International Journal of Engineering Education Vol. 27, No. 6, pp. 1164–1173, 2011
Printed in Great Britain
0949-149X/91 $3.00+0.00
© 2011 TEMPUS Publications.

Pedagogical Implications of Project Selection in Capstone Design Courses*

PATRICIA BRACKIN
Rose-Hulman Institute of Technology 5500 Wabash Ave, CM 165, Terre Haute, IN 47803, USA. E-mail: brackin@rose-hulman.edu

DEAN KNUDSON
North Dakota State University NDSU Computer Science #2740, P.O. Box 6050, Fargo, ND 58108–6050, USA.
E-mail: dean.knudson@ndsu.edu

BAHRAM NASSERSHARIF
212 Wales Hall, University of Rhode Island, Kingston, Rhode Island, USA. E-mail: bn@uri.edu

DEBORAH O'BANNON
Civil & Mechanical Engineering Department, University of Missouri-Kansas City, 5100 Rockhill Road, Kansas City, MO 64110, USA.
E-mail: obannond@umkc.edu

The heart of the capstone experience is the project itself. There are a variety of projects used in capstone design: projects sponsored by industry with or without a fee, service learning projects, student competitions, campus projects, 'paper designs,' and faculty projects. The project management can range from being managed completely by the faculty advisor or the project sponsor to those that are completely managed by the student team. Teams can be allowed to fail or the faculty project advisor can ensure successful completion. Projects may emphasize creativity and/or communication and/or technical depth. This paper evolved from a panel discussion of capstone projects at the Capstone 2010 Design Conference and notes the distinct differences between project types.

Keywords: project selection; project management, program assessment; capstone design

1. Introduction

Capstone design courses have been part of the engineering curriculum for over 30 years. The capstone course is intended to be the culmination of a student's undergraduate experience. Students are expected to creatively analyze, synthesize, and apply knowledge from other courses in addition to learning any additional knowledge that is needed for their project. Accrediting agencies recognize the importance of design, and ABET has established three requirements relevant to the capstone course in their general requirements for engineering baccalaureate level programs:

1. Criterion 3, Student Outcomes, element (c) specifies that graduates must demonstrate 'an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability' [2].
2. Criterion 5, Curriculum element (b) defines design as the 'process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs' [2].
3. Criterion 5, Curriculum, further requires that 'students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints' [2].

At the heart of the capstone design experience is the project itself. Although much attention has been given to the design process, the nature of the project itself has not received as much attention [6]. Project sources can range from projects with industry, with or without a fee, service learning projects, student competitions, campus projects, multidisciplinary projects, faculty projects, 'paper designs,' projects proposed by students, and international projects [5, 12, 14–15]. The project management can range from being managed completely by the faculty advisor or the project sponsor to those that are completely managed by the student team [5, 20].

The interaction between the type of project and the management of the project has implications for student learning.

For capstone design courses, Cheville identified attributes of successful design projects to include 'being viewed as worthwhile' [13], related to the engineering discipline [13], and involving 'modern

* Accepted 15 June 2011.

and emerging technologies with which most of the students would have some familiarity' [6].

This paper evolved from a panel discussion of capstone projects at the Capstone 2010 Design Conference and contains observations made during that discussion. The panel identified the importance of 'cool' projects. There are some projects that capture the imagination of all involved in a way that others do not and bring sustained interest in the difficult design work. Projects have intrinsic appeal when they include innovative technology, allow a wide range of creative solutions, and/or are related to current cultural issues.

This paper discusses the pedagogical implications associated with the various design projects from the perspectives of experienced design instructors from several different disciplines. The intent of this paper is to suggest issues associated with possible types of projects, give suggestions for consideration by the audience and provide insight to the reader. The paper is divided into four sections: project selection, project management, avoiding project pitfalls, and crisis management.

2. Project Selection

The panel agreed that there are certain projects that are ideal for administration and student learning. Unfortunately, it is not always possible to identify those projects ahead of time. Many times it is only as the project unfolds that its fit becomes apparent. Reflection on successful projects helps instructors determine good projects before they are adopted. Table 1 characterizes each project type that will be discussed, rates its potential for the suggested criteria, and highlights possible pitfalls.

