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Work in Progress: Teamwork Skills Development in ChemE Car

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Abstract

Teamwork is widely recognized as an important soft skill for engineers in the professional workplace. ABET includes teamwork skill development in their accreditation criteria, and recent alumni report that teamwork is among the most important skills in their professional lives. However, the typical undergraduate classroom consists of a lecture format, which does not help foster teamwork skill development. An alternate space in which teamwork skills can be fostered is in undergraduate technical clubs, such as those that compete in the AIChE annual ChemE Car regional competitions. The present work-in-progress research study attempts to provide a framework to continuously improve the development of teamwork as a professional skill in a ChemE Car club at a large public university through observations of team laboratory time and interviews of team members. We chose the Katzenbach and Smith teamwork framework, and the related teamwork performance framework developed by Davis and Ulseth (2013), to evaluate ChemE Car teamwork. We contextualized this model with details salient to the specific ChemE car teamwork context, to develop an observation rubric and interview script for data collection in this study. We have interviewed a few students, and preliminary data show evidence of high success in team relationships while team joint-work products can be improved. The results of this study will be used to develop methods for ChemE Car project managers to optimize their laboratory time to develop general members' teamwork skills.

Introduction

Teamwork is regarded as one of the most important soft skills by both engineering graduates and their employers (1-4). A review of studies surveying engineers across engineering disciplines and experience levels found that there are four distinct tiers of importance; communication and teamwork were in the tier with highest importance, while math, science, and engineering knowledge were in the tier second from the bottom (5). Professionals with teamwork skills are desirable because high-performing teams have the potential to become greater than the sum of their members, especially when tackling interdisciplinary challenges (2). However, teamwork does not receive adequate emphasis for such an important skill in traditional undergraduate engineering curricula (4). Engineering students are often expected to work in groups during laboratory or design courses, but a large portion of engineering classes are lecture-based and students compete for grades based on individual work products (6). While there is a growing emphasis on implementing cooperative learning strategies in engineering classrooms, students need to practice teamwork skills for these learning methods to succeed (6, 7). Thus, it could benefit engineering departments to ensure that there are other ways for their undergraduates to gain experience working in teams.

In recent decades, many programs have adopted active and collaborative learning in their engineering programs, and a lot of research effort has been dedicated to studying these experiences. Some effective models of active and collaborative learning have been established which successfully improve academic results both in terms of conceptual understanding and problem-solving performance on examinations (8-10).

Many faculty are still reluctant to use active learning in their classes because active learning can place a greater workload on instructors (9), instructors may encounter student resistance (10), and there is a need for professional development to support faculty who are new to active learning (11). Those that do use active learning are typically focused on improving academic performance rather than soft skill development for students (4, 8).

Extracurricular Opportunities for Teamwork

Where these opportunities for active learning and soft skill development are not present in the classroom, team-oriented student design competitions such as the AIChE ChemE Car competition can provide a platform for the development and enhancement of professional skills. The ChemE Car competition involves teams of undergraduate students building a shoebox-sized model car that is powered and controlled by chemical reactions. An objective of the competition is to provide undergraduate engineering students the opportunity to work on a team-oriented design project (12). These activities are held outside of the classroom and all student participation is voluntary. In previous research examining the educational impacts of ChemE Car, the results have demonstrated that ChemE Car participants developed both technical skills, such as problems solving, and soft skills — especially teamwork and led to better performance in future (3, 4, 13, 14). One study done at a large public university in Spain examined ChemE Car as an application of Learning-by-Doing (LbD), a type of active learning that seeks to have students learn from their experience with hands-on projects, and found that ChemE Car participation achieved the same goals and purposes of implementing LbD in the classroom (13). A similar mechatronics-oriented competition in which students build low cost self-driving cars similarly developed undergraduates' skills for working in teams in hands-on situations (15). The goal of the current work-in-progress study is to develop tools for team-oriented design project clubs to maximize the development of teamwork as a professional skill among their members and thereby improve the productivity of the club as well as their performance at competitions. While this study focuses on ChemE Car as a test case, the framework and methods for this study can be adapted to any undergraduate club oriented towards team-based engineering projects.

