The Relationship between Teamwork and Innovation Outcomes in an Engineering Thermal Science Course: An Entrepreneurial Mindset Simulation

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The Relationship between Team Dynamics and Innovation Effectiveness in an Engineering Thermal Science Course: An Entrepreneurial Mindset Simulation

Introduction

Teamwork is essential to engineering work, and the assumption is that greater team dynamics will lead to greater innovation outcomes. When entrepreneurs pitch their ideas to angel investors or venture capitalists, one of the top considerations is the quality of team dynamics [1, p.244], [2]. In addition, *technological innovation* and entrepreneurship have been promoted as "fundamental drivers of American prosperity and global economic leadership" [3, p.1]. Capstone projects, for example, can be essential opportunities to prepare engineering students to be innovative and entrepreneurial in order to succeed in a globally competitive workforce [3, p.3].

Research is extensive regarding "team performance" or "team dynamics," typically assessed through measures of team communication, leadership, and project management. The pervasive assumption underlying much of this research is that effective team functioning results in effective innovation outcomes. Yet, the relationship between team dynamics and innovation outcomes has not been well studied. Most of the existing research does not assess the effectiveness of the final product of teamwork, nor does most existing research examine innovation outcomes in relation to team functioning. In this paper, we examine the relationship between team dynamics and innovation outcomes. Using an entrepreneurial simulation in an upper division thermodynamics course, this mixed-methods study investigates: What is the relationship, if any, between team dynamics and innovation effectiveness? Can a team achieve high innovation effectiveness if it has low team dynamics?

Literature review

Teamwork is recognized as a critical engineering skill. ABET devotes a student outcome to teamwork skill: "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" [4]. *Transforming Undergraduate Education in Engineering* suggested that "Teamwork should be embedded everywhere – as part of authentic design experiences, if possible – and needs to become a meta-skill for every student." [5, p.21]. Teamwork is valued at the workplace because it promotes productivity and innovation. Montes et al. found that "teamwork cohesion promotes organizational learning and this, in turn, encourages technical and administrative innovation" [6, p. 1159]. Teamwork is also identified as one of the essential skills that a student needs to become a *global engineer* [7, pp.1-31].

Team Dynamics has been defined Team Dynamics has been defined as as “a general term to denote the quality and quantity of interactions among team members;” its characteristics included communication, collaboration and knowledge sharing among members [8, p.465]. Hoegl and Gemuenden developed *Teamwork Quality (*TWQ*)*, an instrument that measured the quality of teams’ interactions, rather than their task activities. TWQ was evaluated through six dimensions: “communication, coordination, balance of member contributions, mutual support, effort, and cohesion” [9, p. 439].

Research related to teamwork outcomes has typically focused on *team performance*. Outcomes are usually process oriented, related to team functioning as opposed to innovation effectiveness. For example, Kozlowski & Klein defined team performance as a construct that “originates in the behaviors of individuals, is amplified by their interactions, and manifests as a high-level, collective phenomenon” [10, p. 55]. Neuman and Wright evaluated team performance at both an individual level and a team level using the following variables: *cognitive ability, job-specific skills, and personality traits* [11, p.376]. Research done by Mesmer-Magnus and DeChurch focused on the impact of *information sharing* to team performance, and they found that the “information sharing-team performance relationship was moderated by representation of information sharing (as uniqueness or openness), performance criteria, task type, and discussion structure by uniqueness (a 3-way interaction)” [12, p.535]. Bradley et al. studied the effects of *interpersonal interventions* on team performance using their “temporal framework of teams and tasks that predicts the expectation of benefit, which in turn mediates the effectiveness of interpersonal interventions on team performance” [13, p.353].

Hoegl and Gemuenden examined the relationship between teamwork and *success of innovative projects* completed in Capstone courses. The *success of innovative projects* was conceptualized as the combination of both *team performance* and *personal success* of team members that was measured by team members’ *satisfaction* of working in teams, and their *learning* opportunities [9, pp. 438 -440]. These authors defined team performance as the ability of a team to meet objectives of quality, cost and time, as assessed by team members, team leaders, and third-party managers of sponsoring companies., and it was measured by *effectiveness* and *efficiency*, [9, p. 438]. Two of these measures (team members’ and team leaders’ ratings) were self-assessments. But the company managers’ ratings were third-party assessments of innovation effectiveness. We did not find evidence of another study that used a third-party assessment of innovation effectiveness. Notably, correlations between team members’ self-assessments of team dynamics and managers’ ratings of innovation effectiveness and efficiency were very low (r=.015-.22 no significant correlations). In regression, team managers’ ratings contributed only 7% to the predictive model [9, p. 442, 445].