2.1 Industrial projects

Industrial projects comprise the largest percentage of many program's capstone projects [3, 9–10]. As shown in Table 1, industrial projects have a high potential for success. The company is responsible for motivating the students about the necessity of the project. Industrial projects, because they are sponsored by companies, are connected to the engineering discipline. Industrial projects can have the potential to apply emerging technologies. Selecting the appropriate project and scope is key to a successful educational experience. Some fields (e.g. civil engineering) typically have large, highly-complex projects [18]. Careful deliberation on project scope can yield exciting student-sized projects, even in fields where professionals work on large teams [17]. The major pitfalls with industrial projects arise with mismatched expectations: who is in charge? what is the deliverable?, and what is the relationship with students? If students feel they are being used for 'grunt' work, their motivation drops drastically. Industrial projects offer great advantages for the university. These can include cash donations, equipment donations, mentoring of students, potential student employment, faculty consulting, faculty research, and faculty sabbaticals.

Perhaps the biggest question that a program must answer is whether or not to charge companies for the project. Typical charges to companies that are reported include requiring reimbursement for approved, out of pocket student expenses; nominal

Table 1. Classification of Projects to be Discussed

Project Type	Viewed as Worthwhile	Related to Engineering Discipline	Modern and Emerging Technologies	Student appeal	Possible Pitfalls	Potential Benefits
Industrial	Low to high	Medium to high	Low to high	Low to high	Mismatched expectations	Improved relationship with industrial partner
Service Learning	Medium to high	Low to high	Low to high	Low to high	Potential liability	Publicity and emotional recognition of engineering potential
Student Competition	High	Medium to high	Medium to high	Medium to high	Failure	Serves as benchmark, strong link to university
Faculty Projects	Low to high	Medium to high	Medium to high	Low to high	Student motivation	Meets a real university need
Paper Designs	Low	Medium to high	Low to high	Low to high	Student motivation, institutional memory	Designed to include relevant areas

charges ($500—$2000) to cover expected expenses, and substantial amounts ($20,000 or higher) to purchase equipment and enhance the educational environment at the university [3, 8, 10]. The decision to charge for services can affect project management. In cases where the charge is very high, either the company contact or the faculty project advisor take responsible charge of the project and students function as apprentices. The person with responsible charge of the project must ensure that the project is successful and may have to actually complete the work if the student team is not able to do so. For smooth projects it is imperative to ensure that all participants agree who is in charge.

A broad continuum exists for the role of the company contact: one that depends on the expectations of the company contact, their employer, and the university. The university may leverage the capstone design practitioners to develop a more active alumni/ae association, and may often build multi-dimensional relationships with the clients through the capstone experience. The client has the opportunity to preview the graduating class, and exercise early job recruitment. The company contacts bring expertise (technical and business) which may not be available among the regular faculty for the capstone class. Certainly, several external influences (ABET, NCEES) encourage the inclusion of practicing professionals in the undergraduate curriculum. The geographic distribution of the clients and company contacts with the university will, of course, affect the intensity of the practitioner's role. High involvement of company contacts in the capstone design experience can benefit all parties, but even mixed or low involvement still has strong educational benefits for the students. Many of the aspects of the company contact's role are explored in Table 2.

The degree of design supervision, as shown in Table 2, can range from merely answering questions when asked to explicit direction of all student work. Occasionally, company contacts think that students should learn everything without help and refuse to answer questions. While it is true that student learning can be very high in this situation, student frustration is also very high. Many companies strive to find a middle ground where the company contact acts as a mentor, receiving periodic updates and offering advice and support to the team. It is possible to mentor and still allow the students to have responsible charge of the decisions that are made throughout the project. It is important that a program develop and articulate the expectations for company contacts. Some academic programs have developed primers for company contacts that detail the expected role. Clear communication about the expected role of the company contact reduces the potential for mismatched expectations.

Another important aspect shown in Table 2 is the company contact's attachment to the university. The industrially sponsored project allows the university to reestablish contact and maintain a close relationship between the program and the company. Often employment opportunities for students and/or interactions with the program result from the relationship. Company contacts are good sources of speakers for classes and student sections of professional societies. Many company contacts

Table 2. Continuum of Interactions between Company Contact and Design Team

Interaction aspect	Low involvement	High involvement
Role at the university	Only provides project	Serves as adjunct professor
Design supervision	Provides project and design specifications, answers questions	Directs student team through design
Frequency of student contact	Occasional	Primary contact on design work
Benefit to company contact	Acts as role-model, gives back to the profession	Company contact's career development is a priority at university
Company contact's attachment to university	Only for project	Relationship is reinvigorated, and now participates in alumni association or Dean's advisory board
Tangible benefits	Release time from employer	Adjunct professor salary
Project challenge	Academic redesign of existing project	New design with sponsor commitment for implementation
Student product quality	Academic-standards for term paper and design drawings	Client-quality standards for report (including quantities) and design drawings
Student professional development	Works with company contact	Company contact discusses engineering ethics, business issues, professional registration, etc.
Intangible benefits	Goodwill between company and university	Good publicity for the university, donated equipment or materials, internships or jobs for students

find interaction with a student team to be rewarding and they feel as if they have made a difference in the students' development.