Teamwork Model

This study seeks to examine the development of teamwork as a professional skill. We therefore chose to use the Katzenbach and Smith teamwork framework (16) for this research because it was developed in a professional context and is based on observations of teams operating in businesses. Katzenbach and Smith highlight the following key features of a team:

- Team has a small number of members
- Team members have complementary skills
- Team members work towards a common purpose
- The team produces collective work products
- Team members are necessarily working with each other and providing continuous feedback to each other on collective work products

- The team has a specific purpose, which is typically assigned by someone outside the group
- The team performance is measured by assessing collective work products (16)

The essence of a team is that they ***have the potential to become greater than the sum of their individual members***. If the above listed features do not apply to a set of people working together, then it is simply a working group, and the working group's potential is limited by the potential of the individual members.

The ChemE Car team at the large, public research institution at which this study takes place is structured such that there are several project teams that focus on a single component of the car (power, control, electrical, and chassis) that fit the criteria laid out by Katzenbach and Smith for teams:

- 5-7 members
- Work together on a single car component
- Everyone works together in lab
- Team has common purpose determined by club executive board and ChemE Car competition
- Performance is measured at competition

These teams then collaborate as a working group, in which the whole is the sum of each project team's work.

While this study focuses on ChemE Car as a test case, the framework and methods for this study can be adapted to any undergraduate club oriented towards team-based engineering projects. These could include the American Society of Civil Engineers Concrete Canoe (17), American Solar Challenge (ASC) (18), and Formula Sun Grand Prix (FSGP) (19), American Institute of Steel Construction Student Steel Bridge Competition teams (20), and others. All of these clubs can follow similar processes for maximizing their members' development and, as a result, their team's performance.

<u>Methods Development</u>

We developed methods based on the prior work of Katzenback and Smith, and David and Ulseth. The Katzenbach and Smith model of teamwork was translated into a conceptual framework that could be used to gather and analyze data by Davis and Ulseth (2013) (21). This framework examines four areas of team performance:

- Team relationships
- Production of joint-work products
- Individual work products
- Knowledge assets

These four performance indicators were then used to develop the data collection methods for this study.

Team relationships deals with how team members interact with each other and how that impacts both individual and team performances. Successful team relationships make members feel included, engaged, and important to the team's success. The quality of team relationships is highlighted by how well team conflicts are resolved (21). Team relationships in undergraduate projects primarily manifest themselves in laboratory sessions during which all team members are physically present. However, team relationships in virtual is also of tremendous importance due to the potential for cyberbullying, and are of the utmost importance during the pandemic, in which all team relationships occur in virtual settings.

Joint work product creation is where teams distinguish themselves from working groups. True teams work together to maximize quality and strive to fulfill team goals. Individual work products that complement each other are also typical of successful teams because they take advantage of individual members' specific or specialized knowledge and experience (20). An undergraduate project team's success or difficulties in joint work products will manifest itself during the laboratory sessions in which they are created, whereas individual work products are typically created outside of such times.

Knowledge assets deal with how teams handle and transfer both logistical and technical information between members. Knowledge assets directly affect team members' ability to work as a single unit, and tie into team relationships (21). Knowledge assets are handled both during laboratory sessions and through virtual platforms.

Based on understanding the situations in which these aspects of teamwork take place, observation and interview data collection methods were developed. We developed a rubric based on the four Davis and Ulseth performance indicators to evaluate successful and unsuccessful team actions. The observation method is designed to primarily assess team relationships with regards to in-person interactions, the production of joint-work products because those are on display in laboratory sessions. The interview method provides insight for team relationships in online and virtual settings, the creation of individual work products, and team knowledge assets.

