

Early Development of Capstone Design Teams through Graduate Student Mentoring and Team Building Activities

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Abstract

Capstone design teams at the University of Idaho undertake year-long, industry-sponsored design projects extending from conceptualization through realization of functional prototypes. Team experiences at the U of I have shown that teams that have early external leadership are more prepared for a successful capstone experience than teams that are left to their own devices. This paper outlines how graduate student mentors facilitate team development. Strategies include leading the teams in introductory meetings and organizing team-building activities such as a ropes course, a shop orientation, tracking early progress on a present condition board, and visualizing accomplishments in team documentation. Successful teams tend to immerse themselves in the project very soon after team formation, generating insightful customer interview questions and producing a realistic schedule for the year. Graduate student mentors increase the likelihood of a successful transition by providing a model for effective team organization. Surveys show that teams benefit from structured activities and assistance received in the early stages of team development, leading to enhanced team confidence and understanding. Discoveries about start-up activities, mentor affirmation, and early design-team interventions from the capstone design program at the University of Idaho are likely to add value in other contexts.

Introduction

Most new team members have difficulty functioning together and trusting each other. Short-term project organizers tend to avoid this problem by creating a high level of organization that forces students to work together efficiently to complete the project within the allotted time. A high level of organization is not an option for long-term projects in which the team itself must organize the project and meet the goals and deadlines. Methods must be developed to assist the team members in creating a bond with one another to effectively and efficiently achieve project objectives.

Many institutions, and even some corporations, use early group activities to promote team formation. In previous years, the Capstone Design Course at the University of Idaho has included the creation of a small multi-tool as a method of shop orientation and mentor-to-team bonding exercise.¹ Some schools have incorporated team dynamics exercises such as group juggling and logic games to help students quickly get to know one another and lower personal boundaries.² Olin College has used an activity of building and raising Styrofoam towers to let prospective students meet and get to know their future peers and faculty during an orientation weekend.³

Other schools have taken a more direct approach to help students get to know one another. California State University (CSU) Northridge for example had student teams spend 15 to 20 minutes making lists of specific traits that each team member had in common with the rest of his or her team. ⁴

One goal of team formation is to build a well-balanced team with individuals who are strong in diverse areas. A skill assessment during the team formation process can produce a well-balanced team. The University of Colorado at Boulder performed a Skills Assessment Inventory before students were split up into teams. This assessment included not only technical skills such as proficiency with CAD systems or machine tools, but also compared how students perceived their peers. The instructors also considered demographics when forming the teams and tried to add a little variety by spreading students of minority groups into as many teams as possible.²

Team roles and rules are an important part of teamwork. Under the philosophy of learning by doing, the CSU Software Engineering Department required students to assume the roles of moderator and recorder in at least one meeting throughout their projects. In a class activity, CSU students assumed hypothetical roles, such as a software developer and a client, and solved a problem under those roles.⁴ Short-term projects often avoid the disorganization associated with the absence of clearly defined roles and rules by keeping the projects structured. The prospective students who undertook the foam tower design project at Olin College were given a defined problem statement, an objective, and a complete list of what supplies they may use to complete the project. ³

Many organizations are concerned with the leadership, philosophy, and methods that develop teams. The book Execution described leadership qualities that increase a team's productivity.⁵ Leaders must provide quick and candid feedback, act as an example, and follow through on all agreed-upon actions. Lingard and Berry identified the need to train teams how to function and stated that students do not learn from dysfunctional teams. Lingard and Berry also asserted that more teamwork is insufficient without a leader's effort to see that "teams are well formed and given the knowledge and tools necessary to operate effectively."⁴ Methods that teach students how to work in a team must be implemented. Prospective students at Olin College felt more relaxed when current students lead the foam tower design competition rather than faculty, who had run the project originally.³ The students at Olin showed that a leader who plays a non-evaluative role at the beginning will make team development easier.

