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Overcoming the Barriers to Teaching Teamwork to Undergraduates in STEM

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Recommended Citation

Goldsmith, G. R., Aiken, M. L., Camarillo-Abad, H. M., Diki, K., Gardner, D. L., Stipčić, M., & Espeleta, J. F. (2024). Overcoming the Barriers to Teaching Teamwork to Undergraduates in STEM. **CBE–Life Sciences Education** *23*, es2. https://10.1187/cbe.23-07-0128

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This article was originally published in *CBE--Life Sciences Education*, volume 23, in 2024. https://10.1187/cbe.23-07-0128

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Overcoming the Barriers to Teaching Teamwork to Undergraduates in STEM

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ABSTRACT

There is widespread recognition that undergraduate students in the life sciences must learn how to work in teams. However, instructors who wish to incorporate teamwork into their classrooms rarely have formal training in how to teach teamwork. This is further complicated by the application of synonymous and often ambiguous terminology regarding teamwork that is found in literature spread among many different disciplines. There are significant barriers for instructors wishing to identify and implement best practices. We synthesize key concepts in teamwork by considering the knowledge, skills, and attitudes (KSAs) necessary for success, the pedagogies and curricula for teaching those KSAs, and the instruments available for evaluating and assessing success. There are only a limited number of studies on teamwork in higher education that present an intervention with a control group and a formal evaluation or assessment. Moreover, these studies are almost exclusively outside STEM disciplines, raising questions about their extensibility. We conclude by considering how to build an evidence base for instruction that will empower students with the KSAs necessary for participating in a lifetime of equitable and inclusive teamwork.

WHY SHOULD WE TEACH TEAMWORK?

Students preparing for careers in STEM fields must explicitly be taught how to collaborate in teams. Research has demonstrated that knowledge is increasingly generated in teams (Wuchty *et al.*, 2007) and that this knowledge has a higher impact on its given field (Singh and Fleming, 2010). Moreover, there is now widespread recognition that finding solutions to highly complex and intractable problems is likely to require teams of individuals collaborating with one another across traditional disciplinary boundaries (Disis and Slattery, 2010). Such findings have prompted the U.S. National Academies of Science, Engineering, and Medicine to call for efforts to improve the efficacy of science carried out in teams through interventions that include education for students and professionals in the workforce (National Research Council, 2015). Moreover, surveys consistently find that across careers, employers hiring college graduates consistently rate teamwork/collaboration as the second most important career readiness attribute, just behind critical thinking/problem solving (NACE, 2017). For such reasons, the ability to collaborate in teams is now included as an undergraduate learning outcome for a wide range of STEM programs (e.g., ABET, [2022]; ACS, [2022]), including the life sciences (Clemmons *et al.*, 2020).

In parallel, research has also demonstrated the potential for a number of educational benefits to undergraduate students who are learning in teams (Lord, 2001). These benefits include improved content knowledge (Carmichael, 2009; Swanson *et al.*, 2019) and conceptual understanding (Parappilly *et al.*, 2015), better retention of material (Mcinerney and Fink, 2003), and reduced social anxiety and greater self-efficacy (Almasri *et al.*, 2021).

However, simply asking students to work in teams is not the same as teaching them the knowledge, skills, and attitudes (KSAs) necessary for teamwork. Participation in a

Cynthia Brame, *Monitoring Editor*
Submitted Jul 31, 2023; Revised Feb 2, 2024; Accepted Feb 9, 2024
CBE Life Sci Educ June 1, 2024 23:es2
DOI:10.1187/cbe.23-07-0128
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successful team does not inherently correlate with an increase in individual students' teamwork competencies, or their ability to demonstrate those competencies in future teams. For those instructors who wish to formally include learning outcomes related to teamwork and support them with appropriate curricula and pedagogies, there can be significant barriers. In particular, instructors in STEM, who may have significant disciplinary expertise, are rarely formally trained to teach teamwork and must, therefore, rely heavily on amalgamating outside resources to incorporate into their particular classroom context (Riebe *et al.*, 2016). There is a critical need to provide instructors with accessible, evidence-based approaches for teaching teamwork and for measuring the outcomes of their efforts.