Methods

The primary data collection method for this study is the observation of ChemE Car teams in laboratory sessions. This will consist of observing team activities in the lab and noting positive or negative team interactions. This method will shine a light on the creation of collective work products and team relationships for in-person settings. This is the time when members will be working most directly as a team and the team deliverable is created, so the actions and interactions of team members in lab have the most direct effect on team success.

The complementary data collection method for this study will be interviewing team members about their experiences on the team that take place primarily outside of lab. This method provides insight for team relationships and engagement in online and virtual settings, the creation of individual work products, and team knowledge assets. These factors in team performance have a massive impact on the ability of team members to perform in lab, and therefore must be accounted for when observing the successes and shortcomings of the team.

Due to the COVID-19 pandemic, laboratory sessions for ChemE Car have been cancelled, and therefore the observation procedure has not yet been implemented. Observation is planned for future laboratory work sessions when COVID-19 restrictions are lifted. The interview portion of the data collection has been adapted to be performed over video conference. This includes the use of an IRB-approved unsigned (verbal) consent process and the use of Zoom sessions with random meeting ID and password, use of Zoom waiting room, and locking the meeting room once the interviewer and participant have joined the meeting for heightened security.

To analyze the data, three researchers examined interview transcripts independently and identified positive and negative teamwork interactions. The researchers then tabulated the successful and unsuccessful interactions according to the following categories and subcategories:

1. Team relationships
    a. Members show respect for each other
    b. Members demonstrate commitment to team success
    c. Members resolve differences to benefit the entire team
2. Joint work products
    a. Members contribute to developing shared team goals
    b. Multiple members produce joint outcomes reflecting synergistic inputs from everyone
    c. Members enable one another to contribute effectively in joint work
3. Individual work products
    a. Teams allocate some work of the team to individuals
    b. Members complete the assigned work for the team
    c. Members pursue resources needed for completing assignments
4. Knowledge Assets
    a. Team members keep one another fully informed
    b. Team members exchange necessary information with outsiders
    c. Teams create reliable records of work and achievements as knowledge assets

All of these categories and subcategories are taken directly from the Davis and Ulseth framework (21). The areas with the greatest opportunity for improvement can then be identified by comparing the ratios of successful to unsuccessful interactions in each category.

A similar method of data collection will be employed for observing in-person laboratory activities when they resume. A single researcher will observe the laboratory activities of a project team, identify positive and negative team interactions, and categorize the interactions according to the above listed categories from Davis and Ulseth.

Preliminary Results and Discussion

Strong relationships

Early results show that ChemE Car teams build strong team relationships. Members report feeling included and valued:

"I feel like the teammates are pretty inclusive, I've never been left out of a conversation or anything like that, I'm always encouraged to give input about things."

Members acknowledged that team relationships deepen over time, as people get to know one another and develop experience with the team, but that they felt welcome and included from the first meetings.

ChemE Car team members also report receiving positive encouragement from teammates, and that all team members regularly contributed to their assigned or expected work products. In our early interviews, these two points seemed to be connected. Team members felt empowered to contribute to the work, supported in part by a structure that assigned certain work tasks to each member or sub-team. This was further reinforced by positive interactions with their peers, in which members were praised by their teammates or invited to share ideas and suggestions:

"Online during the remote semesters, we've had something where we each choose a research paper to present on, and to share with the team. And [there is] some positive encouragement when they are very engaged and say 'This is a nice paper,' or 'These are interesting things,' and 'Thank you for bringing this up,' and those sort of things."

There are regular opportunities for members to express ideas to the project leaders. Management and direction of joint work products was led by team leaders, including week by week task assignments. Team members had opportunities to provide feedback, but most often proceeded with work as assigned by leads:

"...we ask each other questions about something whenever we have to start doing something we're always like, 'Okay, how should we start? Who should do what? What should you start researching?' So we discuss our process first. And then we do it. And we ask each other for their opinions, like, 'What do you think about this? Should we include this? Should we not?' We encourage each other I think."