The examples in the literature cited above assist team formation by helping team members trust one another and work well together. However, there is little attention to growing leadership skills or how team members come to trust the leader for their group. This is complicated by the fact that in large projects lasting several months to several years, team members are often stunned by the scale of the project and have difficulty getting engaged. A catalyst is needed for teams embarking on industry-scale projects.

Capstone Design Course at University of Idaho

The Capstone Design Course in the University of Idaho Mechanical Engineering Department uses a two-semester design-build-test approach. Students take their projects from preliminary designs to a fully functional prototype. The complexity and scale of these projects as well as the level of workmanship achieved by past students can be seen on the course website (<http://seniordesign.engr.uidaho.edu/>). The Capstone Design Course begins with each student submitting a “bid” to work on a particular project. Instructors place the students in 3-4 person teams for each project. Every team receives a graduate student mentor. A Capstone Design team’s first step toward project success is the generation of questions for the project’s client regarding project deliverables, objectives, constraints, and deadlines. After the teams and clients meet in the client interview, the teams have gained enough information to begin designing solutions to the problem. The teams brainstorm ideas and sketch them with the assistance of graphics packages such as *SolidWorks*. After the teams fully explore the design space and gather all pertinent information about their individual designs (such as cost estimates, production feasibility and ease of implementation) they present their ideas to the client for feedback and final approval to focus on a particular design. Once the client has selected the design they wish the team to pursue, the team creates a detailed design and a prototype solution. The team then tests the solution to determine how well the design meets the design goals. Design modifications are made and the prototype is altered or a new prototype is created and tested until the design can perform all of the required functions within the specified tolerances. The Capstone Design Course ends when teams display the results of their projects at the annual University of Idaho Engineering Design Expo. Table 1 depicts a timeline for the first semester of Capstone Design.

Date	Action	Deliverable
Week1	Course Orientation	Project Bid
Week 2-3	Team Formation	Meeting Times and Protocols
Weeks 4-5	Client Interview	Documentation System
Week 6-7	Problem Formulation	Goal Statement and Work Plan
Week 8-10	Conceptual Design	Solution Alternatives
Week 11-15	Preliminary Design	Design Report and Review

Table 1: First Semester Capstone Design Timeline

Observation of Capstone Design teams at the University of Idaho and a review of the present literature on design team formation has indicated that long-term design teams greatly benefit from a few simple guiding principles: 1) External leadership assists early team formation, 2) A mentor role allows teams to see how to function, and 3) Team building activities improve team organization.

Role of Graduate Student Mentors at University of Idaho

Idaho Engineering Works (IEW) is a group of graduate students who choose to commit their teaching assistantship time to mentoring Capstone Design teams. By precedent, most members are graduates of the University of Idaho Mechanical Engineering Program and have experienced Capstone Design. That experience, plus guidance from 2nd year IEW mentors, helps

them perform their duties as Capstone Design mentors. Information on IEW mentor selection and training is given in “Graduate Student Team Formation for Promoting Engineering Skills” which is part of the 2003 ASEE conference.⁶

Early teams are assisted by an external leadership source that helps organize the early stages of the project. Large-scale projects can be overwhelming, requiring groups to form themselves into a functioning team and work together to produce the desired outcome. Many teams do not possess the skills required to organize the project to meet the project goals in an effective, timely manner. The teams often suffer from a lack of cohesiveness in which team members work on their own or don’t work at all if left to their own devices.

An external leader can serve to unite the team toward common goals and give the team an idea of how to begin their project. The leader does so by defining a general list of intermediate objectives for the entire project so the overall path can be seen at a glance. Once the overall format is visible, the preliminary steps can be broken down into manageable pieces. The project then changes from an overwhelming assignment with no end in sight to a project that, while difficult, is not impossible.

Mentors can show early teams how to function as a cohesive team. Mentors are experienced role models for these teams, much like the coach of a youth sports team, and provide the role of project manager initially. The mentors’ experience comes from participating in projects of similar scale and leadership opportunities. The mentors run the first meetings, providing an organized and pleasant first experience for the team. In the first meetings, the mentors instruct the design teams on how to run a meeting, make a reasonable schedule, make agendas, and begin the project. However, as the design teams learn to function on their own, the mentors reduce their control, and become technical advisors.