In the engineering workplace, employers expect teams to obtain innovative, commercializable innovation outcomes, with less concern about team dynamics during the process. In entrepreneurial and intrapreneurial contexts, the value of a potential innovation is assessed along the following three dimensions: 1) the significance of a problem that the innovation is designed to address (Problem Recognition), 2) solving the problem in ways potential customers will value (Value Proposition), and 3) using technically creative, efficient, and effective (and cost-effective) technology (Technical Merit) [16, 17].

Typically, an engineering capstone course requires students to complete a comprehensive innovative project, which prepares students with professional knowledge and skills for working in "a competitive global economy" [14, p. 143]. In a competitive, global economy, lively team dynamics are valued to the extent that they result in effective, commericializable, outcomes. Theodore Levitt (cited by Andrew and Sirkin, 2003) said, "The fact that you can put a dozen inexperienced people in a room and conduct a brainstorming session that produces exciting new ideas shows how little relative importance ideas themselves actually have" [15]. The authors continue: "In fact, there's an important difference between being innovative and being an innovative enterprise: The former generates lots of ideas; the latter generates lots of cash" [15].

Studies of teamwork typically focus on team process outcomes rather than innovation effectiveness. Therefore, the current study examined the relationship between team dynamics and innovation effectiveness in an upper-division Thermodynamics course in which student teams designed solutions to an industrially-based problem, which were evaluated for innovation effectiveness at the end of the term by entrepreneurs familiar with the technology. We assessed *team performance* separately from *team dynamics* and investigated the relationship of each to *innovation effectiveness* (IE). We explored the relationship between teams' functioning and their innovation effectiveness as rated by experts in the field with no prior association with the teams. We asked, 1) What is the relationship, if any, between team dynamics and innovation effectiveness? 2) Can a team achieve innovation effectiveness even if it has poor team dynamics, and if so, how?

Methods

This study was conducted in a thermal engineering course that included 55 undergraduates and master students in the fall semester of 2019. These 55 students majored in mechanical or aerospace engineering; approximately half had experiences working in industry. Early in the term, students were assigned to teams of 3 or 4, based primarily on their ability to meet at the same time. All 14 teams were assigned a term project to produce a biomass pellet burner that met specific design requirements, to be integrated into a boiler. This is an authentic, real-world scenario. Students competed to design the most innovative system. At the end of the term, teams pitched their solutions to a "board of investors" that comprised actual entrepreneurs and investors. The pitch took 5 to 7 minutes for each team, during which time teams attempted to convince the board of investors that their design was worthy of further financial support (being a simulation, projects did not receive actual funding).

Team Dynamics was evaluated quantitatively through a *Team Self-Assessment* survey and qualitatively through interviews. Survey data collected during the term included two administrations of the team self-assessment instrument, which was based on the ABET student outcome related to effective teaming. The instrument was adapted from a) the Mathematics Department at the University of Michigan, b) an Integrated Pest Management class at Cornell, and 3) team-created items based on research literature. The instrument assessed nine dimensions of teamwork: Decision Making, Cooperation, Ability to Handle Conflicts/Differences, Balance of Participation, Project Management, Communication, Support, Team Spirit, and Appropriate Delegation of Tasks. Each dimension was rated on a scale from 1 to 4. For example, Project Management was rated with scale 1 for *no clear schedule or deadlines* and scale 4 for *tasks and*

deadlines were clear. Balance of Participation was rated with scale 1 for *one person did most of the work*, and 4 for *everyone contributed equally*. The instrument was piloted early in the term, modified, then administered as a *Team Self-Assessment* at the end of the semester.

Team Performance was operationalized as the mean of all team ratings across all 9 dimensions of the survey. *Team Dynamics* was a measure of the cohesiveness of team members' experience, operationalized as the standard deviation of team members' ratings on each of the 9 dimensions. *Innovation Effectiveness* was determined by an instructor-created rubric that each investment board member completed for each team. The rubric assessed: 1) Problem Recognition [16, p.2], 2) Value Proposition [17], and 3) Technical Merit. For each of those variables, a team was evaluated for its level of achievement: 1= beginning, 2=developing, 3=competent, 4=differentiating, and 5=transformational (see Appendix). This study considered a rating of 3 or above as high Innovation Effectiveness while a rating of less than 3 as low Innovation Effectiveness. The investment board comprised 2 members who evaluated all 14 teams' presentations. One evaluator is an associate professor at a U.S. university in the Southwest, he owns a company that works on biomass burners, and he has a lot of experience in this specific area. The other rater is an experienced executive in international business and technology, specifically in guiding new technologies from ideation to market launch across diverse markets.

The average of the summed scores of the two raters became the teams' *Innovation Effectiveness (IE)* score. All data were collected according to Arizona State University IRB Protocol # 00010913. No data for the study were used to calculate student grades and the course instructor (who is the co-PI) did not have access to team survey results or innovation ratings by the "board of investors" before course grades were submitted.

