Project Management Applied to Student Design Projects

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Abstract
Student design projects are very useful for practically bringing student knowledge areas to bear, for giving students open ended, creative experiences, in developing team skills and for enhancing communication abilities. Management of these projects through sound project management principles can help expand the range of experiences, as well as simply help keep projects on track. Project management is performed to some extent on many projects in many schools, as a survey in this paper of publications indicates, with mixed results being experienced. The paper then focuses on an extensive application of project management techniques to capstone design courses involving engineering technology students and to other student design projects (e.g. SAE Mini Baja) at Penn State Altoona, through involvement by business school faculty and students. Future plans, lessons learned and student perceptions are discussed and recommendations made.

Introduction

The importance of group design projects to today's engineering and engineering technology programs is indisputable,[1] and multidisciplinary teams on such projects are of growing significance, to give students exposure to other ways of addressing problems and to other fields' content.[2] Project management techniques can help enable multidisciplinary group projects, in an organized way, to enhance the learning experience for students[3] Consequently, many faculty have decided to incorporate project management or multidisciplinary teams to augment design in their engineering or engineering technology programs.

Project Management Courses

It has been found[4] that project managers need to have the following skills, in decreasing order of importance: communications, organization, team building, leadership, coping and technological expertise. To help develop these skills, many engineering programs have implemented project management courses. For instance, a dual-track project management and engineering design two course sequence has been developed,[5] in which the students are taught time management, creative thinking, business memoranda, research and project presentation to help guide them in the project work. Still, disconnects between these two courses took place, and was reduced in part by increased attention to the project timeline at weekly team meetings. In another effort,[6] experiential learning was focused on to improve student skills in time management, rehearsal and flexibility. In a similar vein, another work[7] describes a course in which students gain an understanding of engineering project management. The major components of the course are an introduction to project planning and engineering, execution of the project, and evaluation of the project and techniques. The authors found problems in scheduling and in the students drifting toward an execution-intensive mode. An engineering project management course has been used[8] as a precursor to a capstone design course. This course involves outside practitioners as well as faculty and staff in civil engineering. Students found it interesting to deal with problems for which there is no "right" answer. Some of the elements that can help students in project management courses include[9] establishing good communication of learning objectives, implementing a series of assignments, and providing for effective feedback and assessment. Teaching meeting skills is also important, as exemplified by an effort to teach them as part of a construction engineering curriculum.[10] The elements affecting productivity in meetings are suggested to include setting objectives, planning, control and closure.

Integrated Courses

To avoid disconnects between separate courses, and better represent the real world experience, many efforts integrate project management within the design course. For instance, in one effort, in a very industry-focused way,[11] students can be helped to understand the role of the civil engineering practitioner in the design-construction process by having them actually act as project managers (as well as other agents in the process) through designing and constructing small models. A homemade Gantt chart program is used in another course,[12] which helped students manage a database development project. Students indicated that using the Gantt software "enhanced their learning, improved their team management, and increased their understanding and appreciation of Gantt analysis." A four-course sequence has been developed[13] in which students are exposed to interdisciplinary team design, team skill development and project management elements. The program has an international aspect, too, with students from other countries participating by exchange and at distance. In another effort[14] a renovation of the entire senior year was performed to incorporate project management, merging three design courses into one team-taught yearlong course. The new course makes use of computer-aided scheduling and other project management techniques. Students expressed concerns about the difficulty of working relatively independently on an open-ended design, and on the more performance-based evaluation which the course involved. To help with evaluation, a computer tool was developed by another group of researchers[15] to track project management and team performance information, including individual and team time spent, action items and milestones completed, peer evaluation of team members and private comments to instructors. The project gathered very valuable team and individual performance data in a timely fashion, but only about half of the students took advantage of some of the key project management tools. Two key project management methodologies are followed in one capstone design course:[16] a single individual is responsible for achieving the goals and objectives of the project, and all projects are "planned and controlled to reflect the requirements of all functional disciplines associated [with] the project life cycle phases." Specific elements include development of a work breakdown structure, schedule and resource estimating, and critical path analysis. A company-oriented capstone design course has been developed[17] which includes modules on teams, handling difficult situations, written and oral communications, leadership, time management and project management principles. Implementation has enhanced the maturity of the projects the teams can take on as well as performance on the projects, and has spawned continuing education programs with industry, based on some modules. A senior design project (undergraduate thesis) is taught with the inclusion of project management techniques,[1] including a detailed schedule, a project plan, regular progress reports and a final report. Students are also required to keep a design notebook throughout the course, which is part of the evaluation by a supervising faculty committee. The point is also made that "senior design is nearly equivalent to an industrial internship." A strongly industrial capstone design course has been developed[18] in which rigorous design reviews and acceptance tests help keep the projects on track.

