful 5=Extremely Useful

<table>
<thead>
<tr>
<th>Course(s)</th>
<th>4.3</th>
<th>4.2</th>
<th>4.1</th>
<th>4.0</th>
<th>3.9</th>
<th>3.8</th>
<th>3.7</th>
<th>3.6</th>
<th>3.5</th>
<th>3.4</th>
<th>3.3</th>
<th>3.2</th>
<th>3.1</th>
<th>3.0</th>
<th>2.9</th>
<th>2.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Writing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capstone</td>
<td>4.3</td>
<td>4.2</td>
<td>4.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Elective(s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanics of Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computing</td>
<td>3.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statistics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Graphics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid Mechanics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing Processes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Thermodynamics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elements of Electrical Eng.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Eng. Math</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus II</td>
<td>3.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry</td>
<td>3.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Student Seminar</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Systems</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ordinary Differential Eqns</td>
<td>2.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1 ranks the capstone course usefulness by alumni having graduated 3 years ago, 6 years ago, 9 years ago and 12+ years.
Figure 1. Bar-Graph showing alumni feedback results to the question, “How useful was BYU’s Capstone course to you in your career?” for alumni that graduated 3 yrs, 6 yrs, 9 yrs and 12+ years ago.

Program Design Considerations

Project Selection
Project recruiting and selection is a very important consideration for a course of this type. Once the educational objectives of the course have been established with input from stakeholders, criteria describing the type of projects that are desired to assist in meeting the educational objectives and desired outcomes of the course should be developed. This criteria should be used by those recruiting projects for the student teams to work on.

Since the type of project that the student team pursues will largely drive the technical content of the student’s learning activities, careful consideration of the criteria for selecting projects is important. Recruiting projects that meet the agreed upon project criteria of the stakeholders is an important operational aspect of the program.

Teaching and Mentoring
Another important consideration is what percent of a faculty member’s full teaching load will be allocated to teaching, supervising and/or coaching project teams in the course. Will staff time be allocated to assisting the faculty in recruiting projects and maintaining good relationships with project sponsors? Will there be faculty assigned to coach or mentor each of the student teams or will each team be left on its own? These are important questions that can have an important effect on the learning experience of the students and the resources required to conduct the course and educational program.
In this type of learning experience students learn from mentoring or coaching by the faculty as the students apply a design method to a project. This approach is different than the more traditional approach of having the teacher profess information in a normal classroom setting. Some faculty may be uncomfortable in this kind of educational setting, feeling that they are losing control of the learning environment. The faculty member becomes a ‘guide on the side’, versus a ‘sage on the stage’. The project and the process that will be used to complete the project, become center stage instead of the faculty member.

If faculty coaches are used to mentor the student teams, it is important to select faculty that are interested in this type of educational activity and are committed to its success. Some training of faculty coaches may be very helpful and an ongoing effort is necessary to assist coaches in their stewardship. Being a faculty coach that enjoys helping students succeed in learning the process of design and project work versus learning the ‘material’ may be a challenge that not every faculty member is interested in pursuing. As noted above, we have seen some successful programs in which some faculty coaches are selected from practicing engineers in industry and some are selected from full-time regular faculty.

**Sponsor Relationships**

Another challenge related to the loss of educational control may occur because project sponsors may turn out to be fickle or unreliable in their interaction with the student team or faculty coach. Sponsors’ principal concern is the success of their business and that priority may cause them to slight the student team just when the team most needs feedback and help from the sponsor. These potential concerns must be managed which takes time and resources.

Another consideration is what the consequences of a poor project result will be. Not only the consequence of the grade that the students may receive, but what are the longer team consequences to the students on the team? What about the student’s self confidence as a result of having worked on a project that had poor results?

One of the most important outcomes of education is the confidence that can be built in the lives of the students. Is having the student’s confidence damaged from a poor project worth the risk of the benefits that may be achieved?

**Intellectual Property**

Another program consideration is how intellectual property, created as a result of the student project, will be handled. Will ownership of this intellectual property be given to the sponsoring company or will it be owned by the university? Typically, universities retain ownership of intellectual property created as a result of research activities by the faculty and students under their direction. However, Capstone projects may be considered as design projects and not necessarily research projects. As a result, the university may consider establishing a policy which would give ownership of intellectual property to the sponsoring company. Such a policy can help the university recruit viable projects for student teams to work on. This is an important issue that should be considered carefully in light of the educational objectives and outcomes of
the course and program.

Costs
One of the most important aspects of the educational activity is the cost of running the program. Obvious costs include hardware and supplies for the student teams, but the most significant cost is faculty time associated with instruction of the students and/or coaching or mentoring the student teams by full-time or part-time faculty. These costs need to be considered carefully in light of the educational benefits that are sought from implementation of the program.

Obviously there are many other factors that should be considered in designing such an educational program, only a few of which have been discussed here. The important part of the design process in developing such a program is to continuously seek to improve it over time. This can only occur if those administering and teaching in the program continue to seek input from the various stakeholders of the program. If this is carefully done, the educational outcomes sought by the program will be achieved by the students.

Conclusion
Capstone courses have become an important part of engineering education for a variety of important reasons. The use of a design process that involves the needs, values and want of stakeholders provides an important foundation for developing capstone courses that will be successful.

Bibliographic Information


6 See reference #1


10 Todd, Robert H., Carl Sorensen and Spencer Magleby, *Designing a Senior Capstone Course to Satisfy Industrial Customers*, *Journal of Engineering Education*, April, 1993, pp. 92-100.