Follow-up interviews were conducted based on the results of Team Self-Assessment and Innovation Effectiveness rubric, which revealed three groups: 1) teams having strong TD and high IE, 2) teams having weak TD and low IE, and 3) teams having weak TD and high IE. We conducted follow-up interviews with 12/15 students from teams in groups 2 and 3.

Results

The *Team Self-Assessment* received 55/55 survey responses (100% response rate), of which 53 responses were used (two responses were removed from the data because participants did not consent to participate in the study). Fig. 1 shows results of IE across 14 teams. The IE scores were divided into two categories: high IE with values equal to or above 3.00 (Competent), and low IE with the values lower than 3.00.

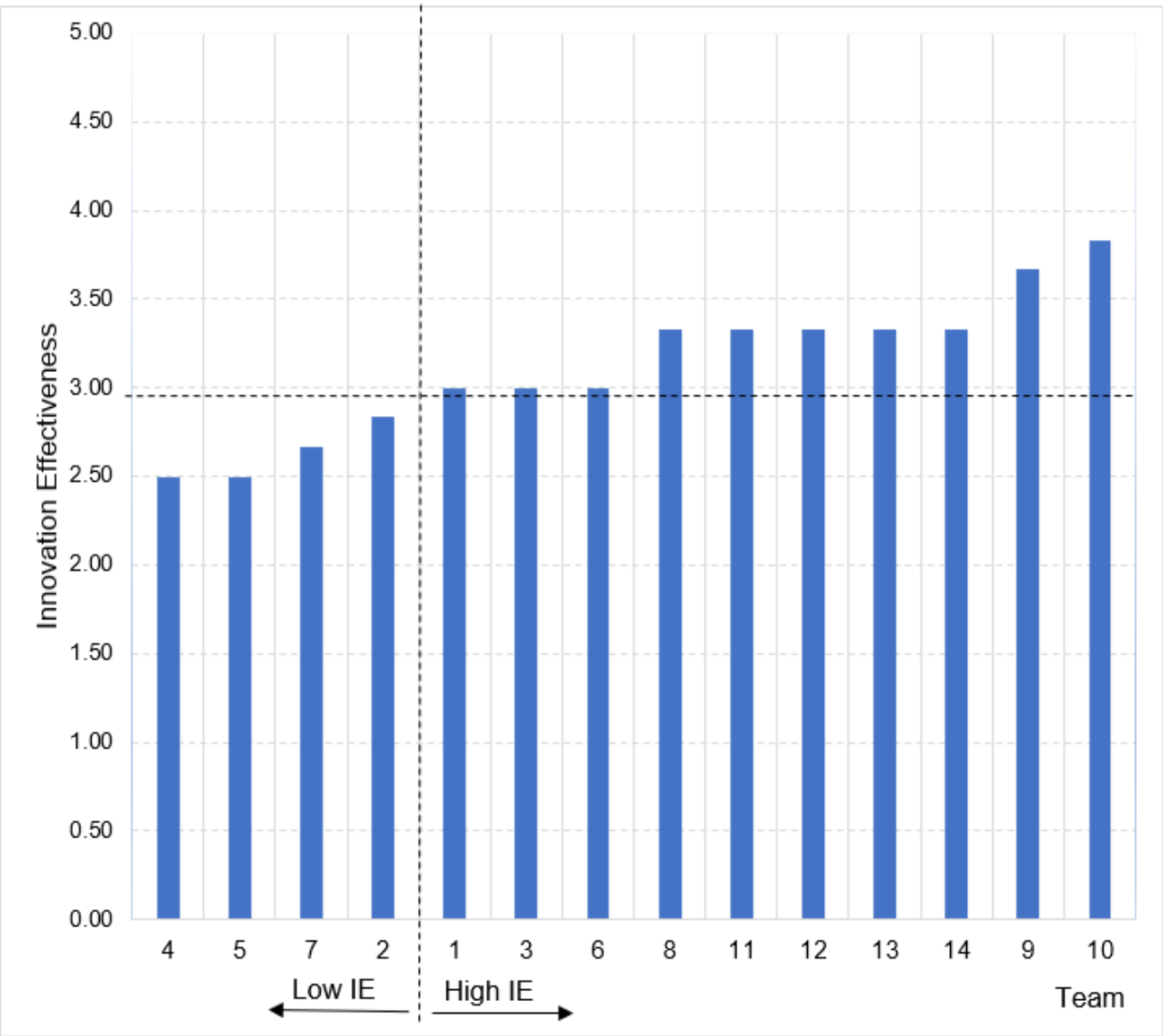

Fig. 1. Distribution of Teams' Innovation Effectiveness

Fig. 2 shows *Team Dynamics* (TD) across 14 teams. *TD* was measured quantitatively using the standard deviation (SD) of team members' ratings on each dimension of the survey, and qualitatively using