Multidisciplinary Teams

Providing glue to join project management and design, interdisciplinary courses[19] can be used to introduce students to the field of project management and to provide other benefits of interdisciplinary interactions. Project management is seen by the author as a critical area for technology and engineering students, who are increasingly likely to encounter project teams and may serve as project managers. Many other efforts focused on team skills. Interdisciplinary teams (industrial engineering and physical therapy) were formed in another program[20] to help implement Americans with Disabilities Act modifications to the campus. Students gain exposure to open ended problems and to a need for others' skills. Even though such teams can often involve conflict, such difficulties can be used to strengthen the team if the conflict is managed well.[21] Using such team skill building, a widely multidisciplinary course has been developed[22] involving a bioprocessing laboratory. Components of the course included team skills, project management, communication skills, creativity and problem solving and library and database research. Students valued the opportunity to put into practice team development skills, and developed good working and learning relationships between team members and with the mentors, but weaknesses of the course included a range of the amount of time students put into project development and excessive instructor time required. Systems engineers and human factors engineers have also been used on teams[2] to help with a project, in this case in a limited way, initially. The systems engineers provided support to "define, develop, plan, and prepare to implement the chosen engineering solution within a broad global and societal context."

Given the good results expressed throughout these works, and using successful elements of many of these efforts, at Penn State Altoona two manifestations of group senior design projects exist which use project management as an aid.

Project Management in Senior Capstone Design at Penn State Altoona

The electromechanical engineering technology baccalaureate program at Penn State Altoona includes a senior capstone design course, currently one (spring) semester (fifteen weeks) long, earning three credits. In the last two years, the course has also included limited project management material. The main goal is to involve the students in putting into practice the areas of electronics, mechanics and computers/microprocessors which have been covered during their undergraduate career. In addition, it is an opportunity to hone project management elements such as teamwork and communications skills, with students usually in teams of two and the course requiring weekly status reports and a final report, as well as three presentations and an acceptance test.[18] One of the additional project management elements of the course is the requirement that the students learn how to use Microsoft Project® 2000 (a three-hour introductory session is held during the first week of class) and apply it to plan and track their projects. Students are required to submit updated project plans along with their weekly status reports, and to include plan tracking charts in their presentations.

Project Management in the SAE Mini Baja at Penn State Altoona

Another student design project which helps to provide both good design and management experiences for students at Penn State Altoona is the Society of Automotive Engineers (SAE) Collegiate Design Series Mini Baja®. The SAE Mini Baja[23] is an international competition that pits student teams from around the world against each other in design, construction and testing of an off-road vehicle. The vehicle (Penn State Altoona's 2000 vehicle is shown in Figure 1) is a single-seat, four-wheeled vehicle, powered by a 10 horsepower gasoline engine, which must be designed to be marketable for a 4000 unit production cost of less than 3000USD.

Figure 1: Penn State Altoona's 2000 Mini Baja Entry

The materials used in the construction, construction techniques, dimensions and arrangements of members in the roll cage and chassis, and other design issues are regulated by strict rules imposed by SAE, safety being a primary concern. Within these constraints, students are free to choose suspension components, chassis shape, body materials, drive train configuration, tires, driver controls and ergonomic features to enhance the appearance and performance of their vehicle. The student teams are scored in a number of categories, including a design report, a safety report, a cost report, and appearance and vehicle performance.

Three regional competitions are sponsored in the United States by SAE: Midwest Mini Baja, Mini Baja East and Mini Baja West. Penn State Altoona has exclusively participated in the Midwest venue. The onsite part of the competition in Midwest Mini Baja takes place in alternate years in southeastern Wisconsin and southwestern Ohio. The onsite competition involves judging by SAE teams on appearance and marketability, structural integrity and other safety issues, acceleration and braking, maneuverability, a skid pull and a four hour endurance race, on a motocross style track. Scoring for the three Mini Baja events is depicted in Table 1.

