AC 2012-4698: A CASE STUDY IN CAPSTONE ORGANIZATION FOR CONTINUOUS DESIGN/BUILD PROJECTS

Prof. Robb E. Larson, Montana State University

Robb Larson is an Associate Professor in the Mechanical and Industrial Engineering Department, in the College of Engineering at Montana State University. He has been with the department since 1993 and teaches the interdisciplinary ME/MET capstone course, as well as courses in alternative/renewable energy, instrumentation, and computer applications.

Dr. David A. Miller, Montana State University

David A Miller is Assistant Professor, Department of Mechanical and Industrial Engineering, Montana State University, Bozeman, Mont.

A Case Study in Capstone Organization
for Continuous Design/Build Projects:
Building a Project Brain Trust, and the Experiences of Senior Engineering Students who Joined "Competition" Projects Already In-Progress

Abstract

The year-long Capstone Design course sequence at State University is a key element of both the Mechanical Engineering and Mechanical Engineering Technology programs. These two programs share a common Capstone course. Given proper pre-requisite coursework, students can enter the Capstone sequence either in the fall or spring, and project involvement then continues for two consecutive terms. Project assignments are made early in the first course of the sequence, when each Capstone student reviews the project list provided by the instructor and submits a petition for inclusion on a project which peaks his/her interest. Teams are assigned - typically consisting of 3-6 members chosen from the combined student roster of ME and MET students - and the student group engages in their project. The first semester course in each program focuses on engineering design and project planning, while during the second semester a high-resolution prototype is fabricated and tested.

In general, this sequence of capstone events functions independently of the project startup semester: However, some projects such as 'Competition' projects, e.g. Formula SAE or the ASME HPV project, involve unique requirements and schedules. These are projects that continue year after year. They offer opportunities to build upon the work of prior teams, and hold expectations of continuous improvement where past problems should not be repeated. The addition of a culminating competition event – usually scheduled near the end of spring term – serves as a desirable performance incentive for participants. Additionally, a springtime competition event date aligns fairly well with the course schedule of a fall-start two-semester Capstone project. However, for spring-start design project teams the competition project schedule is problematic: In general, there is not sufficient time for a spring-start group to design and then complete fabrication of the competition article. Despite this scheduling issue, our programs desired that a means to engage spring-start Capstone students in these unique projects

should be pursued due to very strong student interest. Such a plan was developed and implemented, and is the subject of this case study.

Students joining projects in-progress have a substantially different experience than those involved from the start. For continuously operating projects, this knowledge bridge provides continuity and superior competition results. But are these advantages reaped at the expense of the individual student experience, or can certain advantages to the student be identified? Can this experience help a student navigate similar occurrences in their subsequent career? Should capstone students always design first and prototype later, or can anything be gained if these steps are reversed? This paper describes the methodology developed to permit students to join in-progress Capstone groups, and the practical considerations involved. Positive and negative aspects of this scenario - including survey results from student participants and alumni - are examined. Finally, methodologies and recommendations for information exchange and focus area knowledge handoff are discussed.

Introduction

Most engineering and engineering technology programs at accredited and non-accredited universities incorporate a course structure that requires students to complete a senior-level project-based 'capstone design' course. Variations certainly exist, but the most typical capstone experience seems to involve groups of students working on a design project for two semesters. Corporate sponsorship of projects is common. In most every case the faculty members involved with organization and instruction of these courses develop significant expertise in dealing with the logistics and pedagogical challenges presented. Numerous papers and publications have resulted from these experiences and entire conferences are dedicated to this topic, offering guidance and perspective on many facets of the capstone experience. A number of surveys and survey follow-up papers give perspective to the range of capstone coursework. For instance, Howe[4] and Todd [12] each provide compilations of the practices of a number of engineering programs with regard to capstone organization, faculty involvement, project cost, and a host of other elements pertaining to undergraduate engineering capstone coursework.

