# Small Things to Enhance Capstone Success

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This article posits considerations toward enhancing an engineering capstone experience. These are not data-based conclusions, but are instead "truths" observed from fifteen years of directing a two-semester capstone sequence in an Electrical and Computer Engineering curriculum. Curriculum vitality often stems from evolution. This has certainly been the case behind the discussion to follow.

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## *Introduction*

An engineering capstone project must impart practical and intellectual challenge to incite and aid a transition from study to practice of engineering. As such it is urgent to 1) make the experience as representative of the actual challenges of professional engineering practice as possible and 2) to make the student realize this intent and be excited to pursue it. This is a chance for the student to be part of a high performance team, as has and will often be required in the development of industry and societal-changing products and services.[1]

The following short list of suggestions stem from fifteen years directing a two-semester capstone sequence after a career in computer design and manufacture. Though the methods discussed may not deserve wide adoption, some may prove useful to the reader's program.

The discussion is in three sections. Timely initiation of the capstone experience requires attention to the quick but effective formation of teams and selection of viable projects. Assessment of performance throughout the experience can be assisted by a number of assessment methods. Finally a few methods to promote the program among the lower classes and across and beyond the institution are discussed.

All suggestions are couched within a capstone experience delivered through a two-semester sequence of courses. The first term begins with team and project selections and concludes with Proof of Concept demonstrations. The second semester finalizes design and validation, includes the majority of the project construction and completes with a set of deliverables that includes the final project demonstrations.

It is presumed that worthy components of this article can be integrated into one-semester course or into a three-semester course sequence.

## *A Quick Start*

The academic semester and year pass quickly. A "deliverable based" course (to be discussed later) may include time at the beginning of the term that can be wasted, which in turn will overload the end of the semester or course. Lack of early term productivity can be a big contributor to the late term "all nighters" so common to capstone study.

The initial class meeting can include discussion of this tendency to procrastinate; pointing out that it is a common human behavior. While back-end loading of development schedules is not uncommon in the professional practice of engineering process and product development, it can sometimes be avoided. Another point to consider is that failing to start quickly is one way of not meeting a schedule, which in a capstone can delay graduation.

Suggestion: Provide a schedule of high level milestones at the first class meeting to promote a quick start. Two of these initial milestones should be team composition and project selection.

### Compose the Teams Quickly, but Carefully

Significant work has been reported on team formation and related success factors[2], and the importance of teamwork to successful engineering design is well established. However most engineering students have worked in teams only on small projects and in laboratories prior to their capstone experience and few will have had the large majority of their grade based on team performance. Though they may prefer self-selection, students typically need guidance to ensure the composition of effective teams.

Small teams are known to be more agile and can arrive at consensus rapidly[3]; both needed characteristics in the short-cycle capstone experience. A program of averaging 40 ECE seniors that favors numerous diverse projects per capstone year has experienced best results with teams of three to six members. Four-member teams have been judged optimal by the director and by

multiple instructors. Three-person teams can prove brutal in member workload, and six-person teams provide the weaker student too much freedom to ride along on his or her teammates' work.

Personality type and academic record have been used in an attempt to evenly endow teams.

While personality typing, employing tools similar to those available at www.keirsey.com, provides good lecture material relating to team intra-actions, benefit can be offset by delays incurred by testing and evaluation, and by the time taken to discover that there is indeed value in awareness of one's behavior traits and those of his or her teammates.

Some level of GPA spreading has proven useful, with one counter-intuitive observation. Teams composed solely of the highest GPA students have failed to meet expectations under numerous instructors over numerous years.[4] Any team so composed should be warned that they cannot expect success in this course simply because of their past individual academic successes.

During the initial class meeting, have each student compose and turn in a roster of his or her dream team, based on provided criteria, such as team size. During that class, if timing allows, or no later than before the next meeting, the instructor composes final team assignments incorporating as much of the dream team input as possible, but keeping teams reasonably level in regards to practical and academic skill. Typically each team member will be teamed with at least one person from his or her dream team. This enhances quick acceptance of the team assignments and has proven much better than simply accepting the student's team composition suggestions.

### Quickly Select a Project for Each Team

Teammates, professional societies and faculty members can provide valuable assists in identifying and selecting projects for the teams.

Have the teams meet as soon as they are assigned. Give them an agenda to 1) collect and publish contact information, 2) select a team leader, 3) discuss individual strengths, and preferences relating to the capstone project, 4) discuss possible projects and (5 propose a project.

Societies such as ASCE and IEEE[5] sponsor regional and national competitions which may be appropriate design projects. Teams choosing externally defined projects should understand that they may be on an accelerated schedule and that some of their assignments, such as project definition, must be assessed differently.

Most engineering faculty members have a pet project or two, which they are willing to share with the right students. Have the students interview the faculty for project ideas.

Figure 1 summarizes the busy first week.