To help the design teams understand what is to come, mentors use tools and visualization techniques. One example of a visualization technique is a present condition board. A present condition board is a large poster board that shows the progress each team has made on their project and identifies the team’s remaining stages of design. During the first meeting the mentor describes the typical design schedule for the project such as problem formulation, goal setting, brainstorming, designing, and prototyping. From this the teams create their own schedule and apply it to the present condition board.

Team building activities improve team organization within teams in the early stages of development. Examples of team building activities include a ropes course and shop orientations that require the group to work together as a team in order to complete sets of tasks that would be impossible for an individual to do alone. These sessions help create feelings of unity and belonging among team members and trust between a team and its mentor.

Once the team members realize that they can rely on each other they will begin to divide up project tasks effectively and help each other complete them in a timely manner with an acceptable level of detail and quality. A team that has benefited from the team building activities will be able to manage the day to day functions of their project through working individually and

collectively towards a common goal by combining their work at intermediate goals.

Team Leadership Model at University of Idaho

A key to starting the Capstone Design Course well is a mentor-led first meeting. The mentor addresses initial issues, student questions, and sets an example for how to achieve a productive and fun meeting. One initial issue is the identification of common deliverables for the capstone design course such as reports, presentations, logbooks, research binders, action item matrices, and design failure modes effects analysis (DFMEA). Other issues include machine shop and design suite policies and exchanging contact information and schedules. Students often have the following questions:

- What do we do first?
- What is the mentor's role?
- How does the design project typically proceed throughout the year?

Answering the first question requires more than telling the students what to do. Mentors must lead students immediately into activities that help them learn about their project. Brainstorming technical, social, or business issues related to their project is one beginning. Researching related technologies also helps students define the design space. Achieving a productive first meeting requires that teams leave with tasks for the first week. Depending on the team the mentor may run some subsequent meetings until the team is comfortable with the procedure. At the conclusion of the first meeting mentors recommend that teams do something social outside of school to get to know one-another.

In addition to the time spent with the mentor in the first meeting, the teams build trust with the mentor through minor activities. The main activity the team is focused on initially is the formation of questions for the customer to learn what the goals and bounds of their project are. A mentor is a great asset to a team in this phase of design because he or she has gone through the capstone process and knows what types of questions need to be answered. Many of the teams will build very early prototypes or test basic concepts as part of their exploration of the design space. Mentors frequently lend a hand by assisting the teams with machining or by giving ideas for simple ways to test. At the first meeting teams will often define research tasks such as investigating the customer or related technologies. Some informal interaction occurs when students pose day-to-day questions to the mentors about the use and location of special equipment such as oscilloscopes and data acquisition systems.

Capstone Design teams are encouraged to participate in a ropes course provided by the Outdoor Recreation Program at UI to improve their teamwork skills. A ropes course is a set of activities that promote teamwork and build teamwork skills. The students must work as a group and plan strategies to complete tasks such as lifting one another through holes in a net, carrying objects without directly touching them, and being led blindfolded through an obstacle course. The ropes course adds value to the team formation process by encouraging students to develop their sense of belonging to the team and demonstrating that some activities are extremely difficult when one person tries to perform them alone. In addition, it is a fun, low stress, and low impact

activity for the team members to get to know one another on a more personal level.

Every student will, at some point during the Capstone Design Course, need to construct a piece of the team's prototype. Most teams will need to use hand tools, welders, drill presses and manual and CNC lathes and mills in the Mechanical Engineering Department's machine shop. While a mentor is always present when using a lathe or mill, it is essential for all students to have a basic knowledge of where tools are located and how to operate them safely and effectively. Within a couple of weeks after formation, the teams will go through a shop orientation with their mentor and will complete a shop practical to demonstrate they have a working understanding of the tools and safety. All major equipment is covered with the exception of the CNC equipment, which is handled on a case-by-case basis during the prototyping phase of the capstone process. Students then schedule a time with their mentor to take the shop practical. Between the time of the tour and the practicals the students are encouraged to go back into the shop as a team to study for the practical by reminding themselves of operations and tool locations. Practical are done one-on-one so that each student can demonstrate their understanding and any deficiencies are immediately evident and correctable. The time the students spend together working towards the shop practical helps them build trust and respect for their teammates and their mentor.