Whether or not a program accepts course projects that are on a critical path for the sponsor is an important decision. If the program accepts a project on the critical path, there must be high expectations of success.
Accepting a program on the critical path may lead to high stress in the student team and project faculty advisor. The authors recommend that programs be explicit concerning whether or not they will accept projects on the critical path of a company. Although the projects can be extremely high stress, they can also lead to a deep sense of fulfillment.

Another characteristic of successful projects as noted by the authors is the 'cool' factor. Students want to work on things that are interesting, not drudge work that no one at the sponsoring company wants to do. Some programs assign projects to students while other programs require students to bid on projects. If students are allowed to bid on projects, sponsors want to have projects that will appeal to the best students. It should be mentioned that any project that requires a great deal of domain knowledge that requires significant time to acquire (e.g. special accounting rules, complex unique hardware interfaces, an understanding of detailed radar workings) should be avoided. When recruiting companies for projects, programs need to be explicit concerning the matching of company projects with students.

Good projects should stimulate student creativity. Industrially sponsored design projects have the capacity to be successful as long as companies keep in mind the first two criteria suggested by Cheville—the projects are viewed as worthwhile to the company by the students and the projects are related to the engineering discipline. The capstone faculty member can make suggestions to companies about which projects would appeal most to students, and students can be encouraged to consider emerging technologies. The authors have experienced rewarding and affirming projects characterized by student teams who develop a concept that is totally unexpected by the company, new to both the company and students, and solves the problem elegantly.

The final potential for mismatched expectations is project deliverables and the ability for a team to fail. Programs are advised to state deliverables explicitly and share failure statistics, if applicable. (In some programs, the faculty member is responsible for completing the project if the students are not successful.) In the event that a team fails, communication with the company concerning the nature of the failure is recommended. In addition, sharing the learning experienced by the students can help the company cope with a failed project.

2.2 Service learning projects

Service learning projects are typically sponsored by a community partner and give students the opportunity to interact with people outside their socioeconomic groups and disciplines, and also to include issues other than engineering. The community partner may be local or could be international as in the case of Engineers without Borders. Key components of service-learning include reflection and reciprocity [16, 19]. Reflection requires the student to ponder and articulate the service learning experience. Reciprocity requires that students meet actual community needs—not contrived needs—to address desired learning outcomes.

Table 1 indicates that service learning projects are more likely to be viewed as worthwhile. This is because students meet with a client who expresses a real need. Because of the open-ended nature of the problem, the solutions may not be as technical or 'cool.' Depending on the type of project, there may be liability issues. The program must decide if the potential benefits to students in seeing engineering benefit mankind in a very personal way and to the university in positive public relations offsets the possible liabilities.

There are several aspects of service learning projects that are quite different from industrial projects:

(a) Problem statements are not given in engineering terms. In the service-learning projects the problem statements are often ill-defined and rarely specified in engineering terms. For example, one problem statement consisted of, 'My daughter is getting too heavy for me to pick her up.' These broad statements require that students listen attentively, think creatively, and then design a product to meet a specific need.
(b) Projects often require a creative approach. A high level of technical expertise may not be required, but rather an innovative use of common components to meet a very specialized need. For example, students used a four bar mechanism to allow a student with limited arm motion to brush her hair.
(c) Students must communicate effectively with nontechnical clients. The students may need to communicate with disabled clients and medical personnel. Students, as seniors, have become familiar and comfortable with technical jargon. They must set aside their jargon in order to talk to their clients and they must learn to listen and understand medical terms. In addition, many students choose to find funding

for their client and they must ask local groups for money. Soliciting donations is a new experience for most engineering students.

(d) Students work with a greater variety of outside groups. When working on an industrial project, students usually work with the company and potential suppliers for their proposed design. In service-learning projects, students must work with a variety of different groups. From past experiences, the students have worked with the end user, the end user's family, the medical therapist, vendors, machinists, middle school teachers, and funding sources.

