A Qualitative Investigation of Success and Challenges with Team Roles in Capstone Design

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This study is an initial, exploratory investigation into the use of team roles to structure engineering Capstone Design teams. Team roles in a mechanical engineering Capstone Design course were investigated for patterns of success and challenge in applying the role. Students from three cohorts of Capstone design totaling 491 participants completed a post survey asking them to report on what they did in the role that worked well and what they would do differently in their team role. Data were separated by role and analyzed qualitatively to determine themes across roles with respect to challenges and successes. Results revealed that students were able to articulate specific role responsibilities that had worked to help the team function better. Students were also able to indicate what they would do differently in future design experiences.

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Introduction

Capstone design is framed as a real world, team based design experience. Industry and research have recognized the need for clearly defined roles and responsibilities for team members to work productively – achieving mission, vision, goals and objectives.[1] However, when training students to work in teams, most Capstone Design courses only define the Project Manager or Project Lead role. There are concerns that this can lead to working as a group of individuals rather than a goal-oriented team differentiated into multiple roles.[2] There is an opportunity for the Capstone Design community to learn from industry practices and incorporate these approaches. The present study is an investigation of assigned team roles in one Capstone course that is an industry simulation, where teams produce a real world project for a client. Teams are formed based on common interests and propose who will fill each of seven roles on the team. This structurehelps them create an integrated team that works productively toward their project goals.

Background

Team roles have been a popular concept in business literature since Belbin described eight roles underlying ideal teamwork over 30 years ago.[3] Since that time, role theories have proliferated and the assignment of team roles has become a factor distinguishing teams who work on common goals from groups who work on individual goals within a common organization.[1]

One way to structure the team is by functional roles where roles are classified based on job demands, necessary knowledge and skills.[4] Division into functional roles is a popular method in industry teams. For example, experts in the software-development industry identified roles in the software-development process based on impact on productivity.[5] Similarly, preferences for functional team roles were investigated in construction teams to improve overall team performance.[6]

In engineering education, the development of teamwork skills is driven by ABET accreditation, which requires students to demonstrate the ability to function effectively on a team.[7] Felder et al, 2000[8] describe the assignment of functional team roles as an effective teaching method for implementing cooperative learning techniques in the classroom. In Capstone Design, functional roles have been investigated through studying Capstone team design journals to determine the ways roles shifted over time.[9] These studies coupled with industry practices provide rationale for incorporating functional team roles across Capstone Design teams. The current investigation builds upon previous studies by investigating successes and challenges of team roles in a mechanical engineering Capstone Design course.

CU ME Capstone Design Course Structure

This study took place in the University of Colorado Boulder (CU Boulder) Mechanical Engineering (ME) Capstone Design Course. During the time of this study (AY 2014-2017), course size ranged from 186-244 students.

Course Overview

The CU Boulder ME Capstone Design course is a 3-credit, yearlong, industry-sponsored class. The course is a transitional experience that emulates having an engineering position in a consulting firm. A Tuesday/Thursday block time format from 9:30am - 12:15pm allows for a Morning Meeting (i.e., lecture) and Training Session (i.e., lab). Typical projects follow a fall design cycle and a spring fabricate-test- iterate cycle. Though a framework of possible deliverables are provided, the team negotiates deliverables with their Director (i.e., faculty mentor) and Client that best align with their project requirements. There are no grades associated with specific deliverables, rather students complete individual performance evaluations at the end of each semester with their Director. These evaluations are then translated into a grade.

During the first week of class, all students are introduced to the sponsored projects for the academic year. Teams are formed based on project interest, grade point average, technical background, and professional skills. Teams apply to clients and clients rank their preferred teams. A matching process optimizes the Client and team preferences.

Team Structure Overview

Each team of 5-7 students is overseen by a Director (i.e., faculty member). The Director serves as the primary manager for the team to ensure project progress. Directors assist with framing project goals, schedule, milestone negotiation and implementation of the design process. Directors oversee action items and project deliverables. Directors and Clients meet with the teams on a weekly basis for ~1 hour/week. Executive officers (i.e., course coordinators) provide high-level guidance for curricular and organizational oversight and coordination. Figure 1 displays a typical organizational structure for a CU Boulder ME Capstone Design team.

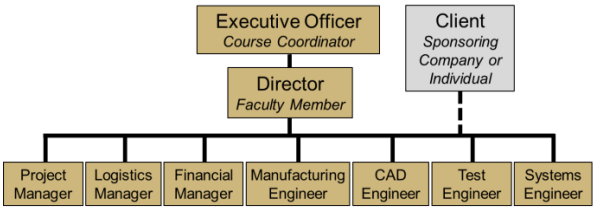

Figure 1: CU Boulder Mechanical Engineering Capstone Design Organizational Chart

Team roles were established in fall 2013 by the ME Capstone Design curriculum team to assist students with moving from a group mindset to a team mindset, where they would be responsible and accountable for their individual contributions to the project. Each team role and corresponding responsibilities are listed in Table 1. It is important to note, that even though each team member has a formalized functional role on the team, they are also responsible for contributing to the overall weekly action items for the project.