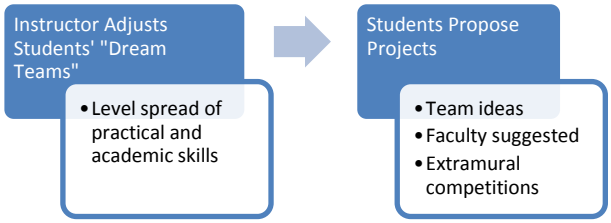


Figure 1: Teams Composed, Projects Proposed

### Insure Viability and Assign Technical Advisors

While some projects are well thought out at the initial proposal, most have significant "Imagineering" content. The as-submitted project proposals may be too easy or too difficult for reasonable success

A single-subject meeting of faculty members to review and discuss project proposals enhances success potential by keeping the projects reasonable and "between the ditches" of too easy or too difficult. Faculty members accept, reject or, accept with required revisions, the submitted proposals. Also, as faculty members discuss team proposals advocacy often surfaces that can steer assignment of specific faculty members as technical advisors for specific teams.

Students often overlook key technical considerations due to data overload they experience during research. A trusted faculty member provides an element of technical guidance. Advising duties are spread across the faculty members and the course instructor serves as a second advisor to all teams. Technical advisors should encourage regular meetings and should provide assessment input to the course instructor in support of final grading.

Figure 2 provides a summary of week two activity.

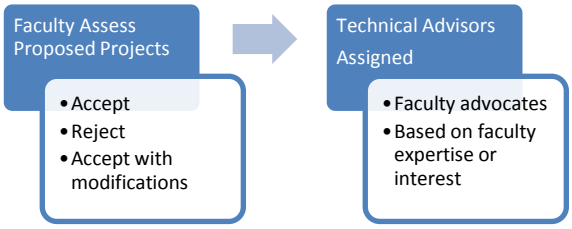


Figure 2: Proposals Reviewed, Advisors Assigned

## *Lectures*

Most senior engineering students would prefer the capstone to be an all-laboratory experience, but a suite of lectures are needed to assist the transition to engineering practice.

Topics on product development with specific lectures on project management, design for (manufacturability, reliability, maintainability, etc.), engineering ethics, teamwork and other professional topics injected weekly keep the student focused on the profession. Detailed

lecture material should be provided on the course website for future reference.

### *Assessment*

In keeping with a professional experience, the capstone course experience can be assessed thought deliverables[6] rather than through testing.

**Early Term Deliverables (First Semester)**

The preliminary project proposal is an initial deliverable. It may consist of a free form single page proposal, but it quickly introduces the concept of a team deliverable on which their final grade will be based. Other early-term deliverables can include preliminary project development plans, schedules, specifications, and an advanced bill of materials.

**Status Reports (Both Semesters)**

Regular oral and written status reports are a professionally proper way to assess progress. The students' ability to accurately, briefly and clearly status the projects' adherence to schedules, specifications and planning costs is enhanced though instructor feedback on these reports.

**Proof of Concept (Late First Semester)**

A proof of concept demonstration is a good mid-year assessment tool. This laboratory intense effort allows the team and its advisor to hurdle some technically challenging aspect of the project without the burden of final project form or functionality.

**Formal Project Proposal (End of First Semester)**

A formal project proposal serves to assess the teams' technical writing and oral presentation skills. Scheduled at the end of the first semester sequence, it exposes students to the roles of marketing and sales in the overall product fulfillment cycle. Students can "spin" their story to devise a pro-forma marketing projection and extrapolate profits based on projected sales.

**Poster Presentations (Early Second Semester)**

Poster presentations 1) introduce the student to this increasingly common form of technical presentation, 2) force a thorough mid sequence progress evaluation and 3) prepare for possible participation in science and math department research competitions that may take a similar form.

**Technical Paper (Late Second Semester)**

A written and presented technical paper summarizing the project assesses and archives the teams' work. Papers formatted to relevant professional society guidelines presented in a symposium-like environment further the experience. Papers from the capstone cohort are bound as proceedings for presenters and attendees, and archived in the institution's library. These technical writing samples prove very useful during department and institution-wide assessment visits.

**Project Demonstration (End of Second Semester)**

One of the final deliverables is a formal project demonstration with all team members, the advisor and the instructor present. A test plan is negotiated with the instructor and technical advisor prior to the demonstration and serves as the assessment tool by which the success of the demonstration is evaluated.

**Video Demonstration (End of Second Semester)**

In this age of YouTube®, a video demonstration allows the engineering team to stretch its creative side in an enjoyable way and documents team accomplishments. Videos are archived on a YouTube channel for viewing by advisory boards and other constituents.