Tools for Measuring Improvements in Teamwork

A teaming rubric (see Figure 1) was created to measure the change in capstone team performance at the end of the first semester of the class. By this time, all of the teams had been through the shop orientation, ropes course, first meetings, and other introductory activities. By the end of the semester it would be evident whether or not teams had benefited from the mentor involvement and team formation activities. The mentors used the rubric to evaluate their teams at the beginning and again at the end of the first semester.

The categories of the rubric were written with the intent of providing a clear understanding of the effects of mentoring with a focus on team self-reliance. The assessment scale is designed to be simple for the purpose of improving accuracy by improving usability and clarity for the evaluator. Three main categories are taken from Bossidy and Charan's *Execution: People, strategy, and day-to-day operations*.⁵ Their approach to team results is derived from definitions of these three processes. They view the people process as being much more critical than either strategy or day-to-day operations. We have reworked Bossidy and Charan's definitions to fit within an academic design environment.

The people process is the ability to candidly and accurately evaluate individual performance. This is intended to accomplish three things:

1. "It evaluates individuals accurately and in depth."
2. "It provides a framework for identifying and developing the leadership talent—at all levels and of all kinds—the organization will need to execute its strategies down the road."
3. "And it fills the leadership pipeline that's the basis of a strong succession plan."

TEAMING RUBRIC

The evaluated: _____

The date: _____

		NOVICE	INTERNS	ENTRY-LEVEL	PROFESSIONAL
		lack experience with projects longer than 3 months	experience limited to class and internship projects	experience and leadership in projects lasting 3 months or longer	experience with projects spanning several years
STRATEGY					
	Team goals are elevating and clearly understood by each member and by relevant stakeholders. In addition team goals satisfy other criteria such as those described by the SMART acronym.				
	The team is results-oriented. They routinely and continuously create appropriate results in the process of completing a project.				
PEOPLE					
	The team uses processes that reveal the strengths of each individual and they create a shared understanding of how each individual contributes.				
	The team uses forward-focused evaluation				
	Conflicts between team members are brought to the team for resolution. The team employs a conflict resolution process that solves the problems and promotes collaboration.				
DAY TO DAY OPERATIONS					
	The team has well understood expectations (e.g. defined levels of quality, on time to meetings, acceptable contribution, etc.).				
	The team follows effective meeting practices. This means meetings have clear objectives, have an agenda, are documented appropriately, begin/end on time, stay on task, and meeting time management is appropriate.				
	The superior quality of the team's work generates external support and recognition.				

Figure 1: Capstone Design Teaming Rubric

The strategy process has to do with development of an action plan that can be used to reach product goals. Developing such a plan starts with identifying and defining the critical issues behind the strategy. The teaming rubric's subcategories are focused on finding the *right* goals before the plan is made. The team must consider what resources are needed immediately as well as toward the end of the project. They must ask themselves questions regarding adaptability and contingency planning.

The day-to-day operations process breaks down long-term output into short-term targets. Day-to-day operations enable the team to reach large goals by executing small tasks such as who does what assignment, when they will complete it, and what help they will need to get it done. Day-to-day operations are also concerned with team management such as being sure that each member knows and agrees on what is expected of them.