Documentation is somewhat less frequently encountered describing capstone design courses that utilize one or more of the available student competitions as the project topic, but some literature capturing experiences relevant to capstone teams participating in these competition events is available. [1, 2, 5, 8, 9, 10, 11] Paulik and Krishnan[11] present results from a long history of capstone projects associated with a national competition team, where each year new teams re-start from the beginning of the design process.

The challenges offered by using student competitions as capstone projects at State University have led to incorporation of capstone course organizational techniques that - based on literature reviews performed - are somewhat unique. This document presents these techniques as an alternate method of administering a continuous capstone project. In addition to the logistics issues encountered with continuous competition project administration, several questions arise regarding the learning experience for those students engaged in one of these continuous projects.

Course description

The year-long project-based capstone design course sequence at State University is a key element of both the Mechanical Engineering (ME) and Mechanical Engineering Technology (MET) programs. Organization of the capstone sequence is mostly conventional, with one exception being that these two programs share a common and capstone course – a scheme that has been the subject of a prior publication.[6] The first semester capstone course focuses on applying the engineering design process and also deals heavily with project management and planning, while during the second semester the focus shifts to high-resolution prototype fabrication and performance testing of the completed project prototype.

Given proper pre-requisite coursework, students from ME and MET can enter the capstone sequence either in the fall or spring, and project involvement then continues for two consecutive terms. Students are given a choice from the smorgasbord of projects which have been lined up by the instructor, usually from industrial sponsors but occasionally from faculty researchers, the university's facilities services department, or from other similar sources. A brief summary of each project is prepared, and the documents are posted on-line to enable students to review the project list. Each student then submits a project requests based on individual preferences. Students are assigned to projects as soon as possible in the first course of the sequence. Teams consisting of 3-6 members are assigned from the roster of ME and MET students, and the student group engages in their project. The fact that ME and MET students are often placed on the same team combined with the department's excellent machine shop facilities permit high-resolution prototyping, but also generate high expectations for a quality project result.

Competition Projects

Our capstone project offerings have included national competition projects in the project mix since fall semester 2005, and participation continues in both of these two original events - the ASME Human Powered Vehicle (HPV) competition and the SAE Formula Series competition (FSAE). These projects have proven to be popular among students, and there are typically more students interested in participating than can be reasonably handled via capstone project work. As an aside, other means are available for non-capstone students to engage in the FSAE projects as presented in an earlier publication[7], and State University now participates in several new competition projects in addition to the HPV and SAE. However, our long-term participation in FSAE and HPV provides the best case study.

A springtime competition event date aligns fairly well with a fall-start two-semester Capstone project, and early offerings of the capstone course began in fall term and finished in spring. But enrollment growth in both the ME and MET programs resulted in the need to offer the Capstone course both terms. For spring-start design project teams, the competition project schedule is problematic. In general, there is not sufficient time for a spring-start group to design and then fabrication of the competition article.

Implementation and issues

Despite scheduling challenges, the instructor and department desired that a means to engage spring-start Capstone students in these unique projects. To facilitate this goal, the initial approach was simply to add some students enrolled in spring offering of Capstone 1 to the project group consisting of fall-start members. The difficulty in this arrangement was that the new team-mates were enrolled in a different course with different class times and a completely different set of course deliverables. These differences did not mesh well with the demands of the competition, but they did address the desire to maintain a project 'brain trust' whereby the spring-start students could help project continuity as they passed along lessons-learned to subsequent fall-start team members.

A new approach was designed and implemented which kept the brain-trust advantage in-place, but also solved the coursework deliverables issue. This involved first identifying the spring-start students who would join the project in-progress, and then quickly performing an administrative transfer to move the affected students from the Capstone 1 course to the Capstone 2 course. These students were expected to join the existing student team and get up-to-speed on the design solutions that were already in-place, and immediately assist the fabrication effort leading towards completion in time for the competition. For these students, their second term in involved enrolling in the Capstone 1 course, where they got a chance to perform the design of the following year's competition project – alongside the new recruits who just started capstone coursework. This technique effectively addressed the desire to have all competition project team-mates working to the same set of coursework deliverables, but clearly the experiences of students starting in spring term differed substantially from those who entered the course in the fall.