Table 1: Mini Baja Scoring

	Venue		
	EAST	MIDWEST	WEST
Static Events			
Engineering Design (Mechanical Design)	200	360	-50 to +100
Engineering Sales Presentation			0 to 100
Cost	150	30	100
Safety	-100 to +50	-100 to +35	with design
Dynamic Events			
Acceleration	50	40	+/- 100
Braking	50	40	
Top Speed	50	40	
Land Maneuverability	100	40	+/- 100
Water Maneuverability	100		
Suspension and Traction	100		
Chain Pull	100		
Sled Pull		40	
Hill Climb		40	0 to 100
Endurance	400	225	400
Total Points	1,350	890	1,000

The 2000 Midwest Mini Baja, a two-day event in early June, attracted 106 student cars from many states and countries. Penn State Altoona has participated in this competition since 1998. Penn State Altoona's engineering and engineering technology programs have been enhanced by participation in the SAE Mini Baja, in recent years with broadly multidisciplinary, industrial-style teams.[24] Project management *per se* has not been a formal part of the effort, but was perceived as being useful to help the project stay on track better. As has been the case elsewhere,[25] there has been little student time in the project for project management, since the technical work crowds it out, and so any planning and control has been nominal. Consequently, the project typically falls behind, and a great deal of effort goes into the last few weeks before the competition. Beginning in 2001, the project faculty advisor decided to try to redress this situation, as well as expand and strengthen the multidisciplinary nature of the team, by incorporating a formal project management element. Project management is now the responsibility of a business student, earning six internship credits under the instruction of a business faculty member, and supervised by the project's engineering faculty advisor. There is also a technical lead for the project, an engineering technology student who is the analog of the technical group leader in a matrix style-organization. This student is responsible for oversight of technical matters on the project, whereas the business student keeps track of the plan and costs, working closely with the technical lead. The course in which the business student's credits are earned usually involves internships in external companies, with the students performing marketing, accounting, planning or business analysis. In the case of the Mini Baja project, the industrial emphasis of the project and the opportunity to work on a team with engineers was quite enough to gain the support of the business instructor and to recruit a student. Another aspect of the recruiting was that the student was instructed by the Mini Baja engineering faculty advisor during the previous summer semester, in a course involving project management principles. The business student has three main duties in the project: manage the project, spearhead the effort to raise external funds for building the car and going to the competition, and collect data and write the cost report required by SAE. In the management of the project, the business student prepares a project plan (with input from the engineering students and faculty advisor), using Microsoft Project project planning and control software, tracks the progress on the project tasks, and develops and implements strategies for forecasting and responding to schedule problems. Cost tracking and the associated detailed resource allocation is not presently implemented.

Several techniques are used to help with the planning and control of the project. Task duration is quite often difficult to estimate, especially if a project has not been performed before, or data on past projects is not available. Students of project management often struggle with how big to make the work packages, the lowest level tasks in the task hierarchy. The business student in the subject project is instructed to break down tasks into durations of no more than one reporting period, the length of time between status meetings (which are held weekly, so the maximum work package length is one week). This gives the student an idea of how to approach the task definition, and helps with tracking, since tasks are reported with only three completion percentages: 0% (not yet started), 50% (started) or 100% (finished). In each status meeting, held with the engineering team leaders, the faculty advisor and the project manager, the project plan is gone over and tasks which have been completed since the last meeting are listed. The meetings also make use of an open task report (OTR).[26] The OTR (Figure 2) is a list of all tasks that are scheduled to be complete but are not, or are scheduled to start in the following two reporting

OTR
6/14/02

ID	Task Name	Responsibility	Plan Start	Actual Start	Plan Finish	Actual Finish
4	Review Statistics	J. Barnes	6/12/02	6/12/02	6/13/02	
23	Install Software	M. Fox	6/18/02	6/12/02	6/20/02	
46	Test Airfoil	S. Howell	6/20/02		6/26/02	

Figure 2: Open Task Report

periods (a reporting period is the time between status meetings). The meeting participants discuss the status of each of these tasks, and notes are taken by the project manager to track the project and provide alerts about potential problem areas.

