International Journal of Engineering Education Vol. 30, No. 1, pp. 31–38, 2014
Printed in Great Britain

0949-149X/91 $3.00+0.00

Capstone Teams: An Industry Based Model*

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Project teams, a mainstay in industry practice, are being employed in many capstone design courses. This paper examines industry models for teams and their application to a specific capstone design course. Following Katzenbach and Smith's basics of high performing teams, teams are formed based on individuals' skills. The team is made accountable and committed both as a group and as individuals through the structure and format of the course. The course structure is then planned so that teams progress through Tuckman's development stages of forming, storming, norming and performing, during their two semester capstone design project.

Keywords: teams; capstone; development stages; design process

1. Introduction

Project teams are a mainstay of current industry practice. Following years of measurable achievements due to teamwork [1], demand for engineers who are capable team players continues to rise.

Academia is listening, to wit surveys report that 80% to 100% of responding programs utilize teams in their capstone design projects [2–4]. ABET Engineering Accreditation includes the outcome (d) an ability to function on multidisciplinary teams. Yet student project teams do not often develop enough to become a true team (as defined in the literature [5, 6]) versus a group of individuals.

Teams, given enough time and pressure, tend to follow Tuckman's stages [7] of "Forming, Storming, Norming, Performing and Adjourning." Another staple in the business world of teams is Katzenbach and Smith's triangle of basics [8] for high-performing teams: "Skills, Accountability and Commitment". This paper examines team development in the Capstone Senior Design experience in the Mechanical Engineering Department at Bradley University (BUME). BUME seeks to create an environment where students experience all of Tuckman's stages and develop a performing team: their team is assigned based on skills and they must work to completion, on small teams with tight budgets.

2. Capstone course

The BUME Capstone Senior Design experience [9] spans two semesters of each student's senior year. The projects begin at the start of the fall semester and continue until the end of the spring semester.
To enroll in the classes, a student must be within three semesters of graduation. The students are assigned to teams of three to four members with a faculty advisor. The entire capstone course is overseen by a Course Coordinator who organizes the course and provides general materials to the students via lectures, discussions, and gateways (a formal review process). Each team also has a faculty advisor who meets with the team at least weekly and serves as a guide, mentor and quality control for the project. Finally, each team has a client contact; an individual client representative that typically meets with the team via biweekly teleconferences to represents the client interests. The team's purpose is to deliver value to the client through an engineering solution to some need. By design, each team is under-staffed, under-funded, and overworked (i.e. profitable).

2.1 Capstone course project selection

Each year members of the faculty solicit projects for the Capstone experience from clients external to campus. The pool of clients includes representatives from large corporations, small businesses, research laboratories, public institutions, and, in some cases, individuals. Each team project must require a significant engineering design component that is identified and documented during the solicitation process. Each client pays actual incurred costs plus a participation fee as part of their commitment, with an expectation of receiving value from the team. The projects are scoped to require about 1200 hours of engineering work by the team, or 10 hours per week per student. This scope is mandated by the length of the academic year.

2.2 Team assignments

The Course Coordinator assigns students to teams in the BUME course. As in other institutions, considered student characteristics include student interest, cumulative GPA, demonstrated ability in project relevant courses, work experience, and software competencies [11, 12]. Historically, Myers-Briggs Type Indicators have also been used; how-

* Accepted 23 July 2013.

ever, due to the prominence of the "INTJ" type among BUME students, the indicators provided little value in team assignment decisions. Although several methods to make the selections with this information have been proposed—including fuzzy optimization [13] and goal programming [11], the process generally involves division by interest, assignment by skill level and the assignor's knowledge of the student personalities. There seems to be no replacement for knowing the individual students that are available to be assigned.

2.3 Project timeline

The timeline for the activity begins with student interest surveys in April. The project launch begins with the announcement of the teams in August. A team leader is appointed in September. A written proposal that is acceptable to the student team, the client, and the faculty participants is completed by the end of October. The proposal includes background material, a description of the client's needs, a problem statement, a value proposition, a completed plan for a technical approach to the problem solution, a description of the required budget, and a list of deliverables. Once the proposal is accepted, the team completes a technical review in February. Further milestones are project and client dependent. The project is expected to be completed by early May. Figure 1 shows the chronology and the related activities of the gated review process.