**Comprehensive Final Report (End of Second Semester)**

This dossier capable of guiding the reconstruction of each project, serves as a final deliverable, and includes:

- The formal project proposal
- A signed copy of the final specification
- A bill of material
- Hardware and/or software design details not included in the specification.
- An Operator's Manual that walks the user through the operation and maintenance of the product
- Recent resumes of each team member
- A well written narrative that ties the report together and imparts project understanding to the reader.

As shown in the sample deliverables chronology in Tables 1 and 2 the second semester has fewer, but more significant deliverables. Practicing design engineers will attest that the demanding final weeks of the second term realistically emulate the pressures of actual engineering project/product releases.

| | *Deliverables* |
|---|---|
| Week 5 or 6 | Oral and Written Status Report |
| Week 8 or 9 | Oral and Written Status Report |
| Week 10 | Preliminary Specification |
| Week 11 or 12 | Oral and Written Status Report |
| Week 13 | Formal Project Proposal |
| Week 14 | Proof of Concept Demonstration |

Table 1: First Semester Milestones

| | *Deliverables* |
|---|---|
| Week 4 | Poster Presentation |
| Week 8 | Midterm Status Report |
| Week 12 | Final Specification |
| Week 13 | Technical Paper and Symposium |
| Week 14 | Project demonstration, video, final report |

Table 2: Second Semester Milestones

### *Promotion of the Capstone Program*

Students are generally proud of their capstone effort. Some way to share this with non-engineering friends and family and with the under-classes strongly promotes continuity across the years.

One such social outlet can be a symposium at which all the technical papers are presented to an audience of students and faculty from across the institution and to family and friends. Refreshments provided by the department or by a generous department supporter go a long way to making this an anticipated event.

Extra- and intramural competitions are great ways to further socialize and enhance the capstone experience. Professional society competitions, such as the regional and national ASCE competitions and the regional IEEE competitions let some students evaluate their efforts against those of teams from other schools. Competitive opportunities exist within many institutions. Research competitions sponsored by the math and science departments often welcome engineering entries. A simple way to encourage cross-campus participation is to require a poster presentation deliverable that precedes and complies with the entry requirement of the math or science competitions.

Entrepreneurial competitions often sponsored by the business school are ripe for engineering capstone project participation. Teams are encouraged to enlist a business major member and enter their projects. This requires added work to better position the project commercially, but engineering entries can win, and significant cash prizes are not uncommon.

### *Summary*

The engineering capstone experience is a critical aid in the transition from student to professional. It should emulate professional challenges as closely as possible. Deliverable-based assessment provides this realism.

Team formation and viable project selection are critical to a quick and effective capstone start.

Effective team deliverables include preliminary project proposals, oral and written status reports, formal project proposals, Proof of Concept demonstrations, poster presentations, technical paper publication and presentation, video demonstration, final project demonstrations and comprehensive final reports.

Documentation and publicity of the capstone projects via a dedicated symposium with archived proceedings, on- and off-campus competitions and entrepreneurial competitions add substance and promote the experience by reaching larger audiences including friends, parents, administrators and lower engineering classes.

### *Future Work and Conclusions*

Better definition of the team leader duties and rotation is underway. Teams are small enough to be managed by consensus, which reduces leadership to mostly administration and facilitation. However, engineering leadership opportunities are rare in an undergraduate curriculum, so this is being investigated as an important learning opportunity. Rotation of the leader duties has been incorporated recently, but leadership assessment methods require improvement.

Engineering capstone methods that work at one institution may not work or may not be suitable at other institutions. The intent of this paper is to report methods observed to be effective in a medium sized Electrical and Computer Engineering two-semester capstone sequence from the fall of 1999 until present. Methods discussed evolved over the period mentioned and are those presently in use.

Some specific outcomes of these methods are included in reference 4 below and others will be discussed at the presentation of this work.

### *References*


[1] Kidder, Tracy (1981) *The Soul of a New Machine*, Avon Books, New York, NY, pp 49-66.

[2] Sarang-Sieminski, et al, "Supporting Successful Teams: Preparation, Team Formation, Teamwork, and Team Health", Capstone Design Conference 2014, Columbus, OH http://www.capstoneconf.org/resources/2014%20Proceedings/Papers/0032.pdf

[3] Smith, Preston G., Reinertsen, Donald G. (1991) *Developing Products in Half the Time*, Van Nostrand Reinhold, Inc., New York, NY, pp 111-131.

[4] Peeples, Johnston W., "Teamwork in Engineering, Know the SCORE", ASEE Southeast, April 2001, Charleston, SC http://www.icee.usm.edu/ICEE/conferences/Conference%20Files/ASEE2001/ASEE2001SE.htm

[5] IEEE SoutheastCon 2016, Norfolk, VA http://sites.ieee.org/southeastcon2016/

[6] Adams, Robert, Alsabbagh, "CS Capstone: Lessons from the Field", Capstone Design Conference, 2010, Boulder, CO http://www.capstoneconf.org/resources/2010%20Proceedings/Papers/Adams_Alsabbagh.pdf