Advanced Project Management

A more advanced project management area which is implemented in the project is the use of Theory of Constraints (TOC) project management techniques.[27] TOC is an approach to management which acknowledges the interdependent of process steps and the uncertainty associated with each process. This combination of factors, along with misconceptions about the root causes of conflicts in systems, can lead to inefficiencies, cost and schedule overruns, personnel problems and external and internal communication difficulties. In project management, the application of the TOC philosophy focuses on development and tracking using a critical chain, which is like a critical path in traditional project management, but takes into account resource conflicts. In TOC project management, the process bottleneck is the critical chain. Task durations are taken as the time in which there is a 50% likelihood that the task will be completed in the time estimated, unlike traditional task completion estimation, which is often padded with time to the 90% probability level. The TOC philosophy is that one reason projects get behind so often is that task durations are padded with time that gets eaten up anyway through "student syndrome" (wait until the last minute to start), multitasking (doing two tasks at once is less efficient than concentrating on one), and the fact that delays in the project accumulate, but advances do not (if one is done early, there might not be someone available to take on the work to the next stage).[28] Of course, simply linking such short tasks together into a project will cause a high likelihood that the project will be late. To reduce the likelihood that the project will be delayed, the critical chain of tasks is protected from impacts which threaten to delay the project completion date through the use of buffers (buffers are time in which no work is to take place), and resources are kept informed in a timely fashion that they will be needed, although no start time for their tasks are given up front. Buffers are established in three places: the project buffer is located at the end of the project, feeder buffers are located where non-critical chain paths join the critical chain, and resource buffers are located just before a new resource becomes allocated. Figure 3 shows a project scheduled with the critical chain technique,[27] with buffers placed. The critical chain is that path through the project which is the combination of the shortest path in time and a path with unique resource allocations (a resource is assumed to be 100% dedicated to the task when he or she is working on the task). The critical chain thus takes into account availability of resources as well as shortest time to completion. In the example in Figure 3, there are three resources: a programmer (P), an engineer (E) and a technician (T). The resources are scheduled at 100% allocation, so the critical chain ensures that not only is the dependence of the tasks in time not violated, but neither are the resources. Buffers are placed at the end of the project, where the feeding paths intersect the critical chain, and where resources which have not been working are about to come on-line.

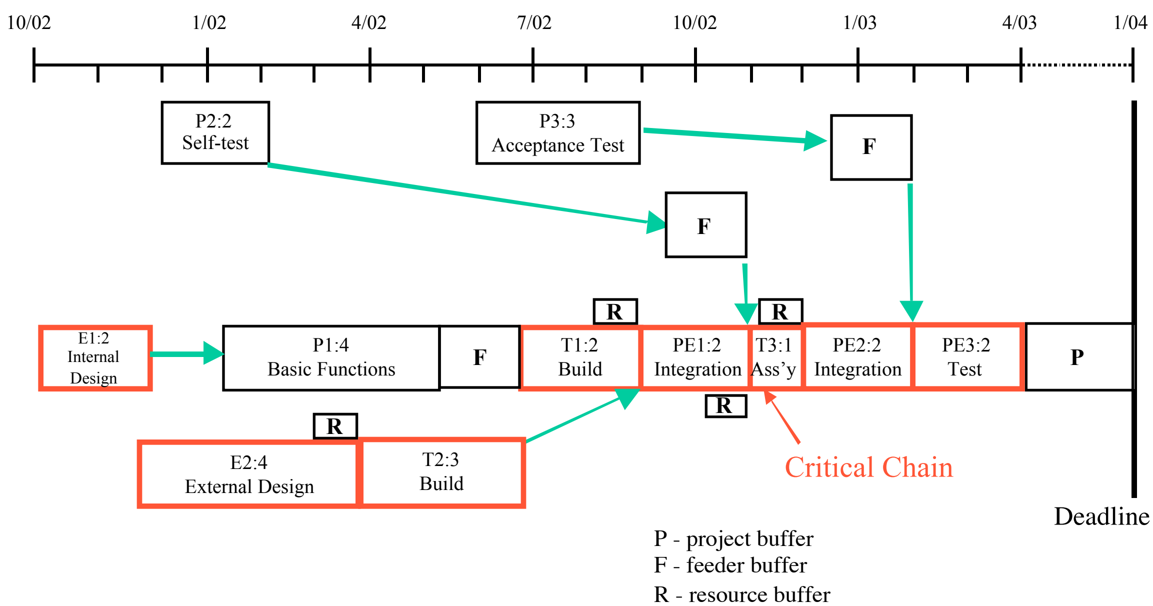

Figure 3: Critical Chain-Scheduled Project

Buffer size is often difficult to determine, but a rule of thumb is that the project and feeder buffer sizes should be one half of the time saved on their paths by estimating 50% completion durations. So if the project is reduced in duration by six months by assuming 50% likelihood of completion for each task, the project buffer size would be three months. In the Mini Baja project, the critical chain is simply the critical path, since resource allocation is not detailed presently. Consequently, only feeder and project buffers are used. These buffers are monitored closely to determine of they are becoming reduced in size, so corrective action can be taken to prevent their collapse and a delay in the project completion date (or, more accurately, shortening of the testing phase, which has led in the past to problems with vehicle performance in the Mini Baja competition venues).