(e) Students develop empathy for the end user of their design. For many of our students, this is their first opportunity to work with the disabled or those from another, poorer culture. The students often voice how much they have taken for granted. They realize that for their clients even the simplest task is enormous, or that the simplest comfort is not available. The groups see their client as an individual who is trying to cope with a serious problem.

(f) Students gain great personal satisfaction from helping others. As they develop empathy for their clients, the students want to help them. In some cases, the group knows that their client will only get worse as the disease progresses. In other cases, the group knows that the client will not live a normal life span. This knowledge gives urgency to their work: they want to help right now. Being able to see a person use their design and improve the quality of their life provides enormous satisfaction to the groups. They feel that they have made a difference for someone, and they see the results of their work.

(g) Students mature. In the service learning projects, students are the 'experts' for the first time in their technical career. With industrial projects the students are seen as novices who might offer help to the company. In the service learning projects, the students are seen as the experts who will make a difference. They are the ones with the technical background who can make the decisions.

(h) Students encounter unusual pitfalls. Students may overestimate their ability to supply what the customer needs. Students are often enamored with their designs and cannot imagine potential failure modes. Clients see the students as experts and do not understand the necessity of consulting an expert to verify the students' work. If another culture is involved, particularly a third world setting, students may not understand the cultural context well enough to define the needs of the community [16].

The university also benefits from service learning projects. Quite often universities use service learning projects to demonstrate that engineering benefits mankind and as a means of recruiting students. Service learning projects also indicate an interest in the community and help develop long term relationships with the community. As interest in sustainability has increased, some universities are using their facilities or maintenance departments as the service learning client. There are real opportunities on college campuses to introduce significant savings and provide interesting designs while partnering with another entity on campus.

In summary, the qualities of service learning projects as shown in Table 1 are viewed as worthwhile to the client by the students, the project may or may not be related to the engineering discipline, the project may or may not use emerging technologies, the project may or may not be 'cool,' and the project may or may not include modern and emerging technologies. For students who select service learning projects, the worth of the project to the client seems to eclipse the other considerations.

2.3 Student competition projects

Student competition projects are often sponsored by professional societies or governmental entities. Some well-known projects include Design-Build-Fly by AIAA, the concrete canoe by ASCE, and the Human-Powered-Vehicle sponsored by ASME. Students have great ownership of the student projects. Although there is a faculty project advisor, students assume responsible charge of the project. As shown in Table 1, student competitions are viewed as highly worthwhile, intrinsically exciting, and centered in the engineering discipline.

The differentiating characteristics of the student competition project are as follows:

(a) Students are more committed to the student competition projects. They develop a team spirit and often work between 20 and 30 hours a week on their project. They often stay at school over holidays or breaks to work on their design.

(b) Students are more open to finding efficient ways to design. They will avail themselves of modeling techniques, testing equipment, and prototyping.

(c) Students must participate in all aspects of the design process. They often fabricate parts, assemble parts, perform maintenance, transport the design, and finally dispose of the design.

(d) Student activities and learning are more varied. They are often involved in fund raising, travelling to the competition, identifying vendors, working with suppliers, and arranging transportation of their design to the competition site.

(e) Students often develop a closer relationship with the university. Returning graduates often mention that they continue to feel a part of the university as they follow the progress of the current team.

(f) Students find the actual competition a learning experience. Evaluating the performance of their design against other designs gives students insight into other possible design paths.

Student competition projects that are successful are often used in university recruiting literature. The projects allow students to benchmark their performance on a particular project against the performance of students from other schools. When a student competition team is successful against the competition, students are energized, motivated, and gleeful. When a student competition team fails, students are typically disappointed. Although their learning may have been very high, students will discount the learning if they don't do well at competition. It is the responsibility of the faculty advisor to console and to guide reflection on the experience. In summary, student competition often fulfill all of the criteria in Table 1—the projects are viewed as worthwhile to the students, the projects are related to the engineering discipline, the projects use modern or emerging technologies, and the competitive atmosphere maintains high student interest.

2.4 Faculty projects

Another source of capstone design projects can be faculty projects. These projects may be tied to a faculty member's research area—perhaps a fixture or experimental device is needed. These projects can often be quite successful and are very similar to the industrially sponsored projects. Table 1 shows the range in ratings for these projects. The need for the project depends on the students' perception. As long as there is a perceived need, and the need has a 'cool' factor, students respond to the need. The person with responsible charge for the project should be determined before the project begins. If both the faculty sponsor and the student team think that they have responsible charge, it is difficult to complete the project successfully. If the students don't see the project as a 'real project' there is a potential for low motivation. Faculty members who can motivate students have seen a high level of success.