While primarily driven by the desire to invent an organizational scheme that would permit capstone students to participate in competition projects whether spring or fall starters, it was recognized that numerous pros and cons existed with regard to the practice. Having students who had attended the competition on the design team was seen as a huge benefit as it enhanced understanding of rules and specifications, provided insight regarding of the level of competition from other participants, an permitted incorporation of successful design features. An additional anticipated benefit was that manufacturing knowledge gained through fabrication would push these students towards more effective and innovative designs.

The idea of boosting student understanding of manufacturing and design considerations by requiring students to fabricate a component from an existing design is certainly not a new one: Historical apprenticeship practices common throughout the world required students to work for an extended period under tutelage of a master craftsman. Trades such as blacksmithing or carpentry would require apprentices to first fabricate common articles and then items requiring increasingly advanced methods until the desired skill-set was ingrained.[3] Trade-school programs in the U.S. effectively employ this technique, and a renewed emphasis on apprenticeship has emerged as a workforce development methodology. In France, for instance, companies are strongly encouraged by the federal government to take on apprentices and can be granted tax relief for doing so.

At State University, an instructional technique from a prior edition of the MET Capstone class provided another good model and an indication of the likelihood of success. At that time, assessment data and observations indicated that MET students in the capstone courses often lacked experience in some fundamental engineering skills – specifically

a.) Students lacked the opportunity to exercise the classroom topics of correctly interpreting engineering drawing details such as dimensional tolerance and surface finish callouts, material references.

b.) Students had no opportunity to plan and execute the manufacture of multiple components from design drawings that had been created by another individual.

c.) Students had little experience with standard industry documentation procedures or 'Engineering Change Request' forms common in many manufacturing fields.

d.) Students did not have experience with part acceptance testing, quality assurance log sheets, or quality control terminology.

e.) Students had no appreciation for the difficulty in producing interchangeable components for duplicate parts, having encountered only one-off prototype parts.

To address these shortcomings this author had instituted a one-credit manufacturing laboratory experience tied to the first semester of the MET Capstone course. The primary activity in that lab section was a "Mini-project" that required groups to design a part, prepare manufacturing instructions with drawings, and then hand off its manufacture to another group. Meanwhile, the original group would fabricate another group's part. Inspection and QC was done on a different group's part. This was not a sponsored project; in fact all groups were instructed to design the same part: The topic of design was a small flashlight during one term, and a waterproof match container in another. Further, each manufacturing group was instructed to build two identical units with all parts interchangeable. This round-robin design/build/inspect/report sequence provided an excellent means to educate students in subtleties of the engineering product life cycle – and convinced this author of the value of having students build someone else's design: The technique of enhancing student learning by incorporating a scheme where students build what others have designed, and then later move on to design articles for production essentially mimics historic apprenticeship schemes. Logically this tried and true methodology seemed to offer a great opportunity to address organizational challenges, provide students with desired opportunities, and to institute a path for continuous improvement in competition projects.

Faculty Push-Back

It should be noted that not all faculty supported the idea of reversing the sequence of capstone courses: One senior faculty member in particular lobbied hard during faculty meetings and personal communications to stop the practice of allowing a student to take the courses "backwards." His rationale for disagreeing with the tactic was that he was convinced a 'design-before-build' experience was critical for development of young engineers. Several faculty members were swayed by this argument and began a small movement to discourage or perhaps disallow the practice. At subsequent faculty meetings a counter-argument was presented speculating that it would be rare for a graduate to be handed a brand new project upon hiring on with a company upon graduation, and that this type of capstone experience might actually be more representative of early industrial experiences. Data from the MET lab Mini-Project which provided further evidence that the technique had merit was shared with faculty. At the present time the drama has subsided and no serious faculty objections to the inverted student capstone experience remain.