We synthesize key issues associated with teaching teamwork, with the goal of providing the basis for overcoming the barriers to teaching teamwork to undergraduates in life science and STEM classrooms. Our approach differs in that we are focused on the pedagogy and curricula for teaching teamwork itself, rather than team-based learning as a pedagogical approach for teaching STEM curricula (Michaelsen *et al.*, 2002). We do not attempt a comprehensive review because, as we demonstrate below, the dispersed nature of the large amounts of literature on teamwork precludes such an approach. We begin by providing a definition of teamwork and considering the component KSAs that have been identified as necessary for successful teamwork. We then consider whether teaching teamwork to undergraduates in STEM fundamentally differs from teaching it to students in other disciplines. This allows us to summarize key insights from the broader literature on the KSAs necessary to teach teamwork and the instruments that are available to evaluate and assess success. Based on this summary, we conclude by recommending future directions for research on teaching teamwork to undergraduate students in STEM.

WHAT ARE TEAMS AND WHAT IS TEAMWORK?

To guide teamwork training, it is essential to delineate what constitutes a team doing teamwork. Innumerable definitions have been offered, both for teams operating in professional settings and teams learning in educational settings. To avoid further complications by offering new definitions, we offer the most cited definitions of teams and teamwork, then offer brief summaries for clarity where necessary:

A "**team**" can be defined as: 1) composed of two or more individuals; 2) performing organizationally relevant tasks; 3) sharing common goals; 4) exhibiting task interdependencies; 5) interacting socially; 6) maintaining and managing boundaries; and 7) embedded within an organizational system, with boundaries and external linkages (Kozlowski and Bell, 2003). We summarize this definition as a group of individuals necessarily interacting with one another to collaborate in achieving common goals. While teams are not infinite in size or scope, the individuals in the group and the goals they work towards are generally part of a larger network of teams.

In turn, teams take a series of inputs (e.g., people, organizational resources) and engage in a series of processes (e.g., behaviors) to reach their common goals (e.g., performance/products) over time (Marks *et al.*, 2001; Mathieu *et al.*, 2008).

The concept of "**teamwork**" can be defined as behaviors including: 1) adaptability, 2) communication, 3) coordination, 4) decision making, 5) interpersonal relations, 6) performance monitoring and feedback, and 7) shared situational awareness (Cannon-Bowers *et al.*, 1995). We summarize this definition as the need for individuals in a team to communicate with one another to coordinate, make decisions, monitor their performance, and provide feedback. However, success also requires shared situational awareness and the ability to adapt where necessary.

The concept of "**taskwork**" can be defined as distinct from that of "teamwork" in that the behaviors do not require interdependent interactions (e.g., coordination and decision making among individuals) among team members (Salas *et al.*, 2009a).

The concept of "**groupwork**" has been proposed to differ from "teamwork" on the basis of the degree of individuality (Katzenbach and Smith, 1993). For example, groupwork may primarily be composed of taskwork where individuals are completing discrete tasks that do not require their teammates, but are nevertheless part of the common goal. In this case, the interdependence identified as key to teamwork is limited. While the terms groupwork and teamwork are used interchangeably in the literature, we adopt the term teamwork throughout.

In the context of teamwork training in higher education settings, Riebe *et al.* (2016) more simply proposed teams and teamwork as "a process involving two or more students working toward common goals, through interdependent behavior with individual accountability."

WHAT COMPETENCIES ARE NECESSARY TO DO TEAMWORK?

To guide teamwork training, it is also essential to delineate what competencies are required of individuals or teams in order to successfully carry out teamwork (Salas *et al.*, 2009b). Competencies can be viewed as the prerequisites necessary for carrying out the teamwork behaviors described above, although competencies and behaviors are not completely distinct from one another in how they are defined. The most commonly cited competency frameworks focus on the KSAs of individuals in a team (Stevens and Campion, 1994; Cannon-Bowers *et al.*, 1995; Hughes and Jones, 2011). For example, Stevens and Campion (1994) derived individual teamwork skills from group and organizational theory and then condensed them into a list of 14 KSAs classified in two categories with five subcategories: 1) interpersonal (conflict resolution, collaborative problem solving, and communication), and 2) self-management (goal setting and performance management, and planning and task coordination). Notably, the KSAs defined by Stevens and Campion (1994) do not differentiate in any way between knowledge, skills, and abilities and their validity has been critiqued (Salas *et al.*, 2000).