Working together virtually

Early results provide some insights into ways that the ChemE Car team experience is changing during COVID-19 restrictions. One team member contrasted the current online virtual work sessions with previous experiences working collaboratively in person. This team member noted that the opportunity to talk with teammates during and after the laboratory sessions helped to foster connections in ways that virtual work session icebreakers do not fully replace.

This team member also described a continuity in the use of online collaborative tools, including the Google file-sharing suite. These tools are used for all members to contribute ideas:

"When we research improvements to the battery, or want to tune a certain variable, every person has to write something down in the Google doc…"

"...we can have everything in one place like and it's all shared with us."

The use of these sharted tools for developing and annotating presentations, and making plans, were implemented before the onset of the pandemic, and have continued as important tools to support collaborative work remotely.

Limitations

A limitation the researchers observed in conducting the virtual interviews was that participants typically discussed their experience from the time that the club was operating virtually. The interviews were conducted nearly 12 months after ChemE Car project teams had been allowed to operate in the laboratory, and therefore participants' recent experiences in the club were in the virtual format. Virtual operations are a temporary adaptation to deal with the pandemic. There may be limitations in the data toward the goal of creating guidelines for project managers about how to best conduct in-person laboratory activities. This presents an opportunity to learn about how teams can best leverage virtual tools.

Objectives Going Forward

With this research, we hope to create a set of guidelines for project managers of undergraduate technical clubs about how they can foster teamwork skill development in their clubs. The result will be higher performing project teams which will create better work products and deliverables as well as team members who are better equipped to move into the professional workplace in which teamwork is the norm.

We also hope to start a continuous improvement cycle, as diagrammed in Figure 1 in which the observation and interview methods employed in this study can be used to evaluate the effectiveness of the project manager guidelines, and further develop and improve the guidelines in the future. We would compare the most recent data to previous datasets to identify areas in which project manager guidelines led to improvements and areas in which further improvement is required. This analysis would be used to revise the project manager guidelines and implement the updated guidelines.

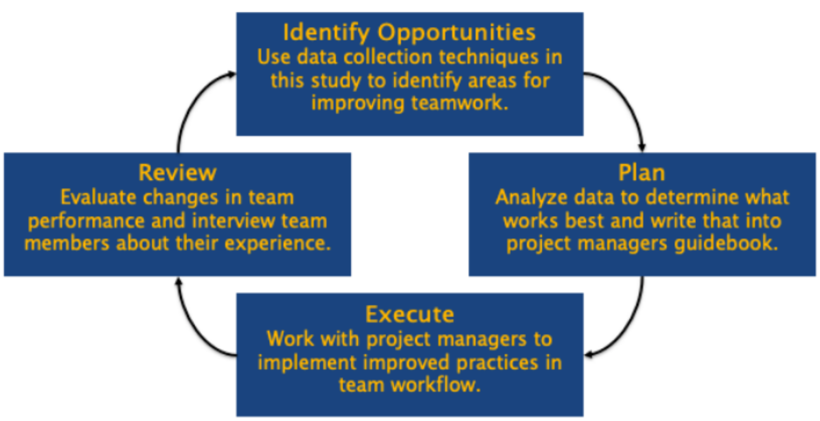

Figure 1: Diagram of continuous improvement cycle process.