Table 1: CU Boulder Mechanical Engineering Capstone Design Team Roles and Responsibilities. All team members are expected to contribute to project action items in addition to these leadership responsibilities.

Project Manager: manages all tasks; develops overall schedule for project; writes agendas and runs meetings; reviews and monitors individual action items; creates an environment where team members are respected, take risks and feel safe expressing their ideas.
Logistics Manager: coordinates all internal and external interactions; lead in establishing contact within and outside of organization, following up on communication of commitments, obtaining information for the team; documents meeting minutes; manages facility and resource usage.
Financial Manager: researches/benchmarks technical purchases and acquisitions; conducts pricing analysis and budget justifications on proposed purchases; carries out team purchases using the department-assigned purchasing credit card; monitors team budget.
CAD Engineer : coordinates, manages and integrates CAD work for the prototype design; establishes protocols for revision control; manages all SolidWorks files; ensures the CAD models match physical prototypes; and, lead on FEA and CFD analysis, if needed.
Systems Engineer : analyzes Client initial design specification and leads establishment of product specifications; monitors, coordinates and manages integration of sub-systems in the prototype; develops and recommends system architecture and manages product interfaces.
Test Engineer: oversees experimental design, test plan, procedures and data analysis; acquires data acquisition equipment and any necessary software; establishes test protocols and schedules; oversees statistical analysis of results; leads presentation of experimental finding and resulting recommendations.
Manufacturing Engineer: coordinates all fabrication required to meet final prototype requirements; oversees that all engineering drawings meet the requirements of machine shop or vendor; reviews designs to ensure design for manufacturing (DFM); determines realistic timing for fabrication and quality; develops schedule for all manufacturing.

For example, the Manufacturing Engineer is expected to contribute to project needs such as concept generation, analysis, and CAD, while taking the lead on planning and coordinating manufacturing. Because of team sizes, some teams require members to combine roles (i.e. CAD/Manufacturing or System/Test) or split roles (i.e. multiple manufacturing leads).

In AY14/15 and AY15/16, the Project Manager, Logistic Manager, and Financial Manager received specialized training regarding the responsibilities of their roles. Starting in AY16/17 Systems, Test, and Manufacturing Engineers also received specialized role training in addition to the workshops.

Guiding Questions

The present study is an initial, exploratory investigation of team role implementation in CU's Mechanical Engineering Capstone Design course. Two questions were posed to Capstone Design participants at the end of the course to understand student perceptions of designated team roles:

- Q1: What did you do in the role that worked particularly well?
- Q2: What do you wish you had done differently for your role?

The research team intends to use the results of these exploratory guiding questions to develop more sophisticated research questions for future work.

Methods

Participants in the study include three cohorts (2015-2017) of Mechanical Engineering Capstone Design at CU Boulder totaling 491 students. Students were divided into teams and selected for one of five – seven roles, depending on team size. The number of student responses in each role is indicated in Table 2.

Students took a Qualtrics survey at the end of the course that included the two exploratory questions presented as open-ended comment boxes for students to write in responses. Students were asked to select their role from a drop-down menu. Collected data were divided by role and analyzed using qualitative coding techniques.[10] Coding of data continued until two themes emerged for each role and guiding question.

Results and Discussion

Table 2 displays what students did in the role that worked well and what they wish they had done differently. Themes are presented in the students' own words as closely as possible.

The "What did you do in the role that worked particularly well?" themes provide insight into how the enacted roles compare to the ideal conceptualized roles

Table 2: Themes for effectiveness across seven ME Capstone Design team roles

Role	What did you do in the role that worked particularly well?	What do you wish you had done differently for your role?
Project Manager N=77	• Keeping the project on target • Keeping everyone involved	• Handle team conflicts early • Negotiate standards for success
Logistics Manager N=77	• Distributing meeting minutes promptly • Managing communications with team members and Clients	• Clear up communication problems individually • Stay on top of scheduling issues
Financial Manager N=86	• Keeping on top of the budget • Shopping for the best value	• Learn more about financial software • Work better with vendors
CAD Engineer N=71	• Creating models to help visualize the design • Organizing the CAD files for accessibility	• Divide up the CAD modelling better among the team • Work on the CAD modelling throughout the process
Systems Engineer N=71	• Having a high level technical understanding of the project • Ensuring the compatibility of all project components	• Work to integrate teammates, not just components • Develop a deeper understanding of the design to foster integration
Test Engineer N=65	• Developing a test plan • Communicating test results to teammates	• Prioritize testing throughout the year • Expect some tests to fail
Man. Engineer N=79	• Leading manufacturing of difficult parts • Outsourcing simpler parts to teammates	• Schedule more time in the machine shop learning skills • Spend more time on the manufacturing

presented in Table 1. For each role presented in Table 2, there is direct alignment with what students reported as working well and the responsibilities and accountability set forth by the instructional team. For example, Project Managers (PMs) felt they were able to move their projects forward toward successful completion, as well as keeping all team members involved during this journey. The Test Engineers were able to generate their test plans and communicate their test findings to the team.