In an alternative approach to KSAs, Cannon-Bowers *et al.* (1995) focused on delineating among KSAs (*N.B.*, attitudes rather than abilities as in Stevens and Campion, 1994). Their approach is widely adopted, including by the National Academy of Science in their report on enhancing the effectiveness of team science (National Research Council, 2015). Cannon-Bowers *et al.* (1995) differentiate between competencies that are context-driven (i.e., specific to the team and task), team-contingent (i.e., specific to the team, but task generic), task-contingent (i.e., specific to the task, but generic to the team), and transportable (i.e., generic to both the team and task). In other words, there

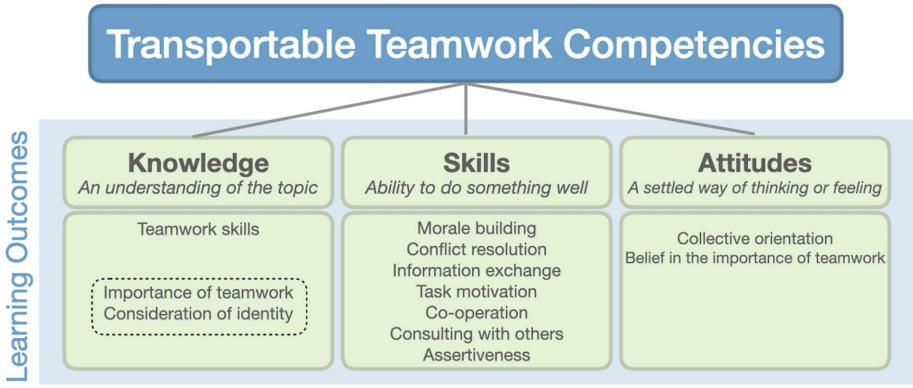

FIGURE 1. Transportable teamwork competencies are those KSAs that are necessary for effective teamwork regardless of the team or the task at hand (Cannon-Bowers *et al.*, 1995). Notably absent are any explicit consideration of knowledge of the importance of teamwork or considerations of how individual identities may contribute to teamwork processes (dashed box).

are some competencies that are specific to a team and a task; teaching these to everyone would be inefficient. Thus, competencies that are generic to both the teams and tasks are likely to be the most valuable in the context of teamwork training because these competencies should be useful for all teams regardless of their tasks. Cannon-Bowers *et al.* (1995) include: 1) knowledge of teamwork skills, 2) skills of morale building, conflict resolution, information exchange, task motivation, cooperation, consulting with others, and assertiveness, and 3) attitudes of collective orientation and belief in the importance of teamwork as transportable teamwork competencies (Figure 1).

There are notable problems with the delineation of teamwork competencies: 1) Teamwork is complex and multidimensional in nature, 2) teams work in diverse conditions and with diverse tasks, and 3) there is considerable confusion in the use of teamwork terminology (Salas *et al.*, 2000). In particular, the ongoing lack of clearly defined terminology, exacerbated by the consideration of teamwork among many disciplines, presents a considerable challenge. For example, Cannon-Bowers *et al.* (1995) found more than 130 terms applied to describe the same eight skills necessary for teamwork. This significantly complicates our ability to determine a common set of KSAs for teamwork and identify training interventions that have been applied and assessed, although such efforts remain critically important.

IS TEAMWORK IN THE LIFE SCIENCES AND STEM DIFFERENT FROM OTHER TEAMWORK?

A well-recognized, but outstanding, problem with research on teaching teamwork is its dispersal across disciplines of higher education, throughout professional training, and as a long-standing emphasis in the study of organizational psychology and development. Much of it comes from fields where there is a strong emphasis on effective teamwork, including healthcare (Morey *et al.*, 2002; Weaver *et al.*, 2010; Deneckere *et al.*, 2013; Weller *et al.*, 2014), sports psychology (Volpe *et al.*, 1996; Martin *et al.*, 2008), military science (Smith-Jentsch *et al.*, 2008; Dalenberg *et al.*, 2009), and business management (Rapp and Mathieu, 2007; Aaron *et al.*, 2014), among others.

Given that teamwork is applied to many disciplines, several authors caution against the application of general KSA taxonomies to teams and tasks that differ in nature (Salas *et al.*, 2000; Sundstrom *et al.*, 2000); coordination, feedback, and communication requirements can differ across different types of work teams. Fiore (2008) suggests that KSA taxonomies can enhance our understanding of science carried out in team settings by identifying the generic competencies from the specific ones that determine success among different science teams. Once particular team competencies and training needs are identified, the training techniques for specific teamwork KSAs can be developed.

If teamwork were to fundamentally differ between STEM and other disciplines, this would limit our ability to apply teaching interventions developed in other fields. For example, the process of knowledge generation and innovative solutions in STEM may place a premium on creativity and innovation. In teams, this may emphasize skills and attitudes that inspire creativity and ingenuity among team members. However, we question whether the creativity and ingenuity necessary for teamwork in STEM somehow fundamentally differs from a field such as healthcare. Similarly, the iterative processes often necessary for experimentation for developing scientific knowledge or iterate on engineering solutions may put a particular premium on skills and attitudes that help manage uncertainty and promote patience among team members. However, we question whether managing uncertainty and promoting patience in STEM somehow fundamentally differs from a field such as business.