Unfortunately the methodology is not a "one size fits all" solution due to student scheduling considerations. Pre-registration locks students into a class schedule and most students maintain a rather busy course and work schedule. Schedule adjustments after the beginning of the term can be problematic. But since much of the work associated with capstone occurs outside of predetermined lecture hours, most students who desired participation have thus far been able to re-work their schedules. Additionally, in our department we have traditionally bypassed on-line pre-registration for capstone in favor of a manual ‘restricted entry’ process that can be more closely monitored for conformance to pre-requisites, schedule conflicts, and other issues.

The authors are investigating a means to enhance this scheduling technique by surveying student project preferences prior to pre-registration, thereby allowing those students selected for inclusion in the competition project groups to correctly pre-register for the appropriate course. However, the schedule for setup and presentation of suitable Capstone projects would not always permit enough time for what would become pre-pre-registration. Thus it seems likely that a hands-on approach to individual student re-scheduling will continue to be standard practice in cases where first-term capstone students are to join competition projects in-progress.

Capstone Assessment Discussion

The assessment of student achievement in capstone coursework is somewhat problematic, and has been the subject of numerous scholarly articles. An outstanding publication by McKenzie et. al.[9] summarizes survey data regarding assessment practices at a large number of institutions, and many of the assessment techniques described as mainstream in that summary are in fact used at State University.

One of the implications of that McKenzie study stated that “Collection of artifacts indicates the performance expectations being assessed are more closely related to project milestones than educational objectives, and are typically holistic or somewhat subjective in nature. Assessments generally are product focused rather than process focused.”[9] This is in fact the case at State University as well, not necessarily always the best situation but admittedly one which encourages active and successful project management as a worthwhile course objective

The methods in-place at our institution involve both individual and group assessment, both at the intermediate point in each project and at project conclusion. A portion of this assessment involves a determination whether - and how well - the resulting design and prototype addresses the customer needs. Project documents are reviewed by instructors, faculty, and our industrial advisory board.

Assessment activities also include compilation of student performance and professionalism metrics such as on-time delivery of project management elements. While a complete discussion of individual student performance assessment is outside the scope of this presentation, it is intriguing that competition projects offer several additional possible grading metrics resulting from the outcome of the competition. In some ways it is unfortunate that the scheduling of competitions generally renders these possible performance metrics inaccessible at the point in time when grades are assigned, so these rarely if ever contribute to student grades. Instead, the competition results can be construed as an indication of the success of the administrative techniques implemented to enable participation, and as a measure of how the educational outcomes and abilities of students compare with peers from other institutions. Our departmental goal of being competitive with peer institutions has definitely been realized from the standpoint of respectable finishes during every competition, with a general trend towards higher finishes and a more refined prototype. In addition to providing evidence of program instructional effectiveness, the results seem to indicate that the student 'brain trust' has been effective in carrying lessons learned between competitions, and has had the desired effect of pushing the state of the design.

A more difficult assessment topic is the question whether these project organizational techniques and perceived project advantages are reaped at the expense of the individual student experience. Grading rubrics in terms of level of effort do not necessarily establish whether student learning been effective, or if group member participation occurred at appropriate levels during both semesters of the capstone experience. Specifically, we wondered what advantages to the student could be identified? The bottom line was - can anything be gained by reversing capstone project elements, or should student projects always be set up so that the design process tasks are undertaken first and prototype later? An additional question is whether involvement in an 'inverted' capstone experience as a senior student could help a graduate navigate similar occurrences in their subsequent career?

Participant Survey

To help address these questions, graduates of our programs who were spring-start competition project students were queried regarding their experience. Questions from the student survey are compiled in Table 1 below, and representative excerpts from student responses appear in Table 2. Faculty members were also asked to weigh in on the practice. Faculty responses were more guarded, and in some cases warned of consequences that might result from implementing the practice. Representative comments from the faculty appear in Table 3.

