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A Checklist to Diagnose Teamwork in Engineering Education*

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Teamwork is increasingly being acknowledged as a necessary part of the engineering workplace, therefore engineering educators may feel a responsibility for teaching teamwork skills to students. Engineering educators cannot improve their students' teamwork skills without first being able to practically diagnose the students' strengths and weaknesses. The present paper focuses on translating team science to a useful checklist for engineering educators to monitor their students' teamwork skills. A qualitative data-sorting analysis of 286 behaviors from 88 interviews resulted in the present checklist, which is broken into six components of teamwork processes and emergent states. The checklist details effective and ineffective team-wide or team member behaviors in such teamwork categories as communication, cognition, coordination, coaching, cooperation, and conflict. While not formally validated, the checklist is empirically derived and in-line with the literature on team performance. This tool will allow educators to uncover what teamwork components require further skill development in their students' project-based learning courses.

Keywords: teamwork skills; checklist; PBL

1. Introduction

Academic research and the popular press alike show a growing concern of an apparent gap between required teamwork skills and the expertise offered by the current workforce. Such claims seem unwarranted at a time when workers are more educated than ever before [1] but the data are consistent and compelling – employers have outlined a number of demands that they believe our labor force is not prepared to deliver, recognizing teamwork skills as a top priority [2, 3]. This problem may be exacerbated for engineering employers, as teamwork is especially necessary when work is complex or ill-defined [4, 5], such as in engineering design. Relatedly, research shows strong positive relationships between collaboration and innovation [6]. We believe that teamwork skills play a large role in the ability to collaborate with others to solve problems, a central component to an engineer's job, which may be why engineers who work on teams get paid more than those who work individually [7]. Employers' need employees to be equipped with the necessary teamwork skills.

Teamwork skills have been defined as observable competencies needed to perform teamwork and team tasks (e.g., adaptability, communication) [8]. We consider teamwork according to Stevens and Campion's conceptualization as malleable skills, not personality, that individual employees possess above and beyond their technical skills that allow them to function effectively in teams [9]. However, teamwork in engineering education has also been shown to increase learning for technical skills [10]. Teamwork has been studied for decades in other disciplines (e.g., psychology, organizational sciences, human factors), yet engineering educators have lamented the lack of team research applied to engineering students' curricula [11]. Therefore, engineering education should be focused on emboldening their students' teamwork skills.

Yet, how can teamwork skills be taught until engineering-specific team behaviors are identified? In this paper, we aim to uncover specific and measurable teamwork behaviors that lead to effective performance in engineering teams by integrating team science with an empirical study of engineering student project teams. Specifically, using a qualitative approach, we captured actual teamwork behaviors as described by participants via interview and translated them into checklist items. These behaviors had not been previously defined except through the participants' experiences, therefore we use qualitative analyses. The result is a behavior-based checklist that provides a practical way for engineering educators to evaluate their students' teamwork skills, especially for culturally diverse engineering teams, and to inform the design of education curricula that address teamwork deficiencies. To our knowledge, no such checklist exists that is tailored to the context of engineering student teams and grounded in evidence of real-world team performance over time.

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2. Literature Review

2.1 Teamwork in Engineering Teams

Teams are groups of people who engage in interdependent work and share a common goal. Teamwork involves the team processes and emergent states, which are derived from individual team members' attitudes, behaviors, and cognitions, and the members' dynamic interactions and adaptations [12]. It is distinct from taskwork, which involves the operations and activities performed by members [12]. These processes and emergent states have been organized into a practical heuristic, which outlines the six key components of teamwork, namely (1) communication, (2) cognition, (3) coordination, (4) coaching, (5) cooperation, and (6) conflict [13]. These six components, while not intended to be all-encompassing pillars of teamwork, are included because they are undoubtedly critical features of teamwork, based on decades of evidence for their impact on team performance, learning, and other outcomes [14]. These six components described further below, serve as our theoretical framework for the basis of the checklist we developed and present here, per recommendations that call for the use of empirically-based theory [15].