Ultimately, we found no explicit comparison in the literature of generic teamwork competencies in STEM to those in other disciplines. Yet, there is also no immediate evidence for teamwork competencies that are wholly unique to STEM; at present, the National Academy of Sciences effectively cites Cannon-Bowers *et al.* (1995) in establishing competencies for team science. Conversely, it is not apparent that there are any competencies that would be considered irrelevant. The emphases that we identify above are likely to be subjects for more advanced training on teamwork, rather than foundational. Thus, while we are not aware of any study assessing the effects of identical interventions to teach teamwork simultaneously across different disciplines, we expect that robust approaches for teaching basic transportable competencies can create value for the field of STEM even if originally developed for other higher education disciplines.

WHAT EVIDENCE-BASED APPROACHES EXIST FOR TEACHING TEAMWORK TO UNDERGRADUATES?

Several systematic studies have sought to classify the state of the field and determine the efficacy of efforts to teach teamwork in higher education, professional education (Morbitzer *et al.*, 2021), and professional settings (Salas *et al.*, 2009a). In particular, a systematic review of the effectiveness of teamwork

training in higher and professional education surveyed 16,849 articles to identify those studies with a control and experimental condition that trained teamwork (as compared with taskwork, as noted above) and measured some aspect of team behavior or performance (McEwan *et al.*, 2017). The review identified only 51 research studies that met their criteria, with only one of those studies set in a higher education STEM classroom (Beranek and Martz, 2005). Many studies introduce curriculum and pedagogy into a classroom over the course of an entire term with some summative evaluation, but the presence of a control group is much less common. Similarly, another review of higher education teamwork pedagogy found that ~75% of the papers reviewed were in the field of business, which suggests the prioritization of teamwork in this field of study (Riebe *et al.*, 2016). Only 14% of the papers identified by Riebe *et al.* (2016) were in STEM higher education settings. Not only does the research on teamwork almost exclusively originate from outside of the life sciences and STEM, but it is also largely focused on describing teamwork training that occurs in classrooms of very particular disciplines.

Approaches for teaching teamwork

A key theme we identified in literature about teamwork from across higher education was a notable difference in the amount of attention paid to what we are describing as the administration of teamwork, as compared with teamwork curriculum and pedagogy. That is, much has been written about the management and facilitation of teams (e.g., Michaelsen *et al.*, 1996; Lord, 2001; Lizzio and Wilson, 2005; Gillespie *et al.*, 2006; Kozar, 2010; Hughes and Jones, 2011; Salazar *et al.*, 2012; Haidet *et al.*, 2014; Patterson, 2019; Swanson *et al.*, 2019; Provaznik *et al.*, 2021). In contrast, much less has been written in higher education settings about teaching teamwork knowledge, skills, and/or attitudes (see reviews by Riebe *et al.*, 2016; McEwan *et al.*, 2017)

Teamwork administration approaches are those that attempt to structure teamwork in some way, either in service of disciplinary learning outcomes or to mitigate negative teamwork experiences. For example, studies that have examined student perceptions of teamwork have consistently observed that students identify inequitable distribution of work (often described as "loafing" or "freeloading") as impacting their experience (Liden *et al.*, 1986).

Approaches to teamwork administration span the different stages of teamwork, including approaches to choosing who is on a given student team (Loughry *et al.*, 2014), approaches that dictate student roles (e.g., notetaker; Lingard, 2010), and approaches that implement some form of peer evaluation to avoid "freeloaders" and improve teamwork outcomes (O'Neill *et al.*, 2020). Most of these approaches have mixed outcomes and lend themselves to inequitable and exclusionary practices. For example, several approaches begin with team formation, with a significant amount of research focused on proactive team composition strategies (Loughry *et al.*, 2014). This tactic focuses on eliminating any challenges that may arise based on who is on the team, creating an unrealistic scenario that attempts to eliminate the need for students to learn how to overcome common challenges encountered during teamwork. Moreover, these strategies can sometimes rely on tenuous or potentially problematic sociocultural assumptions, or success may hinge on a range of perspectives or experiences that may not be consistently available in many contexts. Notably, the success of administrative approaches is generally assessed by the ability to support learning objectives or by student satisfaction, rather than any attainment of team-specific knowledge, skills, or attitudes. Just because a student can perform a role does not mean that they understand that role or when they need to assume it.