responses of open-ended questions and interviews. An SD above 0.80 (considered high SD) indicated at least a 2-unit difference between the highest and lowest ratings across team members for a given item; in other words, at least one member rated TP differently from the others. The lower the SD, the more a team agreed about its TD. Fig. 2. shows only the number of high SD for each team. As can be seen from Fig. 2, all teams having weak TD (i.e. teams 4, 5, 7, 3, 8, 9, 14) had high SD for at least two items. Members of these teams provided comments from the survey and interviews mentioning that they faced teamwork challenges or members did not work well together. Teams with strong TD had strong cohesiveness in their ratings, with a maximum of 3 instances of high standard deviations across the 9 dimensions and

no team member provided negative comments about the team's process on the survey or in interviews.

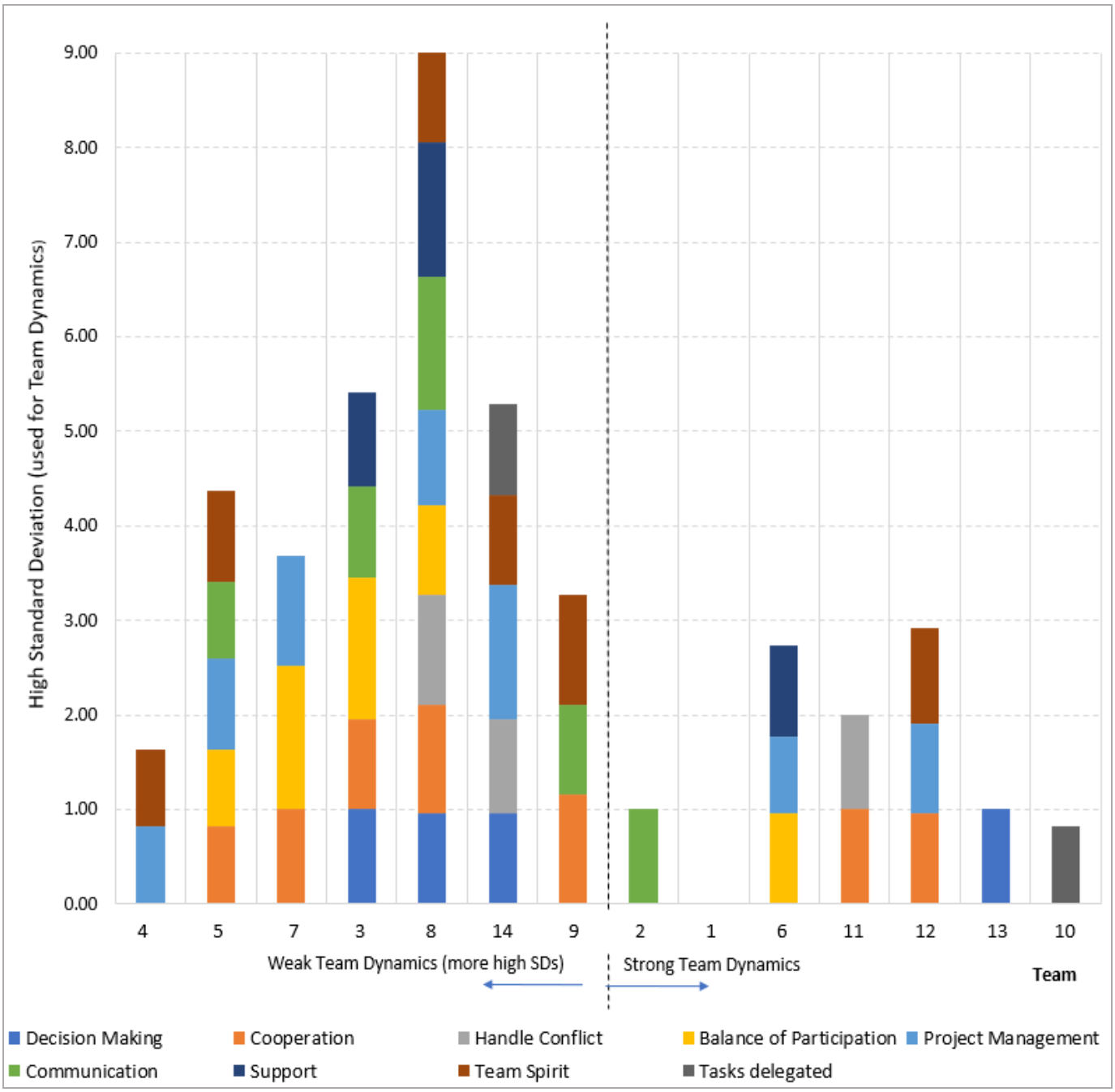

Fig. 2. Distribution of high SDs (0.8 or higher) on 9 dimensions across 14 teams. SDs lower than 0.8 are not shown.