Together these six components encapsulate affective, behavioral, and cognitive aspects of teamwork. Communication refers to sharing information and keeping team members informed [13]. A host of team communication research has demonstrated a strong positive relationship between communication behaviors and team performance [16], as effective communication enables other team processes and emergent states. Cognition refers to the team's shared understanding about their priorities and goals [13]. Team cognition serves as the backbone for such functions as team decision-making and problem solving [17]. Coordination refers to transforming individual tasks to team outcomes, including the provision of supporting team members with back-up behaviors [13]. Coordination is a key component for reaping the benefits of teamwork, as well-coordinated teams can perform better than individuals [18]. Coaching refers to the leadership behaviors team members demonstrate, such as giving feedback to each other [13]. The team leadership literature notes leaders help shape the team's cognition and behaviors [19]. Cooperation refers to the attitudinal and motivational components of teamwork, including the willingness to work on a team [13]. Team cooperation has been linked to outcomes of performance, satisfaction, and team effort [20]. Conflict refers to team members' disagreements and incompatibilities [13]. When teams experience conflict they risk making errors and having a breakdown in performance [21].

2.2 Evaluations of Teamwork

Previous work in the field of engineering education has established many useful tools for educators [11], such as the Comprehensive Assessment of Team Member Effectiveness (CATME) tool, a method of collecting peer and self-ratings for engineering teams. CATME asks students to rate themselves and their teammates on a behavior-based five-point scale in several teamwork-based categories and automatically runs analytics, such as flagging which students have large distinctions between their self-ratings and peer-ratings. There are other tools that create automated evaluations of students' virtual team interactions using evidence-based markers of theoretically-grounded teamwork definitions, such as measuring the amount of time team members monitor each other's communication [22, 23]. Additionally, other studies have used such teamwork measures as pre-post teamwork behavioral assessments and self-report surveys of teamwork abilities [24–26]. There is substantial value to using these tools; the focus of our paper is to neither invalidate nor minimize the impact of previously established metrics.

Instead, we present a checklist to accompany the automated-, peer-, and self-ratings of teamwork that serves as a useful guide for educators to understand how their student teams are performing and where to target development efforts. While there are benefits to using self- and peer-ratings of teamwork performance or to evaluating virtual behavior, we believe in-person instructor ratings are valuable additions to serve as a more holistic evaluation and diagnosis of student teamwork performance. Instructor ratings should be incorporated because research in other educational contexts demonstrates benefits and drawbacks to all three rating systems (self-, peer-, and instructor-ratings), such that students are more likely to rate themselves more poorly and peers demonstrate lower variability in ratings [27]. Other research echoes this finding and concludes significant differences between self-ratings and instructor-ratings [28].

We recognize that asking educators to rate their students' teamwork may appear to require a higher workload, but fortunately, research on teaching soft skills, such as teamwork skills, has been shown to only take up to five hours per academic year [33]. Rather than simply supervising design activities, engineering educators should also train, monitor, and assess teamwork skills [29]. Our goal is to assist in this part of the educators' responsibility to add to the arsenal of teamwork-diagnosing tools. We use behavioral-based items in our checklist to increase reliability and the ease of use for engineering educators. Research indicates that checklists are ideal for outlining tasks that are critical to success, or in other words, tasks that would be detrimental for teams to ignore. These tools simply require an observer to note whether teammates exhibit the listed behaviors or not [29]. Our checklist focuses on both individual- and team-level measurement, which follows as a best practice according to the team performance measurement literature [15, 29, 31]. Once the instructor has collected observational data on the effectiveness of student teams, he or she can address any poor individual teamwork skills, plus any deficient team-level processes and emergent states. This may have an added benefit of increasing student enjoyment in teamwork, which has been noted as lacking in prior research [32].

3. Methods

Our study aims to construct a teamwork evaluation tool for engineering instructors, by extrapolating information from interviews with real team members to shed light on the key competencies that make engineering teams effective. The participants consisted of undergraduate engineering students from across the globe (i.e., Malawi, Brazil, and the United States) participating in a summer engineering design internship program at an urban, southern university in the United States. The engineering design instruction focused on project-based and experiential learning. Participants spent the first week in an intensive course learning the engineering design process. The instruction for this course uses a flipped model. For more information on this specific course and instruction, see [34]. This condensed engineering design process course ensured a similar baseline of knowledge for all participants. Next, participants joined their six-week project team. Within these project teams, the task structure was open-ended, challenging, and required the team to collaborate externally with real-world clients (i.e. companies, individuals) needing solutions to design-based problems.

Two engineering faculty members and one experienced engineering student were accessible for the student teams to seek for support. These support personnel worked with every individual and team, instructing full-time during the week of classroom education on the problem solving process and periodically training use of various technical engineering equipment and helping to coordinate teams' use of the engineering facility. Design teams were not told how to complete their projects but instead encouraged to take ownership of their design projects by making defensible decisions on their own. Additionally, design teams met with their external clients throughout the project to further define the problem and receive feedback. Projects were multidisciplinary (e.g., electrical engineering, bioengineering, mechanical engineering, and chemical engineering) in nature and applicable to a variety of industries, including exhibits at local museums and devices aimed at increasing inclusion for those with physical disabilities. The goals of each team were to develop and deliver an innovative solution to their respective clients by working as an independent design team.