In contrast to administrative approaches to student teamwork, pedagogy involves students learning how their team can be successful and for an instructor to be able to assess that learning. This sort of approach succeeds independent of teams attaining any stated goal that may have justified its formation (e.g., completion of a specific task or project). The objective and success of teamwork pedagogy is characterized by students attaining knowledge, skills, and appropriate attitudes towards teamwork and being able to successfully demonstrate reasoning for their own approaches to teamwork. Where teamwork administration helps teams attain specific objectives in specific settings, teamwork pedagogies support individual learning that can ideally be applied to teamwork in a variety of settings (i.e., transportable).

The methods used to teach effective teamwork across disciplines have broadly been described as falling into four key approaches: 1) didactic dissemination of information, 2) discussions and exercises, 3) simulations based on example activities, and 4) reviews incorporated into actual teamwork (McEwan *et al.*, 2017). Quantitative meta-analysis of these approaches by McEwan *et al.* (2017) find that both teamwork behavior and performance can be improved by any and all of the methods other than didactic dissemination. The largest effect sizes were observed for new teams and where the intervention targeted multiple aspects of teamwork (e.g., both goal setting and conflict resolution). Less clear are the long-term impacts of instruction focusing on teamwork knowledge, skills, or attitudes and how these impact students' performance in future courses or careers.

Among the pedagogical approaches for teaching teamwork, there is an apparent bias towards skills (Riebe *et al.*, 2016). Interventions that teach students teamwork knowledge or attitudes towards teamwork may go undescribed within interventions focused on skills, or may be described in contexts that are not directly connected to teamwork (e.g., conflict management, which is useful for all interpersonal relations). Moreover, while a number of other approaches have been proposed (Johnson *et al.*, 2006), the evidence-base for their efficacy is limited. Nevertheless, we highlight four pedagogical approaches that assessed the effects of experimental teaching interventions on KSAs in academic settings using quasiexperimental or experimental approaches:

- *Team charters* describe the behavioral norms that teams wish to establish at the outset of a project and can have bearing on knowledge (e.g., the need to manage meetings), skills (e.g., effective communication), and attitudes (e.g., importance of working together). Team charters generally manifest as short documents written collectively by the team at the outset of a project and can be referred to over time; importantly, they can provide an opportunity for instructors to discuss all of the different behaviors involved in teamwork. In an

experimental study comparing students working in teams: 1) without a charter, 2) with a charter, and 3) with a charter supported by ongoing instruction and follow up, Aaron *et al.* (2014) measured students' self-reported measures of communication, effort, cohesion, mutual support, and satisfaction. The study found significant improvements given the use of the team charter as compared with the control, but only minimal further improvements given ongoing instruction and support. The exercise of creating team charters, which is generally short in duration, can be directly integrated into STEM education settings that use teamwork-focused pedagogies.

- *Case studies* can also be used as examples of successful and unsuccessful teamwork that teach students teamwork knowledge. Case studies provide short written descriptions of hypothetical, but likely, scenarios that could occur during teamwork and use the scenario as the basis for group discussions that identify the problems and consider potential solutions. Notably, they often focus on scenarios where something has gone wrong, rather than modeling best practices. In an experimental study where teams of students who carried out a group discussion of case studies focused on transportable competencies associated with planning/task coordination, collaborative problem solving, and communication and then asked to complete teamwork were compared with teams of students who were simply asked to complete teamwork, Ellis *et al.* (2005) measured knowledge and its mediating effects on skill outcomes. The study found significant increases in declarative knowledge that increased planning/task coordination, problem solving, and communication. Case studies, which can vary in scope and, therefore, in duration, can be integrated into STEM education settings that use pedagogies with teams, but may also find use with students learning using more task- or group-work focused pedagogies.
- *Role-play* may be particularly valuable for teaching teamwork skills to students. Role-play provides the opportunity for students to practice and receive feedback on how they would respond to hypothetical, but likely, scenarios that could occur during teamwork. They differ in their sense of realism in comparison to case studies and must be guided carefully by the instructor to ensure students are comfortable practicing. In a quasiexperimental study, students in a workshop on bias and discrimination in teamwork were presented with responses that could be used to effectively react to discriminatory acts or speech, then offered the opportunity to practice those responses in role-plays and included an observer that provided feedback. Isaac *et al.* (2023) measured utility judgements and intention to use both immediately and several months after the activity. The study found that >80% of students were likely to try to apply the skills learned, although it is less clear that students actually used them in the long-term. Role-play, which is often short in duration but intensive in nature, can be integrated into STEM education settings that use teamwork-focused pedagogies.
- *Self- or team-reflection exercises* offer the opportunity for students to practice metacognition and grow in their attitudes towards teamwork. Reflection exercises are generally written by students in response to prompts such as: What was achieved by the individual student and the team? How much time was spent on the project? What were the setbacks or challenges? While many of these exercises are done during or after (i.e., postmortem) teamwork (e.g., Mayne, 2012), a quasiexperimental study instead asked students to consider a failed teamwork experience at the start of their projects (i.e., premortem) and then identify mechanisms to avoid such an outcome. Luth *et al.* (2022) measured team satisfaction, perspective taking (understanding of other teammates), and prosocial motivation (desire to help other teammates) before and after the intervention, as well as at the end of the semester. The study found that while students' satisfaction does not change, students may improve in both their perspective taking and prosocial motivation. Reflection exercises, which are generally short in duration but can be repeated many times, can be integrated into STEM education settings that use pedagogies with teams, but may also find use with students learning using more task- or group-work focused pedagogies.