Fig. 3 shows *Team Dynamics* alongside *Team Performance* across 14 teams. TP was the overall mean on all item ratings from all team members. Regarding TP, Fig. 3 presents that except team 7, all teams had high TP, which is 3.00 or above. Does this mean all the teams with high TP had

members that worked well together? The answer is no, not in all cases. TP, derived as a mean across raters, can mask low ratings of one or even two team members. The TD metric, which was operationalized based on the standard deviation across team members' ratings on 9 dimensions was more sensitive to differences across raters. This was born out in survey comments and interviews. Fig.3 demonstrates that teams with weak TD (except team 4) had a bigger summed SD than teams with strong TD. Although team 4 had a low sum of high SDs, its members provided negative comments about their teamwork. In this study, TD was better indicator than TP at assessing the quality of team members' collaboration.

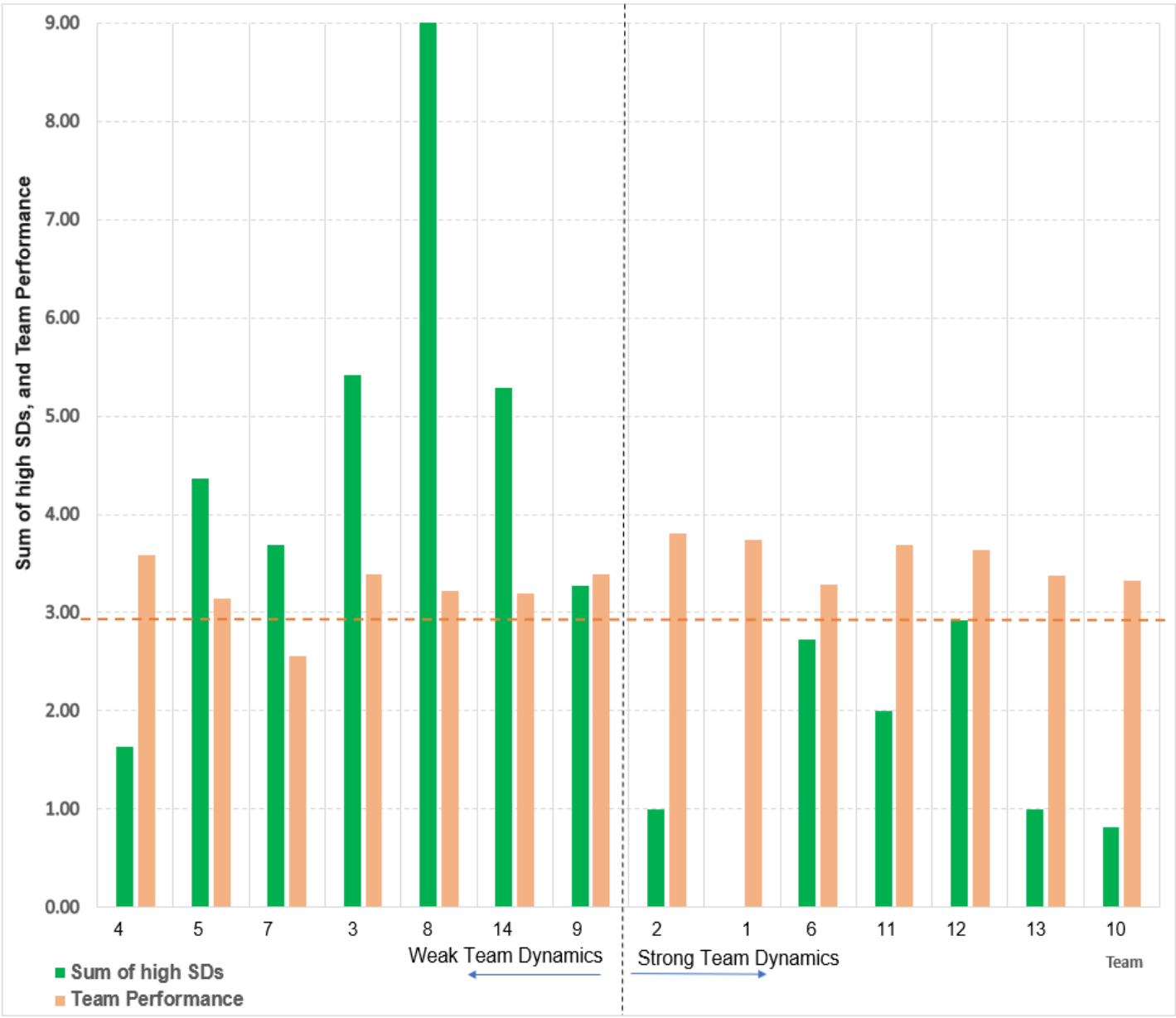

Fig. 3 Team Dynamics and Team Performance

Fig. 4 shows *Team Dynamics* alongside *Innovation Effectiveness* across 14 teams. Seven teams evidence weak TD. Three of those teams (4, 5, and 7) had low IE and 4 teams (3, 8, 9, and 14) had high IE. Why did teams 3, 8, 9, and 14 achieve high IE, while teams 4, 5 and 7 did not? This question was addressed in both survey comments and individual interviews. The interviews were conducted with all members of teams 4 and 8, but one member of team 7 and two members of team 5.