Effectiveness of Team Leadership Model

The mentors universally agree that their capstone design teams were at the "Novice" level on all the skills on the rubric at the beginning of the semester. Although some capstone students ranked higher than "Novice" on some of the skills on the rubric, no team was above that level. The mentors identified that the teams were lacking in teamwork skills such as conflict resolution and the willingness to openly share ideas. The teams lacked confidence and individual team members lacked trust in their teammates. In past years, team members led the first meeting as opposed to the mentors. As a result, there was little productivity and mentors had to take over and explain the Capstone Design Course process to the students. At the beginning of the year, teams had virtually no shop experience and very little practical solid modeling experience; for most students, it had been a year since they had completed the advanced graphics course. Also, teams initially resisted the idea of using solid modeling software in their design.

By the end of the semester, average teams rank at the "Intern" level. The team improvements cover many areas including: running their own meetings productively, independently developing solid models and drawings, and machining 1st prototypes without constant supervision. In team meetings the students openly share ideas and debate alternatives, finishing the meetings with consensus on decisions about actions to take within the week and necessary steps to complete the project. When producing solid models, mentors no longer need to tell teams what to do; mentors just give pointers. Though the mentors' presence is required in the machine shop to ensure safety and promote quality, mentors no longer need to answer simple questions such as, "Where is the drill?"

TEAMING RUBRIC

The evaluated: A & B
 The date: Dec. 17, 2002

		NOVICE	INTERNS	ENTRY-LEVEL	PROFESSIONAL
STRATEGY					
Team goals are elevating and clearly understood by each member and by relevant stakeholders. In addition team goals satisfy other criteria such as those described by the SMART acronym.	A	→	→	→	
	B	→	→		
The team is results-oriented. They routinely and continuously create appropriate results in the process of completing a project.	A	→	→		
	B	→	→		
PEOPLE					
The team uses processes that reveal the strengths of each individual and they create a shared understanding of how each individual contributes.	A	→	→		
	B	→			
The team uses forward-focused evaluation	A	→	→	→	
	B	→			
Conflicts between team members are brought to the team for resolution. The team employs a conflict resolution process that solves the problems and promotes collaboration.	A	→	→		
	B	→			
DAY TO DAY OPERATIONS					
The team has well understood expectations (e.g. defined levels of quality, on time to meetings, acceptable contribution, etc.).	A	→	→		
	B	→	→		
The team follows effective meeting practices. This means meetings have clear objectives, have an agenda, are documented appropriately, begin/end on time, stay on task, and meeting time management is appropriate.	A	→	→	→	
	B	→	→		
The superior quality of the team's work generates external support and recognition.	A	→	→		
	B	→			

Figure 2: Example rubric comparing two teams

Changes in team performance for two randomly selected capstone design teams are shown in Figure 2. Note the growth is highly variable from team to team. The areas of greatest development generally correspond to activities in which teams have the greatest contact with their mentor. As such, it is not surprising that growth is more pronounced in the strategy and day-to-day operations processes. The people process is characterized by more indirect information that we are trying to assess more frequently and reliably. This is complicated by the fact that there is a high degree of self-reporting and self-reflection that is part of this process.

Conclusion

Teams gain confidence, trust, and sense of belonging from early external leadership. Under-performing teams usually struggle with team dynamic problems, such as lack of commitment, rather than technical issues. A rubric, based on teamwork concepts from *Execution*,⁵ helps measure team formation and growth. Mentors and faculty observe that teams research earlier and create better customer interview questions as a result of graduate student leadership early in capstone design projects. Design teams experience the biggest improvements in areas where they

interact with mentors the most, such as shop work, solid modeling help, and regular team meetings.

The results from our preliminary study are threefold: (1) The performance of capstone design teams can be dramatically improved through external facilitation by graduate students; (2) Facilitation that includes mentoring on key teamwork skills will help the team become more self-directed; (3) Structured team activities strengthen early team formation and generate well-founded self-confidence in team members.

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Dr. Karl Rink recently joined the Department of Mechanical Engineering at the UI after spending 10 years in industry researching the combustion and thermodynamic behavior of gaseous, liquid, and solid phase propellants and explosives. He holds 33 U.S. patents with an additional 10 applications under examination. He has received the PACE Award from one patent and is the youngest recipient of Purdue's Outstanding Mechanical Engineer award.