Table 1 Capstone Build-Design survey questions

1.	You were asked to work alongside team members who had done the design work and (in theory) knew this design intimately. Coming in to the build phase cold meant you were potentially at a disadvantage in the group dynamics equation. Were any group dynamics difficulties encountered, and if so, could they be attributed to the mix of newcomers/old hands within the group?
2.	Was the distribution of workload during the ‘build’ term affected (negatively/positively) by this arrangement? If so, how?
3.	Was workload distribution during the ‘design’ term affected (negatively/positively) by this arrangement? If so, how?
4.	You had the opportunity to attend the competition prior to undertaking the design effort: During the second term you worked alongside “new recruits” who worked thru the process in a more traditional fashion. Did you notice differences in the design process knowledge or design philosophy of new versus continuing group members? If so, what? Please be specific.
5.	You may have gained a more complete perspective on the project details, which may have affected your design. Did you do a better job of design, including design for manufacture, as a result of this arrangement? Please give example(s) if so.
6.	One potential advantage of this methodology is that knowledge gained is passed along directly to new group members, as is the ‘culture’ of the project. Was this apparent? Examples?
7.	Would you recommend that this methodology be discontinued or continued for competition projects? Why?
8.	Do you think that this methodology should be expanded to include non-competition projects, where the build phase might involve a completely different project than the subsequent design project?

Table 2. Excerpts from Student responses to Capstone Build-Design survey questions

Question:	
1: group dynamics difficulties	It was difficult to get the group dynamics working quickly.
	It was a little hard to get initially acquainted with the group. There were difficulties figuring out who has what role unless you knew someone personally.
	Group dynamics was not an issue. At first, obviously the "old 4" knew each other better, and knew the limitations of themselves better than we did, but as any new group forms, each person's boundaries were found. The "awkward" time was about the same as it would be for a new group or shorter.
	The group dynamics were not really affected by integration of new team members, but it did take some time to get used to the other members.
	I actually felt like both semesters the groups merged and worked together pretty spectacularly. Of course there were some sticking points but I feel like that was just part of being in such a large design group.
	I think that the biggest group dynamics difficulties were the different skill sets of people on the projects, and having difficulties being able to integrate them into a useful functioning group.
2: distribution of workload-build	
	The build phase workload was not distributed evenly. Some of the returning members took initiative to do a lot on their own, and then tell everyone else about it later. Many of the newcomers were not even informed on when things were going on.
	Having the project already started created an initial delay in finding work to do. It took an initial push for the other members to divvy up jobs for the new members. Once associated with the assigned tasks it was really fun (sometimes frustrating) trying to problem solve from the mistakes the designers (that were MIA) made.
	No, I feel everyone did as much as they were going to do, regardless of whether it was a split group or not. The only exception to this occurred at the beginning of the semester when Capstone group assignments were undecided and it took a few weeks to get

	plugged in to the group.
	I felt as if the load distribution were somewhat unequal during both semesters. The build semester because they knew the design and knew what needed to be done.
	Initially, when the new members joined, there was a definite lack of production by the new members due to having to learn the whole project as well as learn many new manufacturing techniques. Within a month the efforts seemed to even out. However, I almost feel like this was a benefit since all the questions the new members asked forced the guys who designed the parts to rethink their design decisions which probably sped up the overall build.
3: distribution of workload-design	
	The design term went swimmingly. It's more of a fresh start than the build phase so we could all sit down and decide who's doing what instead of it being predetermined for the group. It actually worked out great coming back from the competition knowing what we all generally wanted to work on.
	I can see how this easily could have been an issue, but we had such a hard working group of good guys (with one exception) that I think they were so eager to dive in and get going that we didn't have a problem.
	I felt as if the load distribution were somewhat unequal during both semesters. I felt as if I didn't have as much input because it was "their" design they would be machining and competing with.
	There was a noticeable difference in workload between the new and old members…. but this seems like a lack of project management rather than a fault in the alternating term system.
	Workload distribution was a direct result of individual motivation and prioritizing. I don't think that new v. old had any bearing on how the work was distributed. There were members from each school that put in a large amount of time and effort…
4:	