2.4 Project gateway reviews

A gated review process is used to administer and regulate the activities related to both the course and the individual design process required for each of the projects. The gated review process is an effective tool for systematically controlling the progress of an assortment of teams while managing the risk associated with student performance on the projects. It is also an effective pacing mechanism for inexperienced and often apprehensive student teams.

The review process consists of four phased review elements that span the two semesters. The process used for the course is modeled after that of an industry process for introduction of new products [10]. Each element of the process terminates in a mandated gate review that is staged at intervals during the span of the design projects. Each gate review includes, at a minimum, the evaluation of the student team for both a written report and an oral presentation.

The gateways correlate to the major milestones in the timeline. The first gateway review, titled "Discover & Define," occurs in mid-September. The second gateway review occurs at the end of October and is titled, "Measure & Explore." A project proposal is produced during the period between the first and second gateway. The third gateway review is scheduled for early in the spring semester and is titled "Analyze and Design." The third gateway review is an assessment of technical progress. The fourth and final gateway occurs at the end of the spring semester and is titled "Validate & Deliver."

Gateway 1: Discover & Define: The principal function of this first gateway review element are to rapidly engage the students in their team's project activities, to familiarize the team with their client, and to familiarize the team with their design project. During this element of the gateway process, the students are primarily gathering, learning, and organizing information.

Gateway 2: Measure & Explore: The principal function of the second gateway review element is to develop a written proposal that is acceptable to the student team, the client, and the faculty participants. In addition to the information included in the first gateway report, the proposal must include a completed plan for a technical approach to the problem solution, a description of the required budget, and a list of deliverables.

Gateway 3: Analyze & Design: Preparation for the third gateway review is primarily focused on the development of the design concepts using a thorough engineering analysis. This is a time during which much of the detailed engineering analysis is completed. During this phase of the review process the design teams must add detail to design concepts such that they satisfy the engineering requirements specified in the project proposal. Each project has different needs but activities during this phase could include the use of engineering design tools for activities such as solid modeling, finite element analysis, computational fluid dynamics, and

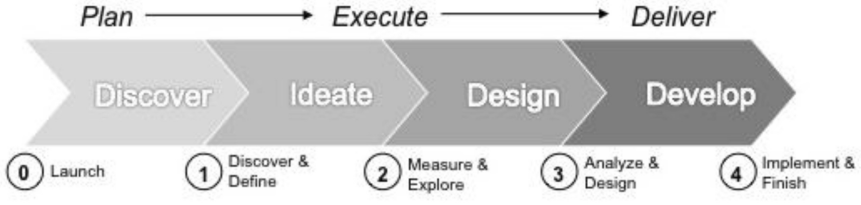

Fig. 1. The Timeline of the Gated Review Process.

others, to predict the performance of the leading design concepts. During this period, the design concepts could evolve to new concepts through an iterative design process. This activity is guided by the ongoing development of the QFD (Quality Function Deployment) plan and the DFMA (Design for Manufacture and Assembly) process. Any significant changes to the technical plan or budget must be documented in a recovery plan and approved by the client and participating faculty.

Gateway 4: Validate & Deliver: The fourth and final gateway review occurs near the end of the second semester of the class. In preparation for the fourth gateway, the team has down-selected to a final design concept, justified and validated the design analysis, communicated their findings to appropriate constituencies, and prepared to transfer the deliverables that were promised in the proposal. The team must also prepare an invoice for an amount consistent with the client-approved budget. The invoice should include all of the cost associated with completing the project.

As shown in Fig. 1, each element of the process is not of equal duration. The first two gateway elements span a three-week and five-week period, respectively. Observation of student teams participating in this course for over a decade has shown that the student teams are slow in starting their projects. The early reviews are effective in engaging the students early and frontloading important parts of the project activity.