3.1 Participants

Each participant consented to participate in the research; the university's Institutional Review Board approved the study. The study sample consisted of 15 participants forming a total of four stable-membership teams. Each team had four members with one member not participating in the current study. There were nine men and six women in the study. The participants were undergraduate engineering students, ranging from 18 to 29 years old. Participants received no compensation for their participation. Eight of the participants were from the United States, four were from Malawi, and three were from Brazil. Of the four teams of four members, three contained two men and two women, while the fourth team was comprised of four men. However, each team was culturally diverse, representing American and non-American cultures, lending to the external validity of the sample when considering use of diverse teams in the modern workforce [35]. This research design allowed for an intimate insight into the dynamics of these design teams, mitigating concerns about small sample size.

3.2 Interviews

Each participant was interviewed for fifteen minutes a week during the teamwork portion of the internship, i.e. six of the seven weeks, by one of two authors. One participant was absent during the third week and one audio file was corrupted, for a total of 88 interviews. During each of the interviews, participants were asked a number of questions. For the current study, data was pulled from their responses to the question: "*What team dynamics have been working in the past week, and what can be improved?*" This question was informed by previous qualitative data collected with this population [36], and is purposely broad to gather information about team processes in a colloquial way. These interviews were semi-structured, so follow-up questions were often asked to encourage elaboration of an answer. All interviews were audio-recorded and transcribed. Participant responses to the interview question were analyzed for the purpose of this paper, detailed below.

3.3 Procedure

Two authors independently coded effective and ineffective student- and team-driven behaviors based on the interview transcripts discussed above. Students answered the two-part interview question describing the team dynamics 'that were working in the past week', mostly effective teamwork behaviors, and areas of improvement, which were largely seen as ineffective teamwork, as described by participants. In addition, per the participants' responses, the coders indicated whether the cited teamwork behaviors were by the team as a whole (e.g., the *team* is experiencing difficulty maintaining effort throughout the design process) or an individual (e.g., a *member* isn't displaying self-efficacy for the project). As participants often named several effective and ineffective behaviors per interview, there were a total of 286 behaviors captured in the interview data. These behaviors were also independently sorted by two authors into six categories of a teamwork heuristic (i.e. communication, cognition, coordination, coaching, cooperation, and conflict) to result in empirically-derived, observable checklist items to diagnose teamwork [13].

Sorting into categories entailed some interpretation of the participant quotes, as is common for diagnosing team problems. For example, due to unfamiliarity with teamwork science, teams will often refer to "communication breakdowns" when they are actually experiencing coordination problems [37]. The two sorting authors had a high level of agreement in their initial, independent sorting decisions (κ = 0.84, $p < 0.0001$). To safeguard replicability of categorization, the two researchers met and discussed any discrepancies in their sorting process and came to a consensus on the categorization. Thus, we used the real-time Delphi method [38], a method useful for leveraging our team science expertise to build consensus over the course of a meeting. This method operates under the assumption that expert consensus is more accurate than an individual opinion [39]. The Delphi method has been used in educational contexts [38] and is considered useful for framework development, including organizing the teamwork behaviors into their categorization [39]. Lastly, we aimed to group and slightly generalize the sorted behaviors for a more useful checklist. For example, if a participant mentioned that they were getting angry at a teammate for the teammate's accent, while another participant mentioned anger at their teammate's slow speed of talking, we combined these two as "complaining about their teammates' uncontrollable personal characteristics (i.e., talking speed or accent)". Figure 1 displays the qualitative data analysis procedure.

4. Results

From this study, totaling 88 interviews, we derived a list of effective and ineffective teamwork behaviors from engineering teamwork experiences. These behaviors fit into several categories of team processes and emergent states, including conflict, cooperation, coordination, communication, cognition, and coaching, per Salas and colleagues' framework [13]. We describe each of these six teamwork categories and discuss why, per the literature, the items in our checklist are considered effective or ineffective. We retain a specific lens on the role of diversity in teams, as teams will become more diverse in coming years [35]. Additionally, we intersperse quotes from the participant interviews as supporting evidence for the teamwork behaviors discussed below. The full checklist of teamwork behaviors can be found in the appendix.

4.1 Communication

Ineffective communication is a commonly reported culprit of team dysfunction. Although it is true that effective communication is crucial for team success, poor communication is often a symptom of a larger underlying issue with teamwork. We narrow this focus by targeting behaviors that emerged from the data that indicate effective and ineffective exchanging of relevant information in a timely and clear manner.