differences in the design process knowledge or design philosophy	It was awesome being able to collaborate new and old ideas with the new members.
	Yes, definitely. The new people had little knowledge of the competition atmosphere and had to constantly ask us what the judges would say. This is one of the main advantages to having a split crew. Half of the crew has an intimate knowledge of the competition and with every part we design, we ask ourselves what the judges would say and made certain decisions based solely on this fact
	Having seen the competition and participated in it, the returning members had a better image in their minds as to what was important and what could be done. This was a valuable addition to the team. We were able to work off of previous experience and design a better model.
	I didn't notice much. The SAE team is unique in that we had a very active club that, at least this last semester, pushed for us to have a clearly documented goal that they could look over and comment on. I think this helped to get everyone on the same page initially as far as design process is concerned.
5: design, including design for manufacture	
	I feel that I had the opportunity to do much better job having the perspective of what works and what doesn't and work on improving past designs/ideas while stemming new ones.
	Most definitely so! That I knew how long it took to manually machine parts or weld items together with accuracy changed how I designed things.
	YES! After working on the frame and suspension last year I had a much better idea of how long it takes for parts to be made. Therefore, this time I tried to simplify the suspension members as much as possible by using lots and lots of spherical bearings with simple thread in ends to minimize difficult part manufacture.
6: knowledge gained is passed along	
	Well, there were lot of things that we saw didn't work with the previous car (made especially apparent during the design competition) that we could pass along to future years.

	This was apparent. I feel this happened almost with every design the new members created and with good cause. The older members had seen it "all" and while the new members are very bright, lacked some of the experience and insight of the older members. Name one part designed by a new member, and with 100% certainty, they asked an older member if "this is a good idea" or "will this work".
	There were definite benefits to having experienced members on the team. Being able to design aspects of the competition and things that were difficult in the past allowed for a degree of preparedness that otherwise wouldn't have been available.
	From working on the brakes on car 23 I had a pretty good idea of where weight could be saved as well as how to design the system to be easy to assemble and work well. I gave my ideas to the guys who were working on the brakes this last semester and I think it was a decent starting point for them as far as design goes as well as for where to start looking for resources.
7: recommend continuation	
	I think it should be continued. Competition and actually assembling/building associated with these project gains so much knowledge that couldn't be gained otherwise
	Continued, without a doubt. Why?...none of the reasons listed above would have been possible. The little problems, such as a couple weeks to regroup during the second semester, were overshadowed by the benefits.
	Formatting the teams in this manner has a great benefit to the team as a whole with the carrying-on of experience, but it was harder for the individuals.
	I would recommend that this methodology be continued for competition projects so that a ground-zero approach is not needed every year. I would recommend that a set number of team members for each competition be established and maintained year over year so that there can be an approximate 50/50 split of winter and spring grads working together.
	I think the continuity of knowledge is a very important part of these larger projects, especially since they are competition projects and we are expected to make something "bigger and better" every year. Without this overlap of students I think our programs

	would stagnate and there would be no point in competing since we would be like a rock in a river continually getting passed by but never moving.

Student responses to Question 8 were resoundingly, NO; this process is something that works only on the competition projects. As one student said, “Being able to work on both sides of the project is critical to developing good engineering judgment. “ This response echoes the belief of the authors, and currently the technique is not planned for implementation for non-competition projects.