3. Effective teams

Katzenbach and Smith's triangle of basics [8] for high-performing teams includes three characteristics: skills, accountability and commitment. The BUME capstone course model uses these three characteristics to set all teams up for success.

3.1 Skills

In industry and in the BUME capstone course, skills are typically the basis for assignment on a team. The focus is on the technical skills stemming from the discipline. The purpose of the project is to bring together the book skills that the students have learned in their previous coursework and apply them to an open-ended design or research problem. As outlined in Section 2.2, the Course Coordinator uses a skills and interest survey to assign the members to the teams. The other factor in the Katzenbach and Smith definition of skills is interpersonal skills. The importance of interpersonal skills on a team is demonstrated by the influence of assignor's knowledge of the student personalities on the resulting teams. Teams where the assignor knows all of the individuals tend to have better results that teams just based on technical skills.

3.2 Accountability

Individual accountability in the workplace often culminates in an "annual performance review". Such reviews are often the basis for promotion, raises and even firing of workers. The BUME capstone course employs two types of accountability assessments: a totem pole and performance review.

In the totem pole assessment, the team members are asked to rank each member of the team in terms of their contribution to the project. The team members complete the ranking each month, with the expectation that the rankings will vary from month to month based on other courses, work or personal responsibilities. Flags are raised to the advisor and course coordinator when an individual is always on the bottom or if there is great disparity between the self-ranking and the ranking from the teammates. By the end of the year, the cumulative rankings provide insight into the team's dynamics and form part of the basis for the individual component of the course grade.

The team also completes the performance reviews for each individual team member. BUME has obtained performance review worksheets from two major corporations and has the student use these forms verbatim. The students learn reviewing both as the reviewer and the reviewee, in a round table discussion during completion of the forms. The concept of average is also covered—in that "meets expectations" should be the most common result. The first performance review is completed in December and the second is completed in March. These performance reviews also form part of the basis for the individual's grade.

The totem poles and performance evaluations are also used for an unpleasant purpose. Students can be "fired" from their teams. Students who are performing at such a level that they are providing negative value to their team or client can be "fired". For example, a student who promises for weeks that they will design or build something and then the resulting product is so subpar to the effect that someone else has to redo it. As in the real world, being fired is not good and has serious consequences. On average, two students per year, in classes of 65, must face being "fired" from their team.

A "fired" student is given a related, small, independent project that, if completed, will benefit the team and, if not, won't do much harm to the team. The student then must work for approximately two weeks on the independent project and submit the completed results to the advisor, course coordinator and team. If the "fired" student is successful, they

earn their way back onto the team. This results in a positive experience for both the "fired" student, who gains self-confidence, and the rest of the team, who regains respect for the "fired" student's abilities and typically learn to understand different working styles. Nearly all "fired" students have had this outcome.

Students who do not successfully earn their way back on the team get one last similar opportunity and then fail the course. Both the student, course coordinator, advisor and the department are aware that this outcome requires that the student stay a full extra academic year, thus while such decisions are not made lightly, students are held accountable for their action or inaction in the capstone course as they would be in industry.

3.3 Commitment

In industry, teams work to complete projects with deadlines. The focus in projects is to *complete* them by the deadline. In schoolwork however, the focus often becomes to turn in whatever you have done by the deadline—and don't look back.

In Bradley's Mechanical Engineering Capstone Design course, the projects are pushed to the industry model of work to completion. Students are not done with their project until their advisor and/or their client says the project meets its intended specifications, as created by the students in their project proposal. Thus the proposal is a commitment by the students to deliver some specified value to the client.

Of course, there are hard deadlines ("no one leaves the office until it's done") and soft deadlines ("if we don't finish it today, it will still be waiting tomorrow"). Student-set deadlines are soft deadlines. If they are not completed on time, there is generally no real penalty, other than delaying the rest of the deadlines. Once a team has missed more than one milestone, however, they are responsible for creating a Recovery Plan to get back on track and must get their client's approval for the plan.