An important finding in recent research is that the quality of communication exchanged is more important to team performance than the frequency and quantity of information exchanged [16]. In other words, more communication is not always better. In engineering teams, this might manifest as delays to forward progress when trying to consider each design idea, as described by Participant ID8:

> "*Right now it's delaying our progress with the project. . . We always have the same things that we reported yester-*

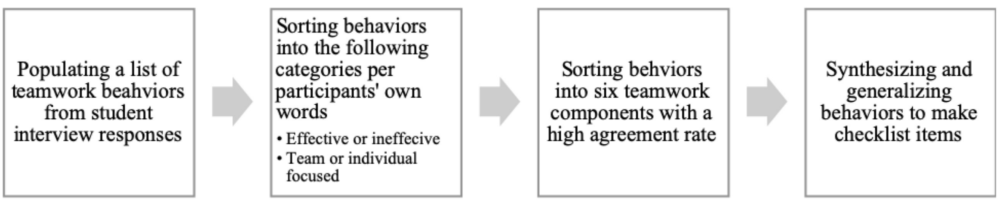

Fig. 1. Qualitative data analysis procedure for creating checklist items.

> *day and we still report the next day and the other day just because people are trying to prove this idea instead of just looking* [at all of the ideas] *and just choosing which of them is best*."

Failing to bring new information to the table and reiterating past discussions caused this team to continue weighing ideas that were already deemed insufficient. As engineering teams often include members from different backgrounds (both culturally and professionally), such reiteration could stem from perceived miscommunication. In general, miscommunication is avoided by speaking clearly and directly [40]. Communication clarity can be a significant barrier for engineering students, especially those working on cross-cultural teams like Participant ID5:

> "*I think communication is a little bit of a problem. Maybe the accent – the accent is trouble. I try not to tell somebody to repeat something just because the accent is different. That's not only for the Americans, like for the Brazilian and for myself*."

Avoiding asking a teammate to repeat themselves is problematic for efforts to maintain closed-loop communication. Closed-loop communication involves the message-sender following up to ensure their message was heard, understood, and interpreted correctly by the intended receiver [41]. Closing the loop is particularly important for teams in which miscommunications can be common (e.g., cross-cultural teams, virtual teams, teams working on highly complex or ill-defined tasks) to avoid clashing ideas about project goals or task progress. Developing a habit of using closed-loop communication can avoid mishaps like the one experienced on Participant ID15's team:

> "*One mistake we made today, we ordered a wrong material. We ordered a thickness that was way too small, and that happened because of lack of communication and discussing 'oh, we've got this and then this thickness' and then we failed to notice it when we submitted the order form. I think if we communicated better on what materials we have that would have been a lot better. We had a document with all our materials that we had ordered, and some of those were there from the previous day, and we just kept those there without checking them over again, but we should have talked about what we already had to make sure it was the right material*."

4.2 Cognition

Cognition refers to the team's shared knowledge and understanding. This does not necessarily mean that team members have identical knowledge, but rather that they have a system for sharing and retrieving knowledge. This system and underlying structure for where knowledge is housed within a team is called a transactive memory system [42]. Having an efficient transactive memory system ensures teammates are aware of each other's expertise so that they know where to find specific information with minimal effort [43]. In engineering teams, each team member often holds a particular set of technical knowledge and skills that contribute to the overall team goal. Teams with effective cognition will know where these assets lie, while teams with poor cognition may spend a considerable amount of time figuring out who knows what or searching for information on their own that is already known by somebody else in the team. Team cognition allows teams to delegate tasks in an effective manner and appreciate the knowledge and skills brought by each member, as described by Participant ID13:

> "*We have a wide breadth of knowledge that we're working with here, lots of varied skills. For instance, we have four different majors that we're working with, which is really nice. It offers a wide range of knowledge, opinions, which is something that I've not had before, because out of my other team members, I think every single person was a [college major] except one, which is just not helpful*."

Another aspect of team cognition that emerged from the data was shared mental models, or a shared understanding of important team aspects like goals, tasks, norms, resources, and priorities [37]. Shared mental models allow for team members to be aware of their own roles, as well as the roles of other members. Through interacting with others and the task environment, teammates begin to form mental models of particular situations as well as expectations for normal versus problem states [44]. Teams often attributed successful performance to having similar visions of "*where in particular we want to go with the final prototype*" (ID6), while dissimilar mental models were often mentioned with unsuccessful performance:

> "*I think we may have separate ideas of what we're actually doing, because I think we're all very committed to it, but that may mean we have a different idea in our head of what we should do. So there may be conflict in what we would do next to move forward or what ideas would actually work on.*"

The effectiveness of team cognitive processes may be difficult to assess, as cognition must be inferred without being physically seen. Nonetheless, it is incredibly important to team performance as the foundation of the ability to coordinate individual work into team performance.