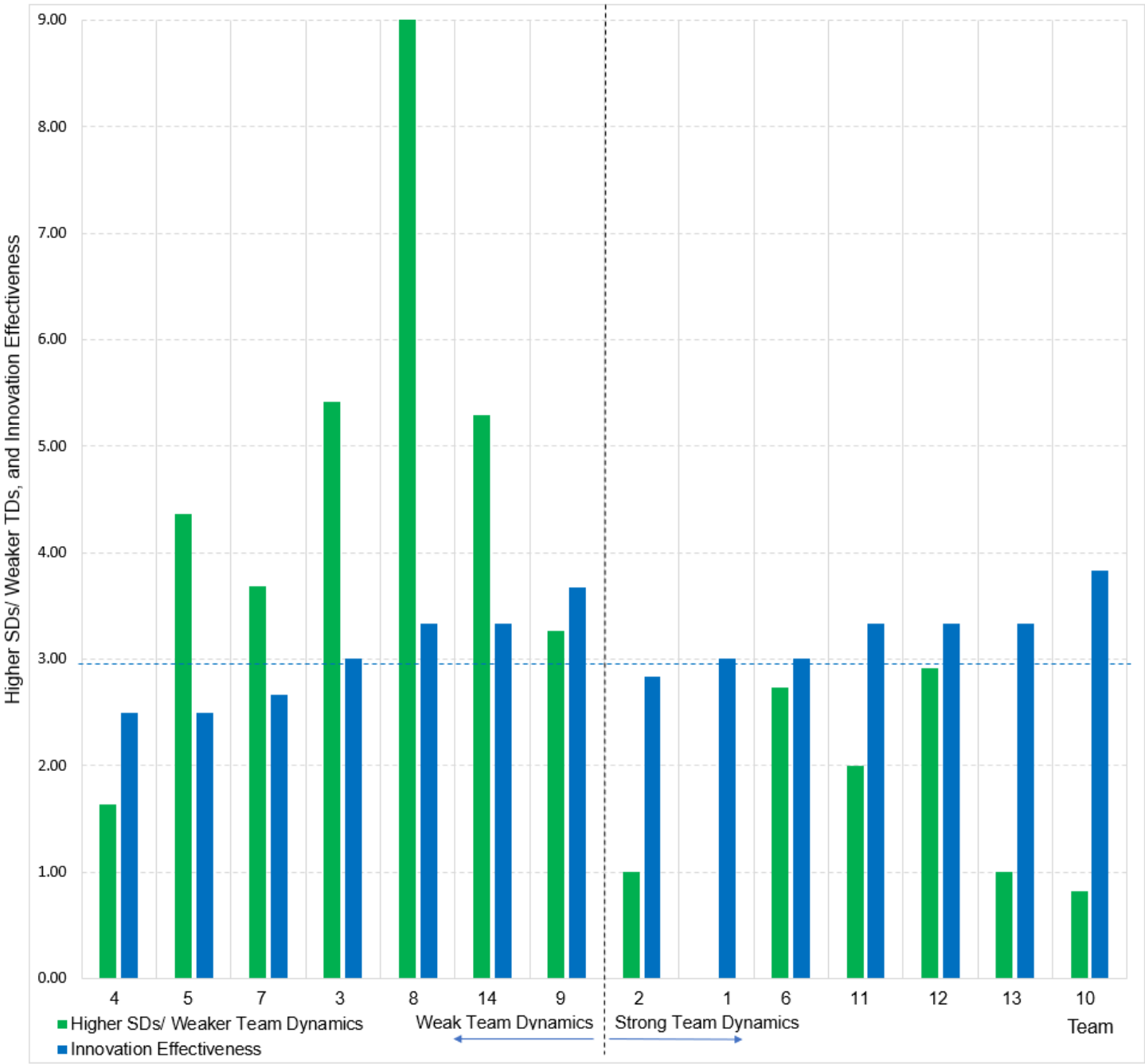

Fig. 4 Distribution of Team Dynamics and Innovation Effectiveness. (Teams with strong TD in all but one case had high IE, but teams with weak TD varied: 4 teams had high IE and 3 had low IE)

Based on the relationship between TD and IE, teams were divided into three groups. Group 1, *strong TD* and *high IE*, includes Teams 1, 6, 10, 11, 12, and 13. Members of this group reported working well together and they achieved a high innovation outcome. For example, members of team 6 shared responsibility on the project and each made a substantive contribution to the outcome: "Each member knew the assigned content assigned to him/her and I couldn't be more thrilled about how the delivery went." Another example is team 11. One member wrote: "Our team members are not afraid to bring up ideas and or concerns during the project period. We were able to compromise on conflicts."