Works Cited

1. Passow, H. J. Which ABET Competencies Do Engineering Graduates Find Most Important in Their Work? Journal of Engineering Education 2012, 101 (1), 95–118.
2. Smith, K.A., Teamwork and Project Management. Third Edition ed. Basic Engineering Series and Tools. 2007: McGraw-Hill
3. Prince, M.J. Does Active Learning Work? A Review of the Research. *Journal of Engineering Education* [Online] **2013,** *93*, 223-231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x (accessed April 19, 2021).
4. Kamaruddin, S.K.; Kofli, N.T.; Ismail, M.; Mohammad, A.B.; Takriff, M.S. Soft Skill Development via Chem-E-Car Project. *Procedia - Social and Behavioral Sciences* [Online] **2012**, *60*, 507-511. https://www.sciencedirect.com/science/article/pii/S1877042812038700 (accessed April 19, 2021).
5. Passow, H. J. and Passow, C. H. What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review *Journal of Engineering Education* 2017, 106 (3), 475-526. https://doi.org/10.1002/jee.20171 (accessed April 19, 2021).
6. Smith, K. A. Cooperative Learning: Making "Groupwork" Work. New Directions for Teaching and Learning 1996, 1996 (67), 71–82.
7. Woods, D.R.; Felder, R.M.; Rugarcia, A.; Stice, J.E. The Future of Engineering Education III. Developing Critical Skills *Chemical Engineering Education* 2000, 34 (2), 108-117.
8. Mazur, Eric. *Peer Instruction: A User's Manual*; Prentice Hall, 1997.
9. Karabulut-Ilgu, A.; Cherrez, N.J.; Jahren, C.T. A Systematic Review of Research on the Flipped Learning Method in Engineering Education. *British Journal of Educational Technology* 2017, 49 (3), 398-411. https://doi.org/10.1111/bjet.12548 (accessed April 19, 2021).
10. Finelli, C.J. *et. al.* Reducing Student Resistance to Active Learning: Strategies for Instructors *Journal of College Science Teaching* 2018, 47 (5), 80-93. https://mydigitalpublication.com/publication/?m=12081&i=489965&view=articleBrowser&article_id=3064339 (accessed April 19, 2021).
11. Bart, M. Survey Confirms Growth of the Flipped Classroom. https://www.facultyfocus.com/articles/blended-flipped-learning/survey-confirms-growth-of-the-flipped-classroom/ (accessed Apr 19, 2021).
12. American Institute of Chemical Engineers. (2020). 2020 Regional Competition Official Rules. Retrieved from https://www.aiche.org/sites/default/files/media/document/chem-e-car_official_rules_2020_final.pdf
13. Dominguez-Ramos, A.; Alvarez-Guerra, M.; Diaz-Sainz, G.; Ibañez, R.; Irabien, A. Learning-by-Doing: The Chem-E-Car Competition® in the University of Cantabria as Case Study. *Education for Chemical Engineers* **2019**, *26*, 14–23.

14. Lewis, R. (2002, June), The Value Of A "Hands On" Experience In A Reactor Design Course Paper presented at 2002 Annual Conference, Montreal, Canada. 10.18260/1-2--10488
15. Arce, D.; Balbuena, J.; Cuellar, F. A Low Cost Self-Driving Cars Project Based Course for Undergraduate Students in Developing Countries. *2019 IEEE International Conference on Engineering, Technology and Education (TALE)* **2019**. https://ieeexplore.ieee.org/document/9225872 (accessed April 19, 2021).
16. Katzenbach, J. R.; Smith, D. K. The Discipline of Teams. Harvard Business Review. 1993.
17. ASCE Concrete Canoe Competition. https://www.asce.org/event/2021/concrete-canoe/ (accessed Apr 19, 2021).
18. American Solar Challenge Home Page. https://www.americansolarchallenge.org/ (accessed Apr 19, 2021).
19. Formula Sun Grand Prix. https://www.americansolarchallenge.org/about/formula-sun-grand-prix/ (accessed Apr 19, 2021).
20. Student Steel Bridge Competition: 2021 Rules. https://www.aisc.org/globalassets/aisc/university-programs/ssbc/ssbcrules.pdf (accessed Apr 19, 2021).
21. Davis, D.C. & Ulseth, R.R.. (2013). Building student capacity for high performance teamwork. ASEE Annual Conference and Exposition, Conference Proceedings.