Teamwork is an integral part of leadership, and many teamwork skills are also leadership skills. This chapter explains how instructors can help students build their capacity for leadership while working in teams.

Team Leadership in Engineering Education

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Teamwork is common in engineering, both in educational and professional settings. Across sectors and industries, engineers solve problems that are too large and multifaceted to be addressed by one person. Teamwork is also an integral part of leadership. Increasingly, leadership theories have begun to embrace teamwork, corresponding to a conceptual shift from leadership as a position to leadership as a process. Collectivistic leadership approaches, such as shared leadership (Pearce & Conger, 2003), team leadership (Burke et al., 2006; Day et al., 2004), and relational leadership (Komives et al., 2006), are particularly beneficial in collaborative environments. These models differ in their details, but all emphasize mutually supportive relationships as a basis for leadership practice. Accreditation criteria for engineering programs in the United States (ABET, 2018) acknowledge this shift; engineering graduates are now expected to have "an ability to function effectively on a team whose members together provide leadership [and] create a collaborative and inclusive environment."

Students may not learn teamwork or other leadership skills simply by participating in a team (Day, 2010; Trede et al., 2020). Teamwork skills can be enhanced by training and coaching (Day et al., 2004; Hackman & Wageman, 2005), which in turn support leadership development (Burke et al., 2006). The teaching of teamwork has become more common in engineering education, although much of the work in our field still fails to draw on the known

science of teamwork (Borrego et al., 2013). This chapter introduces engineering educators to the rich tradition of teams research from industrial/organizational (I/O) psychology, management, and human factors. It discusses teamwork and team leadership theories, applications in engineering education, assessments, promising practices, and suggestions for future research.

Theoretical Foundation

A team is a "set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal…, who have been assigned specific roles or functions to perform, and who have a limited life-span of membership" (Salas et al., 1992, p. 4). Teams have various manifestations in engineering education, including course-based project teams, design teams, and service-learning teams. In most of these settings, students design, build, and deliver a working product at the end of a defined time period. These teams are similar to work teams in professional practice, and many research findings related to work teams apply to the collegiate context.

For teams to flourish, certain conditions must exist. In his studies of self-managed work teams, Hackman (2002) established five criteria: The team must be *real*; that is, the team members must work interdependently toward a common goal. The team must have a *compelling direction*. An *enabling team structure* must exist. The team must operate within a *supportive organizational context*, and the team must receive *expert coaching.* Additional elements necessary for good teamwork include identity safety (Foldy et al., 2009), psychological safety (Edmondson, 2004), and a learning orientation (Day et al., 2004). Identity safety is a necessary precursor to psychological safety. If a team member believes that their colleagues do not value aspects of their identity, achieving psychological safety may be impossible. Teams

with a learning orientation, as opposed to a performance orientation, are better at assessing their performance and learning from both mistakes and accomplishments and may also be more inclusive (Mohammed & Angell, 2004).

Effective teamwork requires both individual and team-level characteristics. Individuals must be competent and reliable, and they must practice good relational skills. But positive individual attributes are not sufficient for good teamwork. Salas et al. (2005) proposed that effective teams exhibit five characteristics which they called the Big Five of Teamwork: team leadership, mutual performance monitoring, backup behavior, adaptability, and team orientation. The focus on interpersonal awareness and adaptability helps team members respond to one another and the task at hand. Leaders, whether formally designated or emergent, practice active leadership by promoting shared mental models and creating a supportive climate. Members of effective teams exhibit a *team orientation*, seeking the good of the team rather than pursuing their own agendas.

The relationship of teamwork to leadership in professional practice is well established (Burke et al., 2011). Many skills necessary for good teamwork, such as defining roles, monitoring performance, communicating honestly, offering encouragement, managing conflict, and giving feedback, are also considered leadership skills, especially within collectivistic models. Team leadership theories provide the bridge between teamwork and leadership. The important distinction between team leadership theories and positional theories lies in how and by whom leadership behaviors are enacted. Team leadership theories all require the presence of "leadership," but most do not specify a particular form. Leadership can be supplied by an external supervisor, by a team member occupying the leader role, or by the team's engagement in collective decision-making. These theories assign a range of behaviors to the leadership function, including sensemaking, planning, assigning tasks, directing and coordinating members' activities, assessing

team performance, and creating a positive and supportive environment. For a comprehensive list, see Burke et al. (2006).

The Team Leadership Cycle (Day et al., 2004) describes how teams build leadership capacity. Each member brings to the team certain capabilities such as leadership skills, domain knowledge, or collaboration skills. If the team provides psychological safety and emphasizes learning, the act of working toward a common goal can build the leadership capacity of the team as a whole. In this way, leadership can be both an input and an output of the process. As the team's leadership capacity grows, team members continue to develop their individual leadership capabilities, and the cycle continues.