The "What do you wish you had done differently for your role?" themes provided reflections into what topics each team member struggled with during the project. Project Managers discussed having difficulties dealing with team dynamics and suggested dealing with the issues earlier in the project. PMs also realized at the end of the project that the word "success" or "quality" had different meanings for different team members and these expectations should have been discussed early in the design project. Test Engineers provided valuable considerations that they should have focused on testing earlier in the process and made it an integral part of the design process, so that they would have had more time to adequately run tests and integrate results into a new design. This feedback from students on their struggles will be integrated into future trainings and workshops associated with the Capstone Design course to better prepare students for the role.

Across roles, students were able to clearly articulate role-related responsibilities that allowed them to play a functional part in their design teams, suggesting that students are adopting the structure and taking ownership of their specific leadership responsibilities for the project. For example, one student in the Project Manager role stated, "Keeping in close contact with my teammates and always checking in to what they were doing was a great way to keep the project on track." One student in the CAD Engineer role discussed learning about the need to continually work on the CAD models, "I wish we would have continually validated our model more frequently throughout the process rather than only every couple months."

Future Work

Further exploration of team roles in the Capstone Design Course was initiated on the mid-term assessment of the current academic year, 2017-2018. As previous results were based on student qualitative feedback, questions were added to the student surveys as well as the surveys for their team's Client and Director to gather quantitative ratings of the effectiveness of the formal team roles. Responses on a four-point scale were in the "good" range (i.e. three out of four on a four-point scale) with responses from 164 students (mean = 3.28/4), 17 faculty (mean = 3.05/4), and 10 clients (mean = 3.60/4) indicating the general effectiveness of assigned roles in the course as triangulated quantitatively across multiple raters.

Future research will dive deeper into the impact of team roles in the CU Boulder ME Capstone Design (i.e., developing teams versus groups of individuals). For example, there were some instances of students modifying their roles during the year by taking a back-up role or dissolving their assigned roles. These results could be explored in more detail via focus groups or interviews. In addition, course outcomes tied to ABET were measured quantitatively in the course surveys and could be broken out by role to investigate numerical differences in skill gains. Lastly, triangulation of the perception and the impact of team roles can be investigated more deeply with additional questions in future surveys of Clients and Directors.

References

1. Kozlowski S. W. J., Ilgen D. R. (2006). Enhancing the effectiveness of work groups and teams. Psychological Science, Vol. 7: 77-124.
2. Buchanan, L. (2015). Teams vs. Groups. https://www.youtube.com/watch?v=uG-FLOi4OOU
3. Belbin, R. M. (2011) "Management Teams: Why They Succeed or Fail (3rd ed.)", Human Resource Management International Digest, Vol. 19 Issue: 3.
4. Lehmann-Willenbrock, N., Beck, S.J. and Kauffeld, S. (2016). Communication Studies Emergent Team Roles in Organizational Meetings: Identifying Communication Patterns via Cluster Analysis. Vol. 67, Issue 1.
5. Yilmaz, M., O'Connor, R. V., Clarke, P. (2015). Software Development Roles: A Multi-Project Empirical Investigation. SIGSOFT Softw. Eng. Notes Vol. 40, Issue 1, 1-5.
6. Ayinde, O. N., Oke, A. E., (2017). Preferred Team Roles of Construction Team Members in Selected Higher Institution Projects. International Journal of Built Environment and Sustainability, [S.l.], Vol. 4, Issue 2. ISSN 2289-8948.
7. ABET (2017) Criteria for Accrediting Engineering Programs, 2016 – 2017. ABET.org.
8. Felder, R. M., Woods, D. R., Stice, J. E., Rugarcia. A. (2000). The Future of Engineering Education II. Teaching Methods that Work. Chem. Engr. Education, Vol. 34 Issue 1, 26–39.
9. Born W., Schmidt L. (2016). An Observational Study on Functional Behavior in Team Design. ASME. 28th International Conference on Design Theory and Methodology. Charlotte, North Carolina, USA.
10. O'Reilly, K. (2012). Ethnographic Methods. London: Routledge.