4.3 Coordination

Coordination is a critical component of all teamwork activities [45]. A team of experts can accomplish little without effective integration of their individual work. Meta-analyses show that the positive relationship between coordination and team performance is especially strong for knowledge-related tasks [46], such as those involved in innovation and design. Team coordination refers to transforming individual tasks to team outcomes through synchronized efforts, including the timing and sequencing of actions [37]. This involves some degree of planning, and importantly, shared mental models about a planned course of action and the role of each teammate. Without a shared understanding of their objectives and the interdependence of each task in the plan, teams are not able to effectively coordinate and achieve satisfactory outcomes [47]. Our data is consistent with past research in suggesting that ineffective coordination can stem from poor planning. One participant stated that his/her team could improve by "*dividing up tasks in a better way*" after recognizing that a task "*didn't need another person because it was a one-person job*," and another described a teammate who would carry out tasks independently and "*expect the team to wait for him*." The following quote by Participant ID2 highlights the contrasting experiences of having and not having a plan:

> *"We're at a point where a lot of the things that we're doing are a lot more open. There's not really a clear guide. Sometimes that can be overwhelming in terms of not really having a plan and not really knowing what we're doing, but we are trying to figure out a plan and talk about what we should do before we do things. I think that's working to some degree. I still think we reach points throughout the day where we run out of things to do and then it's like, 'well, what do we do now?' Then, we have to regroup and talk it over . . . It's a hard process to get through, but once we're back on track and people have things to work on, we make progress."*

Participant ID2 explains that inefficient planning can lead to down time where team members are unsure of what to do until they regroup. This quote touches on a key indicator of poor coordination in teams that emerged in the data – process loss [49]. Process loss occurs when a team is not performing as well as it could have at the onset, such as when time and other resources are used inefficiently, errors are made, the team has to stop and restart, the team members engage in redundant taskwork, or an event occurs that jeopardizes maximum performance potential. This may occur in poorly coordinated teams with incompatible mental models about how teammates depend on each other to complete their taskwork. Consider the following quote, where Participant ID12 describes having a different understanding from others on the team leading to inefficient performance:

> *"I don't really know what I'm supposed to be working on right now. And that's been a weird place, because I don't have a defined role and I'm just confused . . . Sometimes* [two teammates] *just sit down at a computer and start researching, and* [another teammate] *and I are like, 'Did you say something or are you telepathic, because what is happening right now?'. . . I think I'm a little behind them on everything. I'm always like, 'What is happening? What are we doing?'"*

In this situation, dissimilar understandings of the team's course of action led to confusion and process loss in the form of falling behind on progress. Some teams dealt with staying on track towards goals and maintaining shared mental models by conducting mutual performance monitoring. Monitoring behavior involves team members reviewing and sharing information on their progress, resources, workload, status, and surroundings [37]. Monitoring aids coordination by allowing team members to verify that the team is on track to meet deadlines, anticipate any issues, and recognize when a teammate may need help. Team members engage in helping or backup behavior when they recognize unbalanced workload distributions and help each other by taking on extra work when demand increases [50]. Without proactive monitoring and effective information exchange about progress, it is impossible to know when teammates need backup; likewise, it is also impossible to know when shared tasks are completed. For instance, consider the following quote from Participant ID11 who accidentally caused a teammate to do double work:

> *"We started to talk a little bit more about what we are doing . . . It helped because it happened in the past that I did something during the night and I didn't tell it to anybody, so in the beginning of the next day there was somebody doing it again."*

To wit, failing to share key information about task progress hinders a team's ability to coordinate and can lead to wasted effort. In summary, several behaviors emerged from the data that are indicative of team coordination as defined by Salas and colleagues (2015) regarding aspects of information sharing, monitoring, providing backup, and planning.

4.4 Coaching

Coaching, or team leadership, is a key component of teamwork due to its role in encouraging coordination, monitoring the team, and providing support as needed [19]. Team leadership can either be shared among members of the team or take a more traditional, hierarchical manifestation. Likewise, followership goes hand-in-hand with leadership in student teams.