Teamwork and Leadership Development in Engineering Education

Working in teams gives engineering students an opportunity to practice leadership skills (Knight & Novoselich, 2017; Wolfinbarger & Shehab, 2015), build agency (Liang et al., 2019), and develop a leadership identity (Kwapisz et al., 2019; Rosch & Imoukhuede, 2016; Wolfinbarger et al., under review). Although many articles in the engineering education literature discuss both leadership and teamwork, the treatment of these concepts is inconsistent. Teamwork skills and "leadership" (otherwise undefined) are often listed as two of several outcomes of collaborative work, but a direct link between the acquisition of teamwork skills and leadership skills is not clear. Theories from I/O psychology (Borrego et al., 2013) can help engineering educators understand the mechanisms by which teamwork and leadership development support each other.

Functional leadership theories (Burke et al., 2011) capture many of the activities performed within engineering teams. For example, Wolfinbarger and Shehab (2015) and Wolfinbarger et al. (2021) used the Team Leadership Framework (Burke et al., 2006) to identify leadership behaviors reported by members of competition teams. Righter et al. (2019) used the Functional Team

Leadership model (Morgeson et al., 2010) to categorize leadership behaviors enacted within design teams. And a study of teams in a bioengineering course (Rosch & Imoukhuede, 2016) provided evidence for the cyclical development of teamwork and leadership skills described in the Team Leadership Cycle (TLC), although the TLC itself was not cited.

Engineering student teams often resemble self-managed teams, which have become increasingly common in the workplace (Mathieu et al., 2017). Self-managed teams operate within an organizational hierarchy but manage their own operations, often with only limited direction from their supervisors (Hackman, 2002). Such teams are fruitful ground for leadership development. A few engineering education researchers have used collectivistic theories and the self-managed teams construct to explicitly connect the development of teamwork skills to the development of leadership skills in a construction management and architecture course (Zafft et al., 2009), capstone design teams (Novoselich & Knight, 2018) and engineering competition teams (Wolfinbarger & Shehab, 2015; Wolfinbarger et al., under review). Some studies provide evidence that engineering students may prefer self-managed teams. In an investigation of undergraduate software development teams, shared leadership emerged when leadership structures were not specified (Kakar, 2017). Shared leadership was more common than vertical leadership within mechanical engineering capstone teams (Novoselich & Knight, 2018).

Although shared leadership models reflect the reality of engineering work, students may not thrive within these structures without preparation. Because teamwork is intertwined with shared leadership, students must learn how to be good team members before becoming relational leaders (Komives et al., 2006). An investigation of MBA teams (Carson et al., 2007) revealed that a positive internal environment contributed to the development of shared leadership. Teams that possessed a shared purpose, offered social support to all members, and allowed each member a voice were more likely to exhibit

shared leadership—and deliver a better product—than those which did not. Operating in an environment of shared leadership requires maturity on the part of team members. College students may initially be more comfortable with hierarchical structures and need time to develop the confidence necessary to enact leadership within a team (Komives et al., 2006). And because developing effective processes also takes time, new teams or those operating under time constraints may benefit from having a designated leader (Burke et al., 2011). In such situations, the positional leader should endeavor to create an environment where all team members can work interdependently and contribute to decision-making.

Assessing Teamwork

Assessments can help educators measure leadership development. When used as coaching tools or prompts for team discussion, they can also help students learn teamwork and leadership skills. Engineering educators continue to develop useful, scalable, and accurate tools (Table 1). A typical instrument measures some combination of factors related to team effectiveness, an umbrella term that incorporates performance, behavior, and attitude (Adams et al., 2002). Teamwork can be assessed at the individual or team level. Assessments can be completed by the team members or by external raters, and both quantitative and qualitative tools exist. All of the listed tools incorporate theories of teaming from the psychology or cooperative learning literature, although the degree of empirical validation varies.

Table 1

Teamwork Assessment Instruments for Engineering Education

Instrument	Citation	Level of Analysis	Type	Completed by	Purpose
CATME	Loughry et al. (2007) ; Ohland et al. (2012); Purdue (2021)	Individual (primary instrument); team (supplemental questions)	Survey	Individuals	Individual feedback; team-level feedback; early warning; coaching; instruction; grade assignment
Team Member Evaluation Form	Oakley et al. (2004)	Individual	Survey	Individuals	Individual feedback; encourage discussion
Peer Rating of Team Members	Oakley et al. (2004)	Individual	Survey	Individuals	Individual feedback; encourage discussion

Team Evaluation Worksheet	Davis & Wolfinbarger (2018)	Team	Survey	Individuals	Team-level feedback; encourage discussion
Team Diagnostic Survey	Wageman et al. (2005); Team Coaching Zone (n.d.)	Team	Survey	Individuals	Team-level feedback; encourage discussion; research
Evaluation of Progress Toward Effective Team Functioning	Oakley et al. (2004)	Team	Checklist (recall)	Team	Instruction; early warning; encourage discussion
Four-Factor Teamwork Effectiveness Scale	Imbrie et al. (2005)	Team	Survey	Individuals	Curriculum design; pedagogical assessment