Table 3. Excerpts from Faculty responses to Capstone Build-Design survey questions

Question:	
1: group dynamics difficulties	I could anticipate conflicts between the continuing and new students with the continuing students feeling that the new students hadn't "put in their time" yet. It would be very easy for new students to be assigned menial tasks which reduce the amount they learn.
	For the new student, they can probably expect that their opinions will be discounted, or that other members will grow impatient with 'defending' why things were done a certain way the previous semester. I think this is setting this student up for lack of buy in.
	I would expect the existing team to be impatient with the new comer, and to attempt to off load the undesirable tasks of the project, because the other tasks 'require more background knowledge.'
	They might be considered outsiders - not able to help with the build tasks at hand (as good as the old-hands).
2: distribution of workload-build	I think it's probably OK. The new members can provide some help in building, learn from those experiences, and spend time using their knowledge to come up with a better design for their team in the fall semester.
	If the build team is losing previous members, bringing the new member up to speed may result in more work for the previous members, as well as a potential slowdown. Conversely, "new eyes" on the project could potentially bring positive change through a different perspective.

	I can see one of two situations for the carryover student, both of them negative. First, since they will not have to live with the new design for a build, they may be less interested in ensuring the design is considering all potential pitfalls and becoming their best effort. Second, even if they are giving their best effort, they may become somewhat disappointed in the experience, since they don't get to build the cool thing that they have designed. On the flip side, if they are engaged, they may have better input to the team since they have seen some of the problems that come up on the other side.
3: distribution of workload-design	The design semester may be improved with the insight gained by a student having previously completed the build semester. This experience could be valuable toward guiding the design process.
	I would say positively. They should have a leg-up based on their experiences with the previous build group.
	(several faculty provided input to q 2 which was also pertinent to q 3)
4: differences in the design process knowledge or design philosophy	Yes, I think there would be an increased emphasis on simplicity and practicality.
	I think it poses an interesting dynamic of having to build someone else's design. This is something that can definitely occur out in industry so it gives them some real world experience on how to fit in within an existing design team. I do however think students entering this kind of experience in academia might feel like they are along for the ride and not really included in any of the decision making processes.
	To a small degree I would expect them to be more sensitive to some design issues with this exposure.

5: design, including design for manufacture	I think the student undergoing "build then design" would do a better job of all aspects of design as a result of the previous build experience.
	Yes - they should have better experiences.
	In theory the manufacturing experience should help them design a better product
6: knowledge gained is passed along	Absolutely
	It could, but in order to be effective, this would need to be a structured knowledge transfer. Probably with some fairly substantial faculty involvement.
	This would be a good test of the documentation and communication capacity of an existing team. It could be a valuable teaching opportunity.
7: recommend continuation	For the ongoing competition projects, I think it is fine to continue. Some of the potential drawbacks I have outlined above from learning outcomes may be more than offset by a continuously improving solution thanks to knowledge transfer.
	Continued for all the reasons stated above.

	I think there could be positive student learning in terms of communication, documentation, and project management. However, I think we should be very careful about this, as we want to be sure to continue to provide a good product to our industrial partners sponsoring these projects.

Summary

From the student perspective, some of the potential group dynamics issues that were anticipated by faculty were indeed realized, although these were generally short-lived. The faculty concerns that new members would suffer was perhaps over-stated, as the new student team-mates were – again, in-general - quickly assimilated. From the instructor's standpoint, it appeared that in nearly every case the students already on-board welcomed the new recruits, but the 'fit' of each individual took a matter of a few days to a few weeks to work out.

Likewise, the potential workload distribution issues were problematic and elicited responses from several students. But where observed or reported, they often seemed to have more to do with student motivation, skill-set, and responsibility and less to do with the semester of engagement. Several students pointed this out in their survey responses. The fact that some students in a project group underperform is no surprise to educators, and in competition projects a background in the subject is highly desirable. It should also be re-stated that participation in these projects was at the request of the students: In no case were individuals 'forced' to participate against their will.

