How the Idea of Capstone Projects Could be Applied to Assist Classroom Learning

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Overview

This literature review serves as the groundwork for research into understanding the potential of capstone projects. The collections of articles serve as a primer to give a new instructor visibility on why capstone projects are used in the computer science and engineering disciplines. The use of capstone projects was an idea adopted after 1997 when the Accreditation Board for Engineering and Technology (ABET) published the Engineering Criteria 2000 and shifted the academic focus from what is taught to what is learned. The literature review that follows was trying to understand the relevancy of the question, “Can we use the idea of a capstone project in other courses as a means of assisting classroom learning?”

Introduction

While the inclusion of capstone projects as a keystone of engineering majors seems intuitive, it was not always the case. Prior to 1997, ABET accredited engineering programs based on what they taught. The need to have a capstone project was not a requirement in the course curriculum. Twenty years later it is a keystone of virtually every engineering and computer science program. As programs like information technology grew out of computer science to meet new industry demands for education and skills, it also found the benefits of having a capstone project. In time, cyber security programs, which again seems to be developing out of computer science but also influenced by information technology and other hard and soft sciences, will also seek out ABET certification and implement a capstone course.

The reviews that follow try to draw a thread through capstone projects. First, they draw on the requirement to create teams, improve motivation, overcome problems, and assess attitudes. Second, they explore the needs of written and oral presentation skills and design reviews. Third, they explore the ideas of what capstone projects are outside the engineering and computer science disciplines and how ill-structure problems fit into the capstone project. And finally, it explores a newer academic discipline, cyber security, and where some cyber security projects are going.
Annotated Readings and Literature Review


It seems obvious that team projects require arranging the students into teams. Yet, “how” the students are arranged into teams can be a controversial issue where faculty may disagree. Sometimes projects require a pure academic focus, such as computer scientists for research into advanced sorting algorithms, or electrical engineering for a research project in power distribution systems. Some topics, like software defined radios, however, require the skills of multidisciplinary teams. In this case, a mix of computer scientists and electrical engineers have specialties to contribute to the problem that complement each other. This paper makes references to projects that benefit from specialties of engineers in the domains of biomedical, computer, electrical, materials, mechanical, and industrial programs. The most important contributing factor to team selection is academic major. While this paper mentions some other factors that are used in assigning teams, the other key ingredient to their success is an introduction to Engineering Design course that the students must take prior to starting their capstone project, (typically the senior year). When it comes to team size, the paper addresses the normal team size of eight students, where small projects may have as few as four team members and larger projects may have as many as ten team members. While this paper explored the ideas of effectiveness in team performance, the focus is clearly on team creation and not short-term effectiveness or success. As such, the idea of a student’s project preferences may be a factor in the initial weeks of the project but other factors provide much more of the motivation required for team effectiveness and success. This paper also showed how engineering maturity factors (in essence practical engineering experience) was more important in contributing to team success than student Grade Point Averages (GPA or academic performance). And after majors, engineering experiences, academic performance and interest areas are taken into account, they supplement the decision making of team selection with a compilation of specific student skills. While the authors acknowledge further work is needed to understand the variability associated with some factors and the interaction between factors, it is clear their methodology is working better than no methodology.


As the previous paper outlined building effective teams, it is no simple process. Picking the right people for a team can be a tedious process and there are usually disappointments. Obtaining a desired project is only part of the problem as many students have specific individuals whom they want to work
with and others who they may want to avoid. Simply using a method such as similar grade point averages, random selection, self-selection, or an operations research/management science approach may not completely capture the student-to-student desires. This paper builds on the research that “shared interest and motivation” are the best predictors of team performance (Brickell, Porter, Reynolds, & Cosgrove, 1994; Dutson, Todd, Magleby, & Sorensen, 1997), yet not achievable with the methods referenced above. The idea of spending two weeks to facilitate the right skills to be measured by students and reinforcing the idea of not picking teammates by because of friendships is a small cost to pay for a year or more of getting the team right. The idea of a Mingling Exercise actually sounds like a good way to derive the right natural relationships that may enhance building the “right” team. The manner of team selection proposed by the authors seems to get right the logical self-selection that in the end will be a better fit for the students and allow the maximum focus on education that the teachers desire. While this method is applicable to capstone teams, it could find use on small team projects as well.