The continuum of approaches for the administration or teaching of teamwork can also be considered in the context of a continuum of passive-to-active formats (Figure 2). The position of any given approach is rarely fixed, depending on its delivery. Moreover, simple changes can shift common approaches. For example, if the desired learning outcome is that students have the KSAs to facilitate the contributions of others, then a teamwork charter activity that is commonly used in an administrative context (and during which students often intuitively identify letting everyone on the team speak as a desired team behavior) may be complemented by a brief reading about the importance of diverse perspectives for problem solving and a role play that introduces students to, and allows them to practice, phrases they can use to help everyone contribute (Goldsmith *et al.*, 2021).

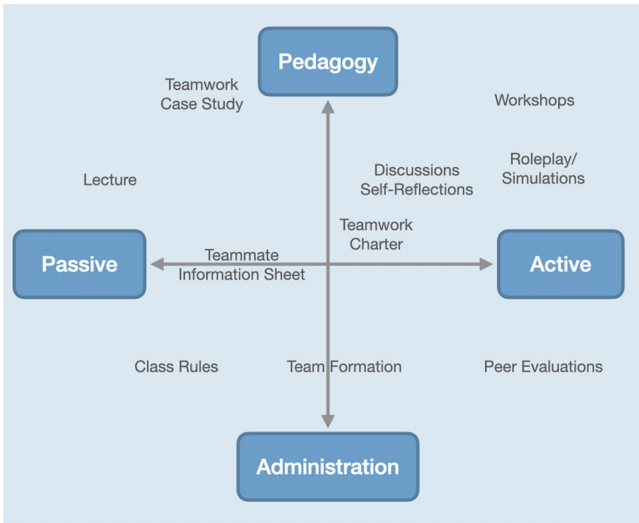

FIGURE 2. Proposed approaches to teamwork in the classroom vary along a continuum from more administrative to more pedagogical in nature and can be delivered in more passive to more active formats. Many approaches can be modified and transitioned to become more active and pedagogical in nature.

HOW DO WE ASSESS TEAMWORK?

Developing an evidence-base for effectively teaching teamwork requires strong instruments for evaluation and assessment (Hughes and Jones, 2011). Here, we focus on evaluating and assessing the dimensions of teamwork (i.e., KSAs) rather than the success of the process or the outcomes of teamwork (i.e., quality or quantity of products produced), although both may be of interest (Britton *et al.*, 2017). Evaluation and assessment must fundamentally be tied to the proposed learning outcomes and will necessarily vary depending on the instructor's priorities. However, Kemery and Stickney (2014) argue that, to be effective, teamwork assessment should be carried out by individuals, peers, and instructors at the level of both the individual and the team at more than one point in time.