2.5 Paper designs

Some institutions determine the learning outcomes that they wish to obtain from a design project and then develop the 'perfect project' that addresses all of the concerns. With some iteration it is possible to develop a hypothetical project that contains all of the desired features for a project. As shown in Table 1 the drawbacks to this approach include student motivation and institutional memory. Students are not as motivated by a hypothetical project as one that they perceive to be real. In addition, students are very good at passing hints, suggestions, and sometimes solutions to the following class so it is difficult to know if each succeeding class is getting the same experience. When comparing these projects to the Cheville criteria—the project may not be viewed as worthwhile by the students, the project is related to the engineering discipline, and the project can be design to use modern or emerging technologies.

3. Project management

Thoughtful project management guides the best capstone experiences. No matter the type of design project (industrial, service learning, etc.), the development of a consistent and well-documented framework for management of design teams and their projects is very important to success of the capstone design experience. Project plans are also important in teaching and communicating the complex process of design project assessment to the student teams. Student teams are better equipped to respond to the demands of the capstone experience when they have an understanding of the evaluation metrics for their projects. Reference 4 details some of the best practices in designing an effective rubric for capstone design projects.

Project management is the process of decomposing, estimating, planning, organizing, optimizing, and managing tasks and resources (people, money, time) to accomplish a defined objective within constraints on resources. Student teams struggle with the entire process of project planning because of their limited experience with the project, costs estimating, organizing, managing, and even considering such aspects as people, facilities, money, and time. Their first attempts at project planning result in a very top level and not detailed plan. However, as the semester progresses their depth of knowledge about the project and execution of the various steps increases and their plans evolve along with the execution of the project. In many cases, the plan progresses at the same speed as the project itself serving as a log of activities performed. However, this is also useful to their learning experience and future endeavors in planning.

Project planning consists of several phases:

(a) Formulate a problem decomposition (estimate the project details). This task is extremely challenging at the beginning of the design cycle because the problems are generally ill-defined or very roughly defined. Decomposing a problem that is not fully understood or defined by its very nature is extremely difficult and vague. As the problem definition matures, the decomposition also becomes clearer.

(b) Develop an initial project plan (tasks, assign resources, analyze). The initial project plan may follow a template from the textbook or from past years' experiences. This initial template is a good starting point for project and team specific refinements.

(c) Refine the project plan to meet constraints on resources. Each project will have specific constraints and resources that will need to be incorporated and plans developed to address those constraints or maximize efficiencies of utilization of resources.

(d) Track and manage the project; report to sponsors and faculty advisors. Tracking and managing the project based on the initial plan is an iterative process. Design teams will need to frequently (weekly) review their project plans, update, and use it to communicate their progress as well as their future plans. Faculty advisors and sponsors will also need to review the project plans and provide feedback to the team regarding their progress and planned activities.

(e) Complete the project, communicate details. Project plans are an important part of the final project reporting and communication of the details of the design activities, progress made, resources utilized, budget, and accomplishments.

Student teams have significant limitations on time (constrained by academic calendar and semester boundary), resources (software, financial, laboratory, machine shop, manufacturing facilities, etc.) and scope (extent of team's experience and knowledge, constrained by project sponsor, academic credit for design course, etc.). As teams plan their projects they must consider the following overarching topics:

(a) Time—The constraint on duration of the overall project as well as each task is constrained by the boundaries of the academic semester. Many programs use a two-semester capstone design sequence. Duration of each phase of design will need to be carefully allocated because this is critical to on-time completion. In a two semester capstone design sequence, there is a major timeline interruption during the winter break. The course instructor(s) will need to establish clear milestones for each semester; for example, complete a prototype by the end of fall semester followed by operation, testing, and redesign during spring semester.

(b) Resources—The constraints on project budget in money, people, equipment, facilities will need to be analyzed and understood by the team. Resources will constrain and limit the scope of the project and define the boundaries of the design options available to the team. Resources may be provided internally by the university, by the sponsoring company, or a combination of both. Project resources will determine the scope of the project that would be feasible in the time allotted for the capstone design course(s).

(c) Scope—The constraint on goals and tasks of the project and the amount of resources required to complete the project. Scope of the projects is driven by both time and resource constraints. The team (and the course instructor(s)) must assess the scope of the project against time and resources to guide the project execution towards a successful conclusion.