Team Effectiveness Questionnaire	Adams et al. (2002)	Team	Survey	Individuals	Instruction; team-level feedback; encourage discussion; research
Checklist to Diagnose Teamwork in Engineering Education	Paoletti et al. (2020)	Team	Checklist (real-time)	Trained observer	Coaching; instruction; encourage discussion

Individual-level assessments incorporating peer evaluations are popular in engineering education. One well validated instrument is the Comprehensive Assessment of Team Member Effectiveness, or CATME (Loughry et al., 2007; Ohland et al., 2012; Purdue, 2021). CATME is web-based and easy to administer, even with large numbers of students. For instructors seeking a paper-based method, Oakley et al. (2004) provide the Team Member Evaluation and the Peer Rating of Team Members.

Team-level assessments provide a holistic picture of team functioning. Instead of evaluating each other individually, each member evaluates the team as a whole on several dimensions. Teams use the results to identify and discuss problems so that they can be addressed while the work is underway. Instruments designed specifically for use by self-managing teams include the Team Effectiveness Questionnaire (Adams et al., 2002), the Team Evaluation Worksheet (Davis & Wolfinbarger, 2018), and the Team Diagnostic Survey (Team Coaching Zone, n.d.; Wageman et al., 2005).

One disadvantage of questionnaires is their reliance on retroactive self-reports. Students may lack the knowledge to appropriately evaluate teaming behaviors (Imbrie et al., 2020), feel social pressure to provide positive scores for teammates (Oakley et al., 2004), or fail to accurately recall events. Observing teams in action can provide rich insight into team dynamics and help facilitators provide relevant coaching (Hess, 2007). New research explores methods for incorporating qualitative assessments, including observation by trained personnel (Murzi et al., 2020; Paoletti et al., 2020) and interviews (Chowdhury et al., 2020).

Implications for Engineering Leadership Development

Engineering classrooms are well suited to developing leadership and teamwork skills (Knight & Novoselich, 2017). The following practices can help

engineering students develop teamwork and leadership skills. Some cited references include details for successful implementation.

1. Form teams intentionally, supporting equity and inclusion (Beddoes & Panther, 2018; Layton et al., 2010).

2. Keep teams together for the duration of the course, unless insurmountable problems arise (Hess, 2007; Oakley et al., 2004).

3. Choose projects that require interdependent work (Borrego et al., 2013).

4. Provide appropriately timed instruction and coaching throughout the project (Hackman & Wageman, 2005).

5. Encourage teams to use accountability mechanisms throughout the project. Non-punitive methods will encourage frank discussion and foster intrinsic motivation (Davis & Wolfinbarger, 2018; Wageman et al., 2005).

6. Help teams develop the precursors to shared leadership: shared purpose, social support, voice (Carson et al., 2007), psychological safety (Edmondson, 2004), and identity safety (Foldy et al., 2009). Support Hackman's conditions for team effectiveness (2002) and teach students how to establish enabling structures and compelling direction. Teach the Big 5 of Teamwork (Salas et al., 2005) and encourage teams to establish standards of excellence (LaFasto & Larson, 1989).

7. Provide scaffolded opportunities for practicing leadership. A typical student enters college with a positional, hierarchical view of leadership (Komives et al., 2006) and may not be ready to adopt shared leadership practices right away. The educator can help students develop a relational, interdependent, process-oriented view. In introductory courses, a designated leader role may facilitate team effectiveness. This role should rotate periodically so that each team member takes a turn as the acknowledged leader. Defining additional roles for key team functions can encourage active participation and help each student make a meaningful contribution. These

roles should also rotate, to avoid reinforcing gender, racial, or other biases. In advanced courses, teams can choose their own structure. Some teams may elect a leader. Others may allow a leader to emerge or may intentionally engage in shared leadership.

8. Provide time during class for teams to work. Observe and assess team functioning for subsequent coaching. Provide coaching during work time but limit work interruptions. Observations, assessments, and coaching can be performed by trained students, such as teaching assistants or those who previously took the course. As a result, these students will practice their own leadership skills.

9. Encourage a formal debriefing process at the end of the work cycle (Hackman & Wageman, 2005). The process should include a team meeting, possibility facilitated by instructor or TA; the completion of team-level assessments; and, if desired, completion of individual written reflections by team members. These elements can enhance students' individual leadership development and capacity for teamwork. Teams that will continue working together may enjoy enhanced team learning and team leadership capacity.

Conclusion

This chapter explained how the development of teamwork skills supports the development of leadership skills. Instructors play a critical role in helping students develop their capacity for team leadership. If engineers embrace and practice team leadership, we can lead the way in creating a more collaborative, inclusive, and innovative society.

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