As the last paper touched on motivation, this paper adds to the discussion about how stakeholder disagreement and different cultures may further hurt or hinder team motivation. First it addresses what success means. In this case, success was twofold. There is a perspective of project management and whether a meet the objectives of meeting time, cost, and quality objectives. Then there is a perspective of product success what measures the final product meeting the project owners’ strategic organizational objectives. Previous research mentioned in this paper showed that more see these two concepts as different than those who see project success as the same as project management success. Thus before we can measure motivation of teams in regard to success, we need to clarify how the idea of success is determined. This is especially important when project managers are in disagreement with project owners. This paper offered interesting results based on the differences of culture when viewing success. The authors state that more work needs to be done as their data set was too few in results to draw any significant conclusions. However, the paper derives good analysis on that when disagreement occurs as to determining a projects success or failure, in all cases the morale of the team was low. As stated in the paper, “If there is agreement on project success then the development team tend to have an above average level of motivation.” Interpreting their data another way could suggest that high team morale is likely to ensure that agreement in determining success is most likely to occur. Be wary if morale gets too low. Also noteworthy from the research is a hypothesis that “The relationship between team motivation and project outcome is however affected by culture when there is disagreement on project success,” but the authors state more data is required to better assert this assumption.
In the field of computer science, few projects consist of a single team “develop[ing], for scratch, a pre-specified piece of software for a known client according to a well-defined process” (p16:1), instead development comes from “distributed teams, who follow different development processes and business models” (p16.1). This special issue of the ACM highlights the state of team projects as to how they must exist in the computing sciences. Their focus on real-life experiences including project management, team building, software estimation and planning, progress tracking, and communication are not normally evaluated well in a typical class environment with a conventional focus on individual computer programming and problem solving. Communication was the central theme to this opening essay for the special issue. It addressed future challenges within the field with large corporate development teams or open source projects whose developers may be spread out around the world and techniques to teach software developers for this reality.

In addition to the previous paper, it is important to understand the problems that capstone teams may face. In this paper, the problems that the student teams encountered in their capstone projects can be grouped into two categories, technology problems or inadequate system functionality and inadequate system quality and social problems or inefficient communication, and lack of taking responsibility. The last two problems could affect any team capstone project, including those in the humanities disciplines. These problems are not only applicable to the hard sciences. Furthermore, the findings of the paper conclude that most of the root causes for any problem “were mainly related to project management, requirements engineering, testing and to soft skills such as communication practices and motivation.” It is important that as an educator facilitating capstone projects that teams are helped to overcome these challenges. While working through these soft skill problems are important lessons to learn, they cannot come at the cost of being detrimental to the learning experience of the discipline. Interestingly, the mitigating factors include team formation as one way to overcome some social challenges of the team, a topic explored in the first two reviews. Other factors included an iterative development process, reasonable project topics, instructions on adopting tools, emphasizing learning and adding controls to facilitate the desired work practices. The future work referenced in the paper that seems most applicable is for further analysis between encountering a problem and learning from it.
Capstone projects have a cost on the facility that may not be apparent and being a project advisor is not identical to being an instructor for a class. One important distinction is the teacher to student ratio. If an average class typically consists of eighteen students, three capstone projects of six students each can require the attention of three advisors. While the advisor may divide their time equally among the projects, the faculty’s load is not trivial. This paper explored the concept of using graduate students to help advise projects with examining the potential benefits. They paper observed differences between faculty and graduate students and surveyed student satisfaction before and after the grad student involvement in the capstone projects. The additional benefits highlighted by this paper included giving the graduate students opportunity to gain experience as a mentor and supervisor within the academic discipline. The manner in which the paper explores effective mentor attributes such as: providing support, providing challenge, and providing vision are all applicable to faculty advisors as well as graduate advisors. The paper calls for advisors to be more than graders and technical advisors. It claims successful advisors, faculty or graduate assistants, need to act as the project manager, act as a communications hub between the students, the sponsors, and the class instructors, and also define and monitor project scope. Interestingly the survey data of years when only faculty were advisors compared to years when the faculty and graduate assistants were advisors showed that student satisfaction went up with the use of the graduate assistants, implying that the graduate assistants had a positive impact on the capstone design class including project productivity and student learning.