Teams in Group 2 evidenced *weak TD* and *low IE*. Teams 4, 5 and 7 fit into this category. Survey comments from this group reflected persistent challenges with Team Dynamics: "We had one team member that didn't do too much and what he did do was last minute. That was a bit difficult to work around," and "We all did well when we worked together, but it was hard to get all of us motivated to meet together or do work separately." The interviews with these teams also confirmed that they encountered problems working together, and they did not solve them well.

Specifically, team 4 faced some challenges in *balance of participation, project management* and *team spirit*, which affected their innovation effectiveness. Although every member chose tasks that he could do, one member who had a specialty on solid fuels did most of the work. He said, "The majority of work calculations fell under my specialty (burn time, ignition energy, adiabatic flame temperature code)". Members also procrastinated and "pushed off a lot of the work to the end", which made them short of time. In addition, two members commented on the lack of team spirit. One said, "Everyone knew what we needed to do and get our work done, but no one wanted to go above and beyond."

Team 7 expected to have 4 members as other teams did, but one dropped the class soon after the first day, which resulted in more tasks being assigned to remaining members. It was even harder for the team to finish the project since there were teamwork challenges among members, specifically *communication, balance of participation* and *project management*. Although the team set up 10 meetings and used *Slack* to support communication, they only made 3 short meetings and two members repeatedly showed up late.

Each member of Team 7 had a specialty, and tasks were delegated to accommodate their strengths. However, two team members did not update their progress and did not send the third member what they promised. The third team member (who was the only member of this team interviewed) recalled the conversation between him and the other members: "It's Monday now. You guys told me that you would be working on it on Saturday, and you haven't sent me anything yet. You haven't said that you've done anything. We have only two days to turn it in, so I guess I have to sit down and do it all myself." When he was done with all that work (i.e. the composition chosen, the burn time, emission analysis, the write-up) and posted on their group, an hour later a member wrote, "Oh yeah I totally did that", and "It was pretty much just a copy of my work." The team member we interviewed expressed frustration that he "had to do very literally most of the work (90%+) for the deadlines to be met with something even resembling acceptable." All these challenges could be the reasons for team's weak TD, which resulted in their low IE.

Teams in Group 3 showed *weak TD* and *high IE*, and this group included teams 3, 8, 9 and 14. What is notable about Group 3 is that these teams encountered challenges in teamwork but found ways to overcome these challenges in order to obtain high innovation outcomes. For instance, a member of team 9 believed that their team faced challenges in *Decision Making*, *Cooperation*, and *Task delegated to accommodate team members' strengths and weakness*, and provided a comment related to Cooperation that each member studied/ focused on only one area of the project, so they had too limited knowledge to cooperate with each other on all of the tasks. However, another member of team 9 pointed out how they solved their problems to achieve their goals: "We set our boundaries very well and we strived towards it. Everyone knows what they are supposed to do with laid out ground rules. I think this helped us really to meet our deadlines and complete project."

We also interviewed all members of Team 8. This team had 4 members. One was enrolled in a PhD program, one was at Master level, and the others were seniors. For the first two weeks they did not make a good use of media tools to communicate with each other. When they set up *GroupMe*, *Google Docs*, and *Slack*, they could reach out to everyone at the same time, share information, update their progress, and set up meetings. Thanks to these tools, the PhD student who had a specialty on fuel cells and was responsible for the critical part of the project – calculations – could also share his knowledge and innovative ideas for the project, and they were consequently "able to be productive and create a more innovative product". Towards the end of the semester, it was hard for members to meet together and finish their tasks on time, due to final exams and priorities for other courses. However, they changed the meeting time to evening, right after the class, and they also "factored in a couple weeks' make-up time … that allowed us to have time in the end to finish up things". It was also essential for achieving the team's objectives that they had "regulations that were to communicate clearly and show up at the meetings because that allowed us to re-organize and re-focus idea every week just so we know how we were progressing… We had [internal] deadlines and due dates which helped overall."

Limitations

The number of teams was limited, and not all team members provided open-ended responses on surveys. In addition, this study was focused on the Innovation aspect of the final project, which was assessed by the "investment board." Yet the investment board rating was not factored into course grades. The follow-up interviews were conducted after the course ended and students already knew their course grade. Therefore, the simulation outcome may not have held the import for students that a real entrepreneurial project might. Future work would be strengthened using larger sample sizes, a systematic way of factoring qualitative data into the TD score, collecting qualitative data from all participants, and increasing the authenticity of the simulation.