There is only one hard deadline—their graduation. All projects must be completed by the end of the spring semester or there are serious consequences. A grade is not issued for the capstone course, until the project is completed. Thus, the graduation of the entire student team could be delayed. The few teams that have experienced this alternative end up working very diligently and complete their project. This drastic measure usually provides enough motivation and creates common sense of purpose to unite the team's efforts—and to avoid such a conclusion.

3.4 Team vs. individual assessment and grading

In industry team and individual recognition are often interlinked and reflected in job satisfaction and annual performance reviews. In an academic setting, students need to receive grades. Much has been published about teams and individual grading [e.g. 13–16]. The faculty of the BUME Capstone Design course has tried several methods.

Team grades based on the project outcomes. This method was the easiest to implement—if the client loved the deliverables, the students got A's. Unfortunately, the students did not see this as fair or reflective of their individual efforts or the tasks that they individually had to do. Not all projects are equal in demands; not all clients have equivalent expectations.

Individual grades based on the project outcomes. This method allowed the advisors and course coordinator to create a range of grades for the individuals on the team based on personal observations. The project outcomes determine the median grade for the team, then students who visibly put in the most effort were graded higher and those who put in the least effort were graded lower. Students still complained at the lack of periodic assessments of how they were doing and what grade they should expect based on their efforts.

Individual grades based on the project outcomes and totem poles. In this grading strategy, the final results of the project and the monthly evaluations outline in the Accountability section were combined to determine individual grades. This strategy was generally accepted; however the subjectiveness of the project outcome portion of the grade left the faculty in a less than ideal position if a student were to challenge their grade.

Individual grades based on 3 mid-project reviews, a final review and totem poles. This is the current strategy that has been implemented for 2.5 years. The strategy involves rubric-based evaluations of 4 project reviews conducted by the faculty, peers, graduate student, clients and alumni in addition to the individual evaluations. To date the only concern raised for this strategy is the emphasis of the presentation about the final deliverables rather than the deliverables themselves. Time (and course assessments) will tell whether this strategy meets the needs and expectations of all of the constituents.

4. Tuckman's team development model

Tuckman's model [7] for small group development includes five stages: forming, storming, norming, performing and adjourning. It is fairly accepted that a team needs to develop through these stages (forming through norming) to get to a point where the team is considered to be highly effective or "performing." Most projects in other undergraduate courses do not achieve all of the stages due to lack of the combined pressure of quantity of work and

methods to ensure commitment. The BUME capstone course model intentionally pushes student teams to pass through the Tuckman stages.

4.1 Team forming

Current practice in most companies involves creation of problem solving teams in all aspects of business—from business planning to technical design to installation and troubleshooting. In most cases, teams are formed by management, who assign individual members to the teams and often appoint the team leader. As outlined in Section 2.2, the Course Coordinator serves as management and assigns the members to the teams.

From such a beginning, Tuckman's first stage of "Forming" starts. The Forming stage occurs in September and October. In this stage, the team is driven by individuals and their need to be accepted into the group and the underlying process of establishing a method of how the group will operate—unwritten rules and expectations between teammates.

As the team begins their project, course coordinator and project advisor observations are used to guide the project leader selection. As in industry, the project leader is assigned and is the primary point of contact between the team, the client and the manager (the advisor). Student teams are encouraged to do individual skill assessments—having frank discussions about the individual team members' strengths and weaknesses. Teams do research into their client, their project area, and relevant synthesis and analysis methods. By the end of this stage, the team has developed a plan of activities with milestones and deadlines that are presented in a written proposal.

Socially, the students with stronger academic backgrounds and sometimes those with more forceful personalities tend to establish some dominance. In a typical student team, those high-achieving students setup the process that leads to the next developmental stage, Storming, by accepting or even demanding more responsibility for the team outcome than would naturally result from each member having an equal share. These students have always survived and maintained their academic standing by just taking over and minimalizing team members who could jeopardize the grade for the team project. Since this has always worked in past schoolwork, the process continues.

The advisor typically follows the implicit recommendations by selecting the naturally dominant student as the leader.