Often in educational contexts, student teams are designed to be leaderless, or perhaps, educators may be called to take a leadership role [48]. Frequently, leadership behaviors are shared among the team, rather than centralized in one formal leader [51]. Evidence demonstrates that shared leadership is more effective than hierarchical leadership structures, due to its capitalization on each individual's skills [52]. That is, leaderless teams allow for shared leadership in which each individual leads components of the project for which they are the expert. Shared leadership is defined as "a dynamic, interactive influence process among individuals in groups for which the objective is to lead one another to the achievement of group or organizational goals or both" [53, p. 1].

With the emphasis on shared leadership, team members should be comfortable in both leader and follower roles. Followership is defined in two ways, either as a role distinguished from the leader, or as the behavior demonstrated by the social counterpart to the leader [54]. In student teams, it may be particularly ineffective for one member to unyieldingly assert a leadership role, as we saw from Participant ID9, who noted that the "*team complains and gets mad when [I] take over and order all the parts and stuff.*" In this case, the student was barring the rest of the team from having a role in the decision-making process and withholding others from leadership, creating a team environment ripe for conflict. However, when shared leadership is performed well, students like Participant ID2 note that "*We're all fairly good at. . . taking direction from others.*" These teams may be more likely to have favorable learning and performance outcomes [19, 53, 55].

4.5 Cooperation

Cooperation represents the motivational plus the affective, or emotional, components of teamwork [13], which can increase both performance and team member satisfaction with the teamwork [20, 54]. Similar to team cognition, this may pose a challenge for educators who are using behavioral items to uncover motivations and affect. Two frequently discussed motivational and affective teamwork constructs are goal commitment and collective efficacy. Goal commitment is the feeling of attachment to the team's goals and the determination to reach those goals [56]. Collective efficacy is the shared belief among team members that the team can be effective [20]. Our participants, such as Participant ID13, often viewed the two constructs as being interrelated.

> "*And beyond that, just a general can-do attitude and, like, willing to work. You know, there's some people where you have to really force them to do something . . . Cause right now, we can say, 'Alright, here's our agenda for the day.' And by the end of the day, it will get done. And sometimes you don't have that. But this team, certainly, it's – I guess there's similar level of dedication because we're all in this together for long, extended periods of time.*"

This participant also taps into an individual-level variable, team conscientiousness, which may be related to goal commitment and collective efficacy. At the individual level, conscientiousness, associated with planning, thoroughness, hard work, and goal striving, is one of the most generalizable predictors of performance [57]. In teams, the mean level of member conscientiousness is predictive of team performance [58]. While conscientiousness is an individual difference, conscientious team members may create a teamwork environment that encourages members to demonstrate goal commitment. For example, Participant ID11 noted that "*everyone is focused on the goal, and everyone always try to be active.*" This is in contrast to ineffective cooperation behaviors, where Participant ID1 said her team could improve because they "*procrastinated a little bit.*"

Educators should note that team scientists have suggested providing "early wins" as a tool for instilling collective efficacy on a team, which can determine how much effort they will exert toward a project and the extent to which they take strategic risks [20; 29]. As the quote by Participant ID11 notes, this collective efficacy may serve as a buffer from potentially demotivating setbacks:

> "*We had a good time. We did some testing on a device that turned out to not be the best results and it didn't really stop us in our tracks. It didn't demotivate us really. We just moved on from that. Discussed ways of moving forward.*"

While cooperation must be indirectly observed through behaviors, we aim to provide the appropriate signals for diagnosing a team's motivational and affective state, including their goal commitment and their collective efficacy.

4.6 Conflict

Team conflict is defined as the incompatibilities and disagreements between members [59]. Conflict in teams can range from minor to major [57], and takes one of three forms: task, process, and relational conflict [60]. Task conflict refers to disagreements on the ideas, opinions, and viewpoints of a task [61], and is common in engineering teams who are discussing several options for a design solution. Task conflict may benefit team performance in some situations, such as when the team members feel safe to speak up and negate performance in other contexts [62]. Additionally, *moderate* amounts of task conflict have been shown to promote team creativity [63] and innovation [61]. Participants, including Participant ID11, note the importance of task conflict as a required predecessor to decision-making for the project goals:

> "*I mean, we need to get better at having natural conflict, natural argumentation. Because right now, we're forcing it, and that's something that is – I mean, it can work. It's just difficult, it's slow. We need to get to a point where, I*

don't know if this is something just involved with having English as a second language, but get to a point where we can very quickly have each member's opinion have equal weight and have it, like, very much argument no matter who said what."