3.1 Project strategy

Student design teams need to develop a strategy for their project before starting to plan their project or use project management software for their project (such as Microsoft® Project). Their strategy should include objectives, scope, assumptions, limitations, resources needed (people, equipment, facilities, etc.), and budget (money) for their project. Professors teaching design courses typically will cover some topics in project management to introduce the topic to the design teams. For example, at the University of Rhode Island, two class lecture hours are allocated to the topic and an online module was developed that students can review outside of scheduled lecture hours to learn about project management and implement their project plan in Microsoft® Project.

3.2 Tracking progress

Design teams must use their project plans to track their progress, monitor their activities and effectiveness and make adjustments to completion status, people resources, budget, and dependency state of each task. Continuous tracking results in continuous improvement of the project plan and execution.

After the team's project has been set up and started, they can adjust actual start dates, finish dates, and percentage complete status of each task. This activity is a tremendous learning opportunity for student teams to excel in project planning and management. It is also crucial to their successful execution of the work.

4. Avoiding project pitfalls

It is noteworthy to also discuss some causes of failures or below expected level of performance on capstone design projects.

(a) *Attitude.* The number one reason why capstone design projects fail is student attitude towards the project, team members, or whatever is distracting them from the focus of being successful with the project. Attitude is the most important enabler or inhibitor of success.
(b) *Scheduling and Resources*. Not enough time, planning, or other resources. Many projects fail because students underestimate the amount of time required for various steps or they procrastinate in planning or getting started. Sometimes a lack of resources (funding, machining facilities, manufacturing facilities, technician support, etc.) can interfere with success of design projects.
(c) *Project Scope.* Unclear goals or expectations; taking too long to define the problem. Design problems by their very nature are ill defined or ill posed. Open ended problems that originate from an industry sponsor are typically difficult to solve and not very well defined.
(d) *Managing Uncertainty.* Student design teams have extremely limited experience in their education in dealing with open-ended problems. The nature of our engineering education programs has been to provide textbook problems that are completely closed and for the most part have only one correct solution. Students are trained and educated with these types of problems until they experience open-ended problems during capstone design. The vast space and scope of the problems confuses even the best of students. Confusion results in taking too long to define the problem. Taking too long in problem definition reduces the actual amount of time available to the team to do the design work. The result is a product or design that is less than expected.
(e) *Project Conflict.* Unresolved disagreements among the people involved. Disagreements regarding the project, problem definition, and details can originate from any number of sources concerned with the project. For example, the team members may disagree on approach or scope to their problem, or the sponsor and the team may disagree on a particular solution or approach. Any unresolved disagreement from whatever source can delay the project and progress. The timeline on capstone design projects is extremely constrained by the academic calendar and consequently any source of delay will interfere with success of the project.
(f) *Clientele*. Poorly defined audience—'trying to please everyone'. Sometime projects fail because the audience for the project is not well defined. For examples, student team might assume that they are designing a product to please their professor as opposed to the actual client. Projects can also fail if the scope remains too broad trying to please a large number of desires or too broad of an audience.

It is important to note that the authors have noticed that failure of a project does not always equate to failure to learn. There have been several instances where the failure taught the students the importance of a certain step in the design process or of explicitly stating assumptions. One example was a high performance competition team that had spent hours designing and testing a craft for the AIAA competition. The university was located at sea level but the competition was held as approximately 5,000 feet. The team failed to take into account the difference and the craft did not fly at the higher elevation. Their failure drove home to that team and ever other senior design team that year the importance of defining the environmental use factors for a design. Although the team was dispirited, they and the entire class learned an important lesson.

5. Crisis management

When project planning and management fails because of the reasons discussed previously, an emergency situation arises for the capstone design team. In emergencies, team problem solving is unusually challenging, especially if grades, careers, or sponsors depend on finding a solution immediately. 'What on earth were the students thinking?' is usually the question going through the professor's mind. Perhaps they were hoping more than thinking. But even if we knew what they were thinking then, it wouldn't help them fix this now.

Managing a crisis occurs often in capstone design projects. Professors and student teams will need to work together to get through the crisis. It is important to manage the crisis [21]. Some tips for professors (and students):

(a) Blame and problem solving do not mix. 'I told you so' does not work. Teamwork in crisis situations requires special care. Shifting the blame does not help the capstone design team in focusing on the problem at hand. If the team survives the crisis, there will be time for accountability through the evaluation (or peer review) process. If the team or project does not survive, finding fault will not matter. Keep the team focused on resolving the issues leading the crisis.

(b) Ignoring the conflict does not work. The professor may need to intervene in the situation.