4.2 Team storming

The Storming stage is where the differences between ideas, work patterns, methods and behaviors of individuals on the team create conflict. In industry, it often falls to the team leader to develop conflict abatement strategies, one of which tends to include their vested authority as leader. However, even in industry, some teams never move beyond this stage. In the capstone project setting, the leader and members of the team are all true peers, so authority is of very limited use. Students are presented with material [14] on teams, roles and responsibilities in the lecture part of the capstone course. The goal is to get each and every team through the Storming Stage as quickly and efficiently as possible.

The Storming stage is the one in which the student engineer develops into an engineer. As work progresses in technical detail, quantity and client deadlines, the pressure mounts. Students learn that their usual coping methods—such as "I'll do it all myself" or "I can forget about it after the due date"—that worked on projects in 'normal' courses don't work due to the magnitude of the projects. Students discover their great ideas to get the project done faster/better are only great when they make themselves heard. Students also realize that there is more to creating value for a client than the pure number crunching many had grown accustomed to. In short, the student engineers storm through not just their team development but their professional development as well.

The keys to achieving both the Storming and Norming phases of team development are the size and scope of the projects. In other projects for other classes, dysfunctional teams are not forced to work together. Diligence by one or two teammates usually covers for the lack of work from other teammates. The BUME capstone projects, however, are designed and scoped so that each team is under-staffed, under-funded, and overworked. Students must work together for the project to succeed and failure is not an option. Subsequent sections on accountability and commitment will explain why.

Depending on the personalities of the team, the team leader, and the advisor, this Storming stage can be either a mild drizzle or a hurricane. The project advisor at this point typically hosts some discussions with the team and sometimes with individual teammates as well. Dominant team members are encouraged to lead with consideration to the strengths of all of the team members. Discussions with these future leaders may include how to listen, how to motive, how to get useful work from all team members or simple advice to do a social activity to build camaraderie. Passive team members are encouraged to speak up and to participate. These students often have good ideas, but were too intimidated to bring them to the team. Discussions with the passive students may include time commitment, taking work assignments instead of waiting

for someone else to tell them what to do, discussion of their strengths and their applicability to the project. The length and severity of the storming stage is affected by individual personalities and the history of the individual students with each other before beginning their capstone project. The problems usually come to a head in late January as the deadline for the technical review approaches.

4.3 Norming

Team norming occurs as the members begin to work together effectively. In the capstone project setting, this is evident as the teams divide the tasks and develop the beginnings of simultaneous rather than sequential activities. Trust of a student's classmates with the student's individual grades can make this process psychologically challenging. So, the common norming phase is when teams divide the work, yet cover each other. For example, a team may divide the tasks so that two students work on one task while two others work on another. More creative teams turn the norming process into more of a round-robin activity. Students A and B work on one task; students B and C work on another task; and students A and C work on yet another task. The norming phase for the BUME capstone students seems to last until the end of March, just after the spring recess.

4.4 Performing

The Performing stage is the goal of teams. In this stage, a ''unified-group approach is applied to the task'' [7]. The team works as a team and accomplishes the work efficiently and effectively.

In the BUME Capstone projects, this stage is when the students finally realize some of the accountability and commitment features of the capstone. The course coordinator and faculty advisors role is generally to get out of the team's way. Weekly meetings, which were essential to ensure progress in September or January, become a way to keep the advisor in the loop rather than a way for the team to get advice.

These young engineers learn the quantity, quality and types of tasks that each team member can handle and divide up the work accordingly. They come to understand that in order for any of them to be successful; they need to be successful together. The sheer quantity of work remaining at this point tends to force the top achievers to trust that even the lowest achievers can do useful work. The low achievers discover that with their degree comes the responsibility to engineer, rather than to nap through lectures.

This exciting phase ends when the project is completed.