Results and Conclusion

In the capstone design course, not only does the implementation of basic project management give the students an introduction to the field and exposure to the planning software, but the need to think through a plan before beginning the project helps the students identify how things should be done, what weaknesses may exist in their technical approach and where things may go wrong in the plan. The rigorous structure to the project maximizes efficiency and minimizes the tendency to put things off, especially crucial with such limited time in the course. Unfortunately, there is not currently sufficient time to allow for more extensive project management training, and there is little room in the rest of the curriculum to allow for a course to focus on this important area. This leads to a very minimal application of the many useful project management principles. Even the extra session required to get the basics on Project 2000 can be ill-afforded during the already tight course itself. Even with the limited project management application in this course, some good results have been experienced: two teams of two students each from the two sections of the capstone design course compete annually with each other and in the American Society of Mechanical Engineers (ASME) Student Design Competition, and in 2001, a Penn State Altoona team won the ASME Region III competition, the first time the campus had entered. To further build on the benefits of the limited project management implementation, beginning in 2002-2003 an independent study course will be offered in the fall semester as a trial. The one-credit course will permit time for more extensive project management training as well as technical preparation for the next semester's work (the first part of the rigorous planning and review process) and a refresher on design methodology.

The presence of the project manager has been well-received in the Mini Baja project by the engineering students, and has helped keep the project on track better than in previous years. Just knowing that there is someone watching out for competition of tasks is incentive for the engineering students to put in extra effort to make sure things get done. The general air of professionalism and enthusiasm has improved over past years. The manager is viewed appropriately as part of the team, yet somewhat separate, given his special access to the faculty advisor and monitoring role. In 2001, the first year the project manager was assigned, the plan did not come together early enough in the semester, but a good workable plan was finally developed, and can be the starting point for next year's manager's planning. Student syndrome is still a problem, but the need for the functional leaders to report on a weekly basis on the status of their tasks provides incentive to help them keep from getting very far behind. To gain some quantitative student perspectives, a survey was administered to the Mini Baja engineering leaders and the project manager (a total sample of 6) querying their perspectives on the use of a project manager. The questions they were asked and responses are shown in Table 2. Responses were on a scale from 1 to 5, with 1 being strongly disagree, 2 being disagree, 3 neutral, 4 agree and 5 strongly agree. The responses indicate that the presence of the business student project manager, learning about project management and multidisciplinary teams are positive things to the students, but also indicate that a better knowledge of the schedule and more help with the project are required.

The more advanced (TOC) techniques have just begun to be implemented, but results so far are promising, with this year's competition yet to be a proving ground. The project manager has been very useful to enable this focus, but the very rational, quantitative and innovative approach appeals to the engineering students as well. It is useful, though, to compartmentalize responsibilities on project teams, especially between business and engineering, yet the teams should be kept as multidisciplinary as possible. The compartmentalization is especially

Table 2: Student Survey Responses

Statement	Average Response
1. The Mini Baja project is going smoothly.	3.67
2. I've learned a lot about project management as a result of this year's Mini Baja project.	3.50
3. I think the use of a project manager will help keep us on track.	4.67
4. We have enough help on the project.	3.00
5. Engineers should learn about managing projects.	4.83
6. I'd take an extra 3-credit course in project management if I could, even if the credits wouldn't count toward my degree.	4.00
7. Working on teams with people from different fields (like business) is important for engineering technology students.	4.67
8. I know what my role is on the Mini Baja project.	4.50
9. I'm familiar with the schedule for the Mini Baja.	3.83
10. It would be better for the engineering students to manage the project themselves.	1.83

important when tightly scheduled curricula make it difficult to do more than nominal formal project management training for the engineers.

As was the case in many of the other schools discussed earlier, the Penn State Altoona experience has shown considerable benefit to implementing basic project management techniques in senior design projects. Projects stay on track better, and professionalism and additional skills are enhanced and augmented. Based on these initial positive results, the future enhancements suggested are very much anticipated to further solidify the place of formal project management in design courses at the campus.

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Biography

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