The overwhelming number of robust (e.g., valid and reliable) teamwork assessments that have been developed in the context of teaching teamwork in higher education settings are focused on self/peer assessment of teamwork behaviors at the individual level. For example, the Comprehensive Assessment of Team Member Effectiveness (CATME) engages students in self and peer assessment of five dimensions of students' teamwork behavior including: 1) contributing to the team's work, 2) interacting with teammates, 3) keeping the team on track, 4) expecting quality, and 5) having relevant knowledge, skills, and abilities (Ohland *et al.*, 2012). Students using the CATME assessment are empowered to carry out peer evaluation following the completion of training through a rater calibration tool that not only standardizes scoring, but may also serve to teach students about teamwork behaviors (Loughry *et al.*, 2014). The TeamUp (Hastie *et al.*, 2014) and Team-Q assessments were developed based on the Teamwork Value Rubric (AAC&U, 2023). The Teamwork Value Rubric is an individual assessment focused on a student's proficiency at contributing to team meetings, facilitation of the contributions of team members, individual contributions outside of team meetings, fostering of a constructive team climate, and response to conflict (AAC&U, 2023). In contrast to instruments focused on the individual, Team CARE and Bare CARE are assessments of team dynamics focused on communication (e.g., conflict management), adaptation (e.g., team monitoring), relations (e.g., trust), and education (e.g., learning together) (O'Neill *et al.*, 2018, 2020). Notably, none of these assessments were explicitly written in the context of life sciences or STEM.

Existing instruments often blend knowledge, skill, and attitude competencies and behaviors (*sensu,* Cannon-Bowers *et al.*, 1995). For example, the categories of the CATME assessment include both behaviors and KSAs. However, any given category (e.g., interacting with teammates) may intrinsically involve multiple distinct behaviors (e.g., communication and decision making). The category on KSAs is just a single prompt, with no differentiation among knowledge, skills, or attitudes. Thus, the assessments tend to favor broader behavioral categories and more holistic approaches. The existing instruments that do address KSAs are primarily focused on skills, but see Mendo-Lázaro *et al.* (2017) for an example of an instrument focused on attitudes towards teamwork. As such, there is a particular lack of explicit and robust means for assessing knowledge of, or attitudes towards, teamwork in the context of educational settings, although such assessments are available in neighboring fields of professional training (e.g., healthcare; Morbitzer *et al.*, 2021). Finally, only limited consideration has been given to how to use assessment of teamwork once completed; O'Neill *et al.* (2018) advocate for a discussion of the results with each team and associated action plan.

WHAT ARE THE PRIORITIES FOR IMPROVING THE TEACHING OF TEAMWORK IN STEM?

We identified potential transportable knowledge, skills, and attitude competencies necessary to engage in successful teamwork that could serve to define learning outcomes for teaching teamwork to undergraduate students in STEM disciplines. Notably absent is the idea that students must explicitly be taught why teamwork is important. We also find that the KSAs necessary to carry out teamwork with teammates from diverse identities are rarely discussed. Nevertheless, a number of different pedagogical approaches, ranging from more passive to active forms of learning, have been proposed for teaching these teamwork competencies. Not all of the approaches that we identified have been rigorously implemented and assessed. To advance our ability to teach teamwork to undergraduate students in STEM, we identify the following five priorities:

An understanding of whether teamwork in STEM differs from other disciplines

To further develop our ability to teach teamwork to students in the life sciences or STEM, careful consideration needs to be given to whether or not the required KSAs differ from those in other disciplines. One aspect that may distinguish STEM is the frequent emphasis on discovery, rather than a well-defined outcome often present in some fields. For example, in healthcare, teamwork may be defined as successful if the patient survives surgery. Scientific research, on the other hand, often focuses on generating knowledge more than predefined task completion; teamwork may succeed by following a robust process, regardless of the outcome. However, while this may shift the emphasis of certain KSAs for some generic and specific team tasks (*sensu* Cannon-Bowers *et al.*, 1995) in STEM, it is not immediately apparent that the dimensions of teamwork fundamentally differ and would thus necessitate a change in how teamwork is taught. We encourage further consideration of whether there are additional generic team or task competencies that should be addressed in STEM-specific curricula.

An evidence-base for teaching teamwork to college STEM students

Even if teamwork does not fundamentally differ among the life sciences, STEM, and other disciplines, there is a clear need for well-designed studies on teaching teamwork. For such efforts to be effective, the studies should: 1) compare control and experimental groups, 2) take steps to improve replication through intra- or interinstitutional collaboration, and 3) consider targeting specific interventions, rather than a series of interventions over time (McEwan *et al.*, 2017). Emphasizing these principles would address the results from a recent review of studies teaching teamwork in pharmacy, which found that study sample sizes ranged from 12 to 554 students in activities ranging from 20 min to six semesters in duration (Morbitzer *et al.*, 2021). In tandem, there is also a clear need to develop robust new quantitative and qualitative instruments for assessing efforts to teach teamwork, particularly those that focus on more generic (transportable)

KSAs. The implementation of mixed methods, or inclusion of qualitative and quantitative assessment frameworks, can provide a deeper understanding of the discourse between students, instructors, and institutional framework that allows broader generalizability and application (Johnson and Onwuegbuzie, 2004; Truscott *et al.*, 2010). All of these efforts would create significantly more value if the associated curriculum, pedagogy, and instruments were consistently made openly available so that instructors could adapt it to their own contexts.