(c) Assessing solutions on their merits must become the focus. The creditability of the originator of a proposed solution is less important than the value and effectiveness of each solution. In a crisis, the workability of the solution is more critical than team dynamics or politics.

(d) The team must act decisively and immediately. Frequently the reason that the project is in crisis is because the team is delayed in their progress. Delaying action entails risk to the project and to the team. They can no longer afford to leave problems unresolved and must act immediately and decisively.

(e) Students must let go of the focus on themselves. Their self-interest is less important than the interest of the team and project success. For example, it is not acceptable for students to be solely concerned with their own grade on the project when the entire project is at jeopardy.

(f) Team members must accept and honor their interdependence. As a member of the team, they must accept the responsibility or make a commitment to the project and honor the team's expectations. Unless they make every effort to work toward the success of the project, doing something different from what they promised can seriously complicate the crisis.

(g) Listen and adopt a positive perspective. In a crisis, descriptions of problems or other bad news provided by the team members is often fractured, unclear or disjointed. Faculty should listen patiently and save questions for the end of the report. Most important, faculty (and students) should adopt a positive perspective. When comparing alternatives, discussions should be framed in terms of the relative advantages of the options, rather than their relative disadvantages.

6. Conclusions

There are attributes that suggest a successful capstone project: perceived worth of the project, relation to the engineering discipline, use of emerging technologies, and a 'coolness' factor [6]. Despite these attributes, finding a successful project remains an art rather than a recipe. Once the project is selected, there are strategies for project management. Scoping, planning, and tracking progress are valuable tools for maximizing the success of a project. However, even with the suggested tools, there will be crises. Having a crisis management plan enables the capstone practitioner to respond to the crisis in a calm and rational manner. While a failed capstone project often leaves both the student, sponsor (if applicable), and faculty project advisor disappointed, this doesn't mean that learning has not taken place. The authors have noticed that the overconfident student sometimes has to fail before developing the willingness to listen. Even though a failed capstone project has learning potential, most practitioners prefer a successful project.

This paper addresses the implications of various types of design projects and offers advice on project management and crisis management. The authors seek means for improving the capstone course because they have experienced the benefits of a successful capstone project. A successful capstone project energizes all the participants. It provides a valuable learning experience, gives the participants' confidence, and often provides a lasting benefit to the sponsor and a sense of pride to the student and faculty member. For further work, it may be interesting to quantify the various aspects used to compare types of projects, develop additional criteria to those presented by Cheville [6] and the authors of this paper, and practice predicting success of projects before execution.

References

1. A *Guide to the Project Management Body of Knowledge (PMBOK)*, Project Management Institute, 2000.
2. *Criteria for Accrediting Engineering Programs*, 2011–2012 Review Cycle, http://www.abet.org/forms.shtml , 2010.
3. P. Brackin and J. Gibson, Methods of Assessing Student Learning in Capstone Design Projects with Industry: A Five Year Review, *Proceedings of the 2002 ASEE Annual Conference and Exposition*, Montréal, Quebec 2002.
4. B. Nassersharif and C. Rousseau, Best Practices in Assessing Capstone Design Projects, Capstone Design Conference 2010, Boulder, Colorado, 2010.
5. M. Cambron, W. Collett and S. Wilson, Recent Capstone Design Projects at Western Kentucky University, *Proceedings of the 2008 ASEE Annual Conference and Exposition*, Pittsburgh, Pennsylvania, 2008.
6. A. Cheville, Designing Successful Design Projects, *Proceedings of the 2010 ASEE Annual Conference and Exposition*, Louisville, Kentucky, 2010.
7. D. Davis, J. McCormack, S. Beyerlein, M. Trevisan, H. Davis, R. Gerlick, P. Thompson, S. Howe, P. Leiffer and P. Brackin, Assessing Team Member Citizenship in Capstone Engineering Design Courses, *International Journal of Engineering Education,* **26**(4), 2010, pp. 771–783.
8. P. C. Dinsmore and T. J. Cooke-Davies, Right Projects Done Right: From Business Strategy to successful Project implementation, John Wiley and Sons, Inc., 2005.
9. S. Howe, R. Lasser, K. Su and S. Pedicini, Content in Capstone Design Courses, Pilot Survey Results from Faculty, Students, and Industry, *Proceedings of the 2009 ASEE Annual Conference and Exposition*, Austin, Texas, 2009.
10. S. Howe, Where Are We Now? Statistics on Capstone Courses Nationwide, *Advances in Engineering Education*, **2**(1), 2010.
11. L. Ireland, *Project Management*. McGraw-Hill Professional, 2006.
12. J. Layer and C. Gwaltney, International Capstone Design