Stated previously, the two other types of conflict include process and relational conflict. Process conflict is when teammates disagree with how to arrive at an outcome, product, or deliverable. This form of conflict has been demonstrated to be harmful to team performance [60]. Relational conflict is the disagreements between team members stemming from interpersonal incompatibilities such as personality differences [61]; unlike the other forms of conflict, relational conflict affects both team performance *and* team member satisfaction [59].

However, there is also an interplay between types of conflict and how it evolves and is expressed over time. For example, teams with big differences in how members express task conflict (i.e. directly or indirectly) are likely to have subsequent relationship conflict in the team [36]. It is likely that there are cultural explanations to differences in conflict expression, something that culturally diverse teams should consider when engaging in task conflict. Overall, conflict based on uncontrollable personal characteristics such as culture, accent, talking speed, etc. should be avoided. However, this can be challenging as these factors have a tendency to covertly manifest during task conflict episodes.

"*So on Monday we had a pit stop in which we're like, "Okay, what is working, what isn't working?" There had been some miscommunication. ID14 has complained that I talk too fast. I complained that ID14 talks too softly. We all complain ID2 talks too softly.*"

This kind of relationship conflict has the potential to impede performance [21] including via communication breakdowns. However, when avoided, Participant ID10 said "*we were able to talk to each other and not have any issues.*" But once relationship conflict is established within a team, there are several conflict management strategies, with some strategies seen as more effective than others. For example, while setting rules for things like a cooling off was effective for some, others note that open communication about the interpersonal conflict was not effective [65].

Engineering educators should focus on ensuring that their students have moderate, not high or low, levels of task conflict while avoiding process and relational forms of conflict. Educators should also be advised that task conflict can later manifest as relational conflict, especially in diverse teams.

4.7 Guidelines for Use

Educators, either instructors or teaching assistants (TAs), can use the observational checklist at regular intervals of team performance episodes for best results. Direct observation is most desirable, although if not possible, observers may consider practical alternatives, such as observing video-recordings of student meetings. A new checklist should be used for each assessment of a team. While using the checklist, if an effective behavior's box is left unchecked or an ineffective behavior's box is checked after an observation period, it indicates the area to focus skill development efforts on in order to improve student team performance. The time frame of observation periods may vary depending on the project, but in general, we recommend completing the checklist at salient milestones throughout the lifecycle of a project (e.g., after planning, designing a prototype, delivering the final product).

After reviewing the completed checklist, educators will have insight on effectively tailoring student development toward teamwork competencies to supplement technical skill education. This information may be passed on to the students via grades or informal feedback. In cases where an entire class is lacking an area of teamwork skills, it may indicate a need for a brief lesson on the teamwork category in question. For example, problems with team communication may prompt a need for a tutorial in closed-loop communication as the new standard for sharing information within the team. More specific interventions for team performance are available in the literature [66].

5. Discussion

Although teamwork skills are generalizable across performance contexts, teamwork in engineering student teams looks slightly different from teamwork in typical organizational contexts and requires particular competencies that are currently unaddressed in engineering education. Our contribution provides understanding of these idiosyncrasies particular to the engineering performance context, resulting in a useful checklist for engineering educators. After analyzing qualitative responses for indicators of the six processes and emergent states of teamwork, we compiled a list of effective and ineffective behaviors that can be identified with observations of team performance. Our findings informed the development of a teamwork checklist for engineering educators to use to observe and assess students' teamwork performance (see the Appendix). The purpose of this checklist is to provide specific, evidence-based guidance for educating engineering students. It is intended to be used as a diagnostic 'thermometer' that highlights content areas to target in learning initiatives. To do so, educators must monitor the performance of engineering student teams, focusing on behavioral items of the six core competencies of teamwork outlined by Salas et al [13]: communication, cognition, coordination, cooperation, conflict, and coaching.

While we feel our research study is important and valuable for engineering educators, there are some limitations to address. This study has not been formally, quantitatively tested or validated as a predictor for team performance or team learning; however, is empirically derived from engineering students working full-time in project teams. Instructors should use this checklist with caution until future research can enrich this tool. Additionally, this checklist was developed with a culturally-diverse and somewhat gender-diverse sample. There may be concerns about whether certain checklist items are relevant for more homogenous teams (e.g., "Do students refrain from blaming their non-native English speaking teammate for not being as talkative as native English speakers in discussions?"). While we acknowledge this concern, we feel that the vast majority of items are appropriate for most interdependent teamwork observations; we have distinguished the items that may be most applicable for diverse classrooms in the tool.