Is attitude that important? That may be a question we cannot answer as optimism and pessimism seem to run deep in an individual’s personality. This paper was an interesting study on attitude towards completion of the capstone program at one university. The paper set out to answer questions on attitudes based on Gender of student and in the stage of the capstone project. The study found that differences between the males and females observed were not significant in so much as a reflection on the program of study but more so on the backgrounds of the individual and confidence initially observed. One previous finding that was explored was that if female students are less likely to have positive attitudes towards computers, they may be less likely to value their learning and to practice more on their own when
compared to male counterparts. This finding was interpreted to mean that males usually do the coding and that females usually do the documentation. I found this to be a weak assumption that could be developed further than the one anecdote. The more important finding in this paper was how students’ attitudes improve throughout the course. Both genders observed how attitudes near the end of the course are better than in the beginning. Maybe it is fear of the unknown, or as the paper comes to conclude that “The lower confidence of the students during the proposal stage may be explained by the fact that they do not know yet the processes of the proposal stage of the Capstone Project.” One comment in this paper that seems to serve as a broader theme is that capstone projects serve “as an introductory course to the actual IT [CS and EE) industry software project practices.” Or in other words, Capstone projects are good examples of what students can expect for future work in these career professions, and not simply a tool of academic evaluation.


In this paper, one of the observations from industry was that engineering students’ communications capabilities in producing reports, posters, and giving oral presentations are often below what is expected of them. While this paper was focused on the communication skill set of students from Non-English Speaking Backgrounds and Cultures (NESBC), the observations made of group of 140 students (34 NESBC, 106 local or native English speakers) highlighted the benefits of a series of English classes for Engineers or as called by the authors, an Intervention and Enhancement session. Additionally, these six weeks of classes had a positive effect on both population groups. One metric used to measure the improvement was the students’ grades in the capstone project. In the two years since implementing the classes, the average improvements were more than 10 percent higher. The other metric used was student satisfaction with taking the course. In measuring student perception of the course, application of learning, and overall satisfaction: results were above 80% in all areas. While the research can be improved in multiple ways, the benefits of this initiative seem of immediate value and in response to industry needs.


Conducting a capstone project serves two great benefits for the student. One benefit is it provides a real-world experience for the engineering students. While the other benefit is, it brings together an
overall educational experience, allowing the student to practice what they have learned in multiple classes within their academic careers. This paper focuses on the real-world experience, while the next paper focuses on the idea of bringing together the experiences learned. As to the real-world experience, a project is more than just engineering design and application. This paper brings out the necessity of conducting design reviews. First, it highlights why we have the need to conduct design reviews by illustrating the financial costs of not conducting design reviews and by highlighting the benefits provided including design safety, awareness of resource commitments, and providing design efficiency for the students. Second, it offers how to get at successful design reviews by referencing the compatibility, authenticity, and adoptability of the design reviews. For example, not all engineering disciplines merit the same review processes. A nuclear engineering design review for a power plant would be different than an electrical engineering design review for a pace maker battery system. Both may be just as critical for loss of life yet, their approach to adherence of safety regulations would be uniquely tailored to their respective fields. The author makes the case for a successful design review by its realism. Third, it breaks down the reviews into how they typically fit into a two-semester capstone project: a problem definition review, a conceptual design review, and a final design review. Finally, the paper offers three benefits of the design reviews on capstone project: design quality, learning professional skills, and data assessment. While the framework brought forward by this paper are greatly applicable to successful capstone projects, elements of design reviews could also be applicable to individual classes that could culminate in end of course projects. Moreover, the applicability of design reviews on engineering capstones projects is just as useful as design reviews on smaller mini projects.

Heinemann, R. (1997). The Senior Capstone, Dome or Spire?

Understanding that a capstone project is fundamental to the computer science and engineering disciplines, it was important to see Capstone projects in other majors. This paper addressed capstone projects for communication majors with two opposing perspectives. On one hand, the author references the dome or intellectual consolidation; meaning that the capstone project should bring closure to the academic experience. Conversely the other point of view is for the capstone project to be a spire, or intellectual expansion; meaning the capstone project highlights a way for further student exploration of learning. Applying the capstone project moniker to a senior thesis is applicable and while not necessarily a group project, it is nonetheless a capstone experience for a humanities student. The author makes the case for a dome experience using four lenses including: Practical Necessity, Market Necessity, Semantic Necessity, and Pragmatic Necessity. The four lenses tie nicely together to explore different ways the closure is not only useful and meaningful to the student but also how it also ties together the area of study (especially when the area is not as mature as others and while the author mentions communications as an
immature field in 1997, you could take this perspective today with cyber security degrees). In the case for
the spire experience, the author views the capstone as preparation: including preparation for the “real
world” of work, preparation for the changing communication world, and preparation of citizenship. While
this argument is valid, I did not find it as strongly developed as the dome methodology. Actually, I side
more with this perspective when it comes to the science, technology, engineering, and math (STEM)
disciplines where continued research fuels technological developments. Overall, I think the blend of dome
or intellectual consolidation and spire or intellectual expansion are needed together but should be
explained to the student so they obtain the right mindset in framing their capstone experience. Finally, I
most respected the author’s point that “students need to be able to pull together all the ideas presented in
different courses and construct some sort of integrated, meaningful whole.” While this idea could be
centered on the academic major of the student, I prefer to see it as a whole of the educational experience.
For an undergrad student, the capstone project should draw on their entire undergrad experience gained in
all coursework, not just their major.