Projects: Evaluating Student Learning and Motivation Associated with International Humanitarian Projects, *Proceedings of the 2009 ASEE Annual Conference and Exposition*, Austin, Texas, 2009.
13. J. A. Marin, J. E. Armstrong and J. L. Kays, Elements of an Optimal Capstone Design Experience, *Journal of Engineering Education*, **88**(1), 1999, pp. 19–22.
14. I. Milanovic and T. Eppes, Capstone Projects for Engineering Technology: Issues, Benefits and Trade-offs, *Proceedings of the 2009 ASEE Annual Conference and Exposition*, Austin, Texas, 2009.
15. S. Nokes, *The Definitive Guide to Project Management*, 2nd Ed. London (Financial Times/Prentice Hall): 2007.
16. D. Nieusma and D. Riley, Designs on Development: Engineering, Globalization, and Social Justice, *Engineering Studies*, 2010, **2**(1).
17. D. J. O'Bannon, E. G. Schmitz and T. J. Kimes, How a university-public works partnership benefitted civil engineering education and the municipality, *Journal of Public Works & Infrastructure*, **1**(1), 2008, pp. 107–116.
18. C. Somerton, A Solar Heated Worm Compost Bin, *Proceedings of the 2009 ASEE Annual Conference and Exposition*, Austin, Texas, 2009.
19. E. Tsang, Why Service-Learning? *When Community Enters the Equation: Enhancing Science, Mathematics and Engineering Education through Service-Learning* Campus Compact, 1998, pp. 13–28.
20. G. Watkins, Defining the Role of the Faculty Advisor in a Mechanical Engineering Capstone Design Course, *Proceedings of the 2009 ASEE Annual Conference and Exposition*, Austin, Texas, 2009.
21. J. Weiss and J. Hughes, Want Collaboration? Accept and actively manage conflict. *Harvard Business Review*, **83**(3), 2005, pp. 93–101.
22. J. Widmann, Enhancement of Capstone Industry Sponsored Senior Projects Through Team-Based, Product Realization Activities, *Proceedings of the 2008 ASEE Annual Conference and Exposition*, Pittsburgh, Pennsylvania, 2008.

Patricia Brackin is a Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. She has significant industrial experience as a designer and is a Professional Engineer. She has taught design classes, including capstone, for over 30 years. She is a consultant in developing assessments for capstone design and has advised over 100 capstone projects during the past ten years. In addition, she is a member of the Engineering Accreditation Commission of ABET and serves on the Committee for Engineering Accreditation for the American Society of Mechanical Engineers.

Bahram Nassersharif is a Professor of Mechanical Engineering and Distinguished University Professor at the University of Rhode Island. He has over 28 years of experience in teaching and research and over 10 years of experience in developing and teaching senior capstone design courses in mechanical engineering. He has supervised a large number of design projects over the past four years (48 projects involving 242 students). Approximately 70% of the projects are industry sponsored, 20% are national design competition projects and 10% are research originated. Dr. Nassersharif was the recipient of a Presidential Young Investigator Award in 1986. He has over 110 technical refereed contributions in journals and conferences. He has been continually funded since 1983 for his research totaling over 15 million in a total of 46 projects from government and private sources including: NSF, US DOE, US DOD, US NRC, NASA, Los Alamos, SAIC, and Boeing.

Dean Knudson is an Associate Professor in the Computer Science Department at North Dakota State University. He has over 35 years of management experience including director level with over 80 software developer direct reports. He has worked for companies including Bell Labs, ITT Advanced Technology Center, Honeywell Systems and Research Center, Northrop Grumman and Microsoft. Dr. Knudson has led over 60 very successful Computer Science capstone team projects over the past five years for companies such as IBM, 3M, Rockwell Collins, Microsoft, Thomson Reuters, Polaris and John Deere.

Deborah O'Bannon is an Associate Professor of Civil Engineering at the University of Missouri-Kansas City. She is a Professional Engineer, a Fellow of the American Society of Civil Engineers, and a Fellow of the Society of Women Engineers. The capstone design class that she directs was honored in 2009 by NCEES with their Engineering Award for Connecting Professional Practice and Education. Dr. O'Bannon's research area is natural systems water pollution and hydrology, and is currently researching urban raingarden performance. She also has a weekly radio show, 'Building Kansas City' on KCMO TalkRadio 710.