Discussion

In this section, we address the two research questions that drove this study:
1) "What is the relationship, if any, between team dynamics and innovation quality?"
2) "Can a team achieve high innovation effectiveness if it has low team dynamics?"

What is the relationship, if any, between team dynamics and innovation quality?

The results of this research showed that the relationship between team dynamics and innovation quality was not linear, as might be inferred from research on teamwork that relies on team dynamics as a proxy for performance. Teams in this sample that evidenced strong TD did tend to achieve high IE, with the exception of team 2. However, teams having weak TD obtained low or high IE.

Can a team achieve high innovation effectiveness if it has low team dynamics?
The answer to this question is a conditional yes. Some teams that had weak TD, figured out how to overcome the problems they faced, in order to achieve high IE. Unlike Group 2, which had low TD and low IE, Group 3 teams made adjustments to mitigate the effects of their low TD. For example, members of team 8 utilized proper media tools late in the term that helped them share knowledge and solve their problems just in time to complete the project. Members of this team actually practiced *self-monitoring, self-diagnostic* and *self-motivating* at team level, which is the application at team level of self-regulation theory [18, p. 249]. The team also changed its meeting time and concentrated on finishing their work at the end of the semester. They worked at the last minute, as the need arose, but they were successful.

This study also shows that using team dynamics was a measure than team performance for assessing team functioning. Team performance—the average of all ratings, can mask internal tensions within a group. Using standard deviation helps identify lack of team cohesiveness by highlighting individuals whose team experience might be contrary to others in the group.

Conclusion

Teamwork in engineering education is ubiquitous. Yet we know from student reports and tools such as CATME, that teams may not function optimally, or even well. The same might be true in the workplace. Understanding how teams mitigate poor team dynamics could increase student learning as well as professional productivity. The results of this pilot study warrant fuller investigation.

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Appendix.
Innovation Rubric

	Beginning	Developing	Competent	Differentiating	Transformational
Problem recognition	Exhibits limited or surface level understanding of the problem to be solved.	Exhibits a developing understanding of the problem, but may not yet be able to clearly tie a proposed solution to causes of the market or societal need	Exhibits clear and deepening understanding of a market or societal need and has a sense of how a solution might meet that need; there may be one or more identified pain-points that the proposed solution does not fully address.	Exhibits a deep and broad understanding of multiple dimensions of a problem that needs to be solved (e.g., social, behavioral, economic, environmental); potential solution is deeply connected and responsive to multiple dimensions of the identified need.	Exhibits a deep and broad understanding of multiple dimensions of a problem that needs to be solved (e.g., social, behavioral, economic, environmental); potential solution address need in a way that could drastically alter the current state of technology.
Value proposition	The proposed solution is not new or different from a solution already available; the proposed solution does not respond directly to the client or customer need or is out of sync with the customer profile; the proposed solution seems farfetched	Product/project is an interesting idea, but not fundamentally distinctive from existing approaches; if the idea is distinctive, there may be some significant gaps related to realistic implementation of the idea, such as an untenable risk for expected return on investment, or	Product/project is clearly defined and responsive to archetypal customer's defined need; solution is an improvement upon existing approaches and demonstrates potential to have real impact on the problem. There may be still be some details to work out in terms of	Product/project is clearly defined and responsive to archetypal customer's defined need; solution is fundamentally distinctive from existing approaches and demonstrates proven ability to impact the problem in a new way (ie it could be viably implemented and sustained in the real	Product/project is clearly defined and responsive to archetypal customer's defined need; solution is fundamentally distinctive from existing approaches and demonstrates proven and transformative ability to impact the problem in a new way (ie offers previously unknown value to customer); idea generates

	and unlikely to realistically be implemented to address the problem.	significant questions about the viability and sustainability of the product or project design and operations. Customers or potential investors are not yet ready to engage with the idea enthusiastically.	developing a prototype or market test for the solution, but overall potential customers/ clients respond favorably to the idea.	world); idea generates enthusiasm from potential clients, investors, and other stakeholders.	enthusiasm from potential clients, investors, and other stakeholders.
Technical merit	Exhibits limited or surface level understanding of technical challenge; little technical justification for solution.	Exhibits developing understanding of technical challenge; technical justification is present and accurate, but needs further improvement.	Exhibits clear and deepening understanding of the technical challenge, technical justification is complete and at a level expected of someone with knowledge of the field.	Exhibits deep and broad understanding of technical challenge, resulting in differentiated technological approach that has not been previously demonstrated, but has sufficient justification.	Exhibits deep and broad understanding of the technical challenge, resulting in a transformative technological approach with sufficient justification and the ability to alter future technological developments in this or other fields.

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