5.1 Future Research

Future research should test the usefulness of this checklist for several purposes, namely for observations and as a team-wide rating measure. However, it may be the case that this checklist also has some value for intra-team evaluation. That is, all team members or the team's leader may find this checklist useful as a way to evaluate the teams' performance. While this was not the original purpose of the checklist, future research may find that teams can self-diagnose their own strengths and weaknesses, particularly for those who have extensive experience working in team projects, such as college seniors working on a capstone project. If all team members are rating their team, instructors should look for agreement among team members, as widely different assessments between members may indicate potentially biased responses. A research study should investigate the checklist's effectiveness when used for observations (1) by instructors or TAs, (2) by each team member rating the team, or (3) by a team's internal leader.

6. Conclusions

Teamwork skills remain an important part of engineering education. Currently, there are methods to assess engineering students' teamwork skills, each with its own benefits and drawbacks. Rather than negate any of the past work, we found an opportunity to increase the ease of instructor-rated teamwork skills. The current study sorted 286 teamwork behaviors into six categories of team processes and emergent states according to a theoretically- and empirically-sound teamwork heuristic to develop a checklist for educators to reference when assessing teamwork in team-based design projects. Thus, we provide first steps for educators to get a quick pulse on their students' teamwork skills. Guidelines for use, limitations, and future research directions are all addressed.

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Appendix

Instructions: Please mark off each box next to the observed behavior. Please use a new sheet for each team observed.

Communication

Does **each student**. . .

- ☐ Convey their understanding of their teammates' ideas?
- ☐ Acknowledge receipt of key information (i.e. repeating back task assignment)?

Do **students refrain** from. . .

- ☐ Reporting the same information (unnecessarily) many times?
- ☐ Failing to document tasks during/immediately after completion?

In **diverse** environments, do students. . .

- ☐ Communicate effectively cross-culturally?

Cognition

Does **each student**. . .
- ☐ Understand their teammates' professional skills (e.g., public speaking)?
- ☐ Seek information from teammates with relevant expertise?
- ☐ Understand the team's ideas and goals?

Does **the team**. . .
- ☐ Clearly outline the tasks needed to achieve the goal?
- ☐ Ensure every team member understands the goal?

Does **the team refrain** from. . .
- ☐ Working on a project without a vision for the final product, i.e., goal?
- ☐ Doing tasks without a clear plan?

Coordination

Does **each student**. . .
- ☐ Update the team on their task progress at the proper time?
- ☐ Help their teammate(s) when others are falling behind on tasking?

Does **the team**. . .
- ☐ Agree on task(s) before completing it (them)?
- ☐ Sequence the order of tasks to reduce time spent waiting for another teammate's work?
- ☐ Create a list of tasks that need to be completed each day before the workday starts?
- ☐ Complete tasks on time?
- ☐ Divide large tasks among themselves, especially under time pressure?
- ☐ Adapt to new situations by making a new plan?

Do **students refrain** from. . .
- ☐ Sitting idle because the team lacks a plan?

Does the **team refrain** from. . .
- ☐ Doing a task more than once (e.g., because the task completer failed to update the team that the task was completed)?

Coaching

Does **each student**. . .
- ☐ Feel comfortable taking direction from another teammate?

Does **the team**. . .
- ☐ Shift leadership roles as the task demands change based on relative expertise?

Do **students refrain** from. . .
- ☐ Making unilateral decisions on behalf of the team?

Does the **team refrai**n from. . .
- ☐ Relying on a single member to explain what tasks should be done?

Cooperation

Does **each student**. . .
- ☐ Express enthusiasm for the project and/or tasks??
- ☐ Exert the proper effort towards the goal?
- ☐ Draw on past successes to motivate the team?
- ☐ Demonstrate a "can-do" attitude?

Does **the team**. . .
- ☐ Maintain effort through the less exciting phases of the design process?
- ☐ Retain motivation though setbacks (e.g., design failures)?

Do **students refrain** from. . .
- ☐ Getting distracted from the task by socializing or browsing the web?
- ☐ Getting distracted between project tasks?
- ☐ Procrastinating tasks?

Conflict

Does **each student**. . .
- ☐ Disagree with others using a cordial, civil tone of voice?

- ☐ Express disagreement in a respectful way?
- ☐ Address interpersonal problems kindly but directly?

Do **students refrain** from. . .

- ☐ Complaining about their teammates' uncontrollable personal characteristics (i.e., talking speed or accent)?
- ☐ Expressing frustration towards each other?

In **diverse** environments, do students **refrain from**. . .

- ☐ Blaming their non-native English speaking teammate for not being as talkative as native English speakers in discussions?

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