Participants generally felt they did a better job of design after attending competitions. Several faculty members mentioned that this situation probably matches the early industrial experience of graduates more closely than does a conventional design-build arrangement -a great topic for a follow-on survey of alumni.

Finally, both faculty and students were nearly unanimous in their voicing support for this practice for competition projects only – while recommending that non-competition projects do not use the methodology. In the words of one faculty member, the "Pros outweigh the Cons" in competition projects.

Conclusions

The Mechanical Engineering and Mechanical Engineering Technology programs at State University have implemented what has proven to be a reasonable alternative to the classical Capstone 1 (design) - Capstone 2 (build) methodology. This alternative method enables a transfer of knowledge from year-to-year for capstone projects that compete in national competitions in late spring/early summer timeframes. Feedback from many students who completed a Capstone 2 experience prior to the Capstone 1 experience have identified minor concerns with the experience, but support the overall process and speak to the concept that learning objectives are not compromised and may even be enhanced.

An obvious and strongly recommended follow-on research topic is to pursue a future survey regarding the industrial experience of graduates who participated in competition projects under this situation. At present the low number and short employment duration of alumni with this experience precludes inclusion of that data, but further follow-on is planned.

References

1. Brackin, P., D. Knudson, B. Nassersharif & D. O'Bannon (2011) Pedagogical Implications of Project Selection in Capstone Design Courses. *International Journal of Engineering Education,* 27**,** 1164-1173.
2. Carrano, A. L. & B. K. Thorn (2005) A multidisciplinary approach to sustainable product and process design. *Journal of Manufacturing Systems,* 24**,** 209-214.
3. De Munck, B., Kaplan, S., Soly, H. *Learning on the Shop Floor: Historical Perspectives on Apprenticeship,* Berghahn Books, 2007
4. Howe, S. (2010). Where are we now? Statistics on capstone courses nationwide. Advances in Engineering Education, 2(1);
5. Labossiere, P. & L. A. Bisby (2010) Lessons Learned from a Design Competition for Structural Engineering Students: The Case of a Pedestrian Walkway at the Universiteacute de Sherbrooke. *Journal of Professional Issues in Engineering Education and Practice,* 136**,** 48-56

6 Larson, R., Cundy, V., (2007) Combined ME/MET Capstone Projects: Organization, Issues, Case Studies, and Lessons Learned". Presented at the 1st Annual Capstone Design Conference, June 14-16 2007, Boulder CO. Conference Proceedings.

7. Larson, R. (2008), "A Snapshot of Success - How Student-initiated Automotive Design Became Integrated into the ME and MET Curricula", Presented at the 2008 ASEE National Conference, Pittsburgh, PA, June 2008. Conference Proceedings.

8. Marchman, J. F. & W. H. Mason (1997) Freshman/Senior Design Education. *International Journal of Engineering Education*, 13**,** 143-152.

9. McKenzie, L., Trevisan, M., Davis, D., Beyerlein, S., (2004) Capstone Design Courses and Assessment: A National Study, ASEE 2004 Annual Conference Proceedings

10. Paretti, M., R. Layton, S. Laguette & G. Speegle (2011) Managing and Mentoring Capstone Design Teams: Considerations and Practices for Faculty. *International Journal of Engineering Education*, 27**,** 1192-1205.

11 .Paulik, M. J. & M. Krishnan (2001) A competition-motivated capstone design course: The result of a fifteen-year evolution. *Ieee Transactions on Education*, 44**,** 67-75.

12 Todd, R. H., Magleby, S. P., Sorensen, C. D., Swan, B. R., & Anthony, D. K. (1995). A Survey of Capstone Engineering Courses in North America. Journal of Engineering Education, 84(2), 165–174.

13. Vargas Hernandez, N., Davila Rangel, J.G., Delgado, A. E., 2009, “Management of Transitioning Teams During Design Projects”, Proceedings of 2009 International Conference on Engineering Design – ICED09, Palo Alto, CA.