of Ill-Structured Capstone Projects in an Advanced Electronics Lab.

In this short paper, the authors explored ill-structured problems as they related to capstone
projects addressed with physics, electronics and general experimentation. While the projects were limited
in number they were very broad in scope as ill-structured problems. This paper explored the expectations
of instructors and students before and then after the capstone project. The expectations of the instructors
and students had some overlap in the case of relearning the physics behind the experiments and
application of learned electronics knowledge to the physics experiments. As to some of the expectations
that did not overlap, as with teachers’ expectations that were more precise than the students was attributed
to the students general being unaware of the details of the task. Thus, the student expectations were
generally more open-ended. Some comments made as outcomes to the project were the teams learned “a
lot about troubleshooting” and how to “break [the problem] down into smaller pieces and this was a good
opportunity to solidify that.” Future work in this paper is investigate the details of how the students went
about solving the ill-structured problems and what kind of difficulties the students encountered by
analyzing audio and video recordings of in-class observations. The takeaway from this paper contradict
the aspect of the spire brought up in the last paper. Through this lens, the ill-structured capstone project, is
much more of a dome-culminating experience approach and not the preferred opportunity for independent
learning.
Are cyber security projects any different than electrical engineering, computer science, computer engineering, or information technology projects? Unfortunately, this academic article was a synopsis of a panel for five researchers in computer science, mathematics, and information technology. The range of the projects were from technical, low-level programming exercise that allowed a student to conduct an attack to conceptual policy regarding passwords in a mixed windows and UNIX lab. Generally, the projects dealt from a point of view as either the system administrator, the security officer, or the programmer/user. While these projects all touched on advanced topics, they were all presented as courses in their own right, and not as a cyber capstone project. This paper was a start at cyber security projects but more cyber security capstone projects are needed. One problem may be that in virtually all other cases, the students are building or creating something. This is what engineers and computer scientists do, but when it comes to the cyber security discipline, unless you are building or creating secure computing applications or platforms, the projects are usually building on or breaking down someone else’s work. This article was most linked to the previous article on the physics students because both the cyber security students and the physics students may not be trying to create original work. Instead, they are building on their existing knowledge and applying those skills to a larger challenge that should fill at least a semester in duration. The presented cyber security projects were generally very structured and did not allow for as much discovery learning as did the physics problems in the previous paper. Of course, this was by design as these cyber security problems are not capstone projects and instead end of course projects. Additional research in the area of cyber security capstone projects are needed by the cyber security community as the demand for cyber security jobs will grow. One could assume cyber security employers will likely mimic the engineer and computer science employers in requesting culminating academic experiences offered by capstone projects. Therefore, it is only a matter of time before ABET accreditations of cyber security programs will require a cyber security capstone project.

Relating Ideas to Teaching

The focus of this Lit Review was to research background to address the question, “Can we use the idea of a capstone project in other courses as a means of assisting classroom learning?” The research informed how the idea of capstone projects could reinforce learning, and even place students on path to continue learning beyond their existing knowledge. However, the research also brought up other costs that may easily be forgotten, such as forming teams, advising the teams through the learning experience, and evaluating the project experience. Additionally, one of the most important aspects of the capstone project
was using outside project owners. Outside project owners contributes to the experience with additional sources of influence on the students that generally contributes to the learning by offering a more realistic work experience. In general, the idea of a capstone projects could serve as primers for students to excel in their culminating capstone project but the right conditions and support structure would need to be emplaced. In conclusion, the lit review has accomplished the task of background data and future research would include developing metrics to observe how using the idea of capstone projects to assist classroom learning would be the logical next step before attempting to incorporate this idea into a regular course.

**Bibliography**

The following articles were used to inform the author on this lit review on the subject of capstone projects. *Papers marked were reviewed by the author.