4.5 Adjourning

The Adjourning stage is the natural wrap-up to a successful project. In the case of capstone projects, adjourning tends to be more emotional in that it is not just the project or the team that is concluding, but rather the end to many students' undergraduate years. On the technical side, the projects are presented to the University in an open poster display and to the client with a final presentation and transfer of the deliverables. The team also collects and collates all of their team's research and information to give to their advisor for maintenance of the knowledge base for subsequent teams. The BUME Alumni Advisory Board hosts a dinner with the teams after the poster display, as a formal indicator of a last activity together. As the annual graduation activities occur, the adjourning stage is omnipresent. Without any formal intervention, team members and their advisors regularly see each other at the graduation events and meet each other's families and 'grieve' and celebrate the end of their projects. Alumni who have been through this process and achieved a performing team report that they maintain contact with their senior design team members long after they have left the institution.

5. Course implementation history

The capstone course in the Mechanical Engineering Department at Bradley University has existed in much of its current form since 1999. During this time, the course has been a two-semester sequence of industrially sponsored projects with teams of three to four members plus a faculty advisor and a single overall course coordinator.

As enrollment has changed, practice has shown several critical features in sizing. A single course coordinator in our system can handle a maximum of 18 projects, based on the amount of time that goes into the tracking of the financial information, gateway/evaluation requirements and the management loads. Faculty advisors typically should advise one or two projects as part of their standard teaching load; four projects is a maximum for our advisors due to our teaching and research loads. Teams of 5 or more members tend to alleviate the work pressure from the absence of one member—making it too easily to be absorbed by the remaining members of the team. This tends to hamper the ''accountability'' mechanisms that are presented in this article and the ''storming'' phase is also significantly blunted in its impact to individual students. These practices are now firmly established at this institution.

Several features presented in this paper have a more recent genesis. In 2004, the concept of ''firing'' a team member was introduced. Since then an

average of two students per year, in classes of 65, have been fired with approximately half of those students earning their way back onto their team. From a practical standpoint this has greatly strengthened the accountability for students in the course—in that they must complete this course to graduate and failing the course necessarily delays their graduation. The faculty and the students do not take the process lightly. In 2008, the gateway process was introduced. The gateways were introduced to aid in pacing the students through the design process. Previously, students tended to work in major hills and valleys, putting in hundred hour weeks near the deadlines and zero hour weeks when not under pressure. Though not completely successful, the process has reduced complaints from other faculty that the students are ignoring other courses in order to complete their capstone projects. In 2010, the gateways were further developed to aid in evaluation of the projects and to better balance the grades earned across teams and therefore the students in the course. At each gateway, rubrics are used to evaluate the progress and presentation of the team against their own proposal. Scores from the faculty, peers, graduate student, clients and alumni are compiled to form a grade for the team. Separate individual evaluations are used to create a deviation from the team grade. So, a top student performance on a poor team can still earn an A; a poor student performance on a top team can earn a D. Failing marks are reserved for students who have been "fired" from their team and have still not performed acceptably. These practices are still being improved upon based on results and reflections from the constituents.

Since 1999, nearly 800 BUME students have formed 217 project teams. Nearly all of the teams have completed their projects and transferred all of their proposed deliverables to their clients. A few projects, however, have had their deliverables adjusted during the year due to discovery or happenstance (e.g. equipment failure or a client representative changing jobs) that made the original deliverables either impossible or infeasible to achieve. Typically two projects per year do not finish by the May deadline. Those teams usually complete their project in one or two additional weeks. Every three to four years, a team chooses to make decisions that result in a lengthy (a month or more) delay in completion. The institutional student oral history then encourages future teams to make better decisions for a few years.

6. Conclusions

This paper presented a model for capstone design courses that attempts to have student teams experience teamwork in a way that closely follows accepted business practice. Using Katzenbach and Smith's triangle of basics [8] for high-performing teams, teams are formed based on individuals' skills. The team is made accountable and committed both as a group and as individuals through the structure and format of the course. Tuckman's group development stages [7] are generally commonly accepted as stages that every team goes through. Through course planning, policies and expectations, student teams pass through each stage during their two-semester capstone project. This complete experience leaves the students poised for success as they begin their careers as engineers and team members.

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