An emphasis on STEM students' knowledge of, and attitudes towards, teamwork

Research to date on teaching teamwork to undergraduates in STEM has placed a considerable emphasis on skills associated with teamwork. The implicit assumption has been that students know why teamwork is important, what constitutes teamwork, and what skills and behaviors are necessary to do it effectively (Cannon-Bowers *et al.*, 1995), or that they will gain that knowledge simply by practicing teamwork. Large-scale surveys of undergraduate STEM students do find that they perceive teamwork skills to be very important for their professional lives, but do not necessarily ask why they perceive that to be true (Varsavsky *et al.*, 2014; Itani and Srour, 2016; Wilson *et al.*, 2018). Thus, there is almost certainly a need to improve students' foundational knowledge of why work is often carried out in teams and how teamwork and taskwork differ.

Then, when teaching teamwork skills, the reasons for teaching those skills must be made explicit. For example, a number of studies focused on the administration of teamwork in higher education have proposed assigning explicit roles (e.g., notetaker) to each student in a team, without explaining to students that team performance can be improved when teams know the different roles that individuals can assume (Mumford *et al.*, 2008) and how those roles might vary over time. Doing so would also provide the opportunity to explicitly address biases that lead to students assuming stereotyped roles based on their identity.

Similar to students' knowledge of teamwork, there is comparatively little research on affecting students' attitudes towards teamwork (Pfaff and Huddleston, 2003). In the context of higher education settings, negative attitudes towards teamwork are primarily considered in the context of the way in which coursework is structured (e.g., grading and distribution of work; Tucker and Abbasi, 2016). Regrettably, negative teamwork experiences can be a source of stress and anxiety (Hsu and Goldsmith, 2021), and influence students' attitudes towards future experiences (Ruiz Ulloa and Adams, 2004). Teaching students to have a positive attitude towards teamwork may be challenging. However, the significant relationship between attitude towards teamwork and teamwork behaviors, including mature communication, accountable interdependence, common purpose, role clarity, and clear goals described by Ruiz Ulloa and Adams (2004) suggests that teaching students the knowledge and skills that they need to carry out teamwork is an important first step.

An explicit consideration of equity and inclusion in teaching teamwork

Despite widespread recognition that more diverse teams produce more novel and impactful science (AlShebli *et al.*, 2018; Yang *et al.*, 2022), approaches to teaching teamwork rarely consider issues of equity and inclusion that arise when working with diverse identities. Teamwork in classrooms can lead to inequitable interactions and a sense of exclusion among students of different identities (Eddy *et al.*, 2015; Cooper and Brownell, 2016; Hirshfield, 2018); in turn, there is evidence that this results in differences in learning outcomes among students (Meadows and Sekaquaptewa, 2013; Theobald *et al.*, 2017).

There have been several interventions proposed to encourage equitable participation and a sense of belonging among students in teams, but they are almost exclusively focused on teamwork administration, rather than teamwork training. For example, administration techniques include deliberate consideration of team composition (e.g., allowing students to choose teammates who make them feel comfortable compared with the instructor assigning teammates; Theobald *et al.*, 2017) with the subsequent assignment of team roles (e.g., to avoid women serving solely as notetakers; DeCosta *et al.*, 2020), and the ultimate consideration of equity and inclusion in teamwork rubrics used for assessments (e.g., "facilitating the contributions of others"; AAC&U, 2023). These approaches build infrastructure that supports equity and inclusion, but do not necessarily teach students how to foster positive interdependence that promotes future equitable collaboration outside of the classroom.

There is some evidence that even brief interventions teaching students to recognize implicit or explicit behaviors that affect equity and inclusion can be successful. For example, Lewis *et al.* (2019) demonstrate that showing students brief video scenarios illustrating students who are verbally dominating team discussions compared with students who are participating equitably in discussion can improve gender gaps in team participation. Isaac *et al.* (2023) demonstrate that activities focused on implicit bias training increased both students' ability to identify biases and their willingness to use tools to address discriminatory comments. While these approaches are promising, significant work on teaching equitable and inclusive teamwork remains to be done. Moving forward, all research on teaching and assessing teamwork should explicitly consider equity and inclusion.

An effort to empower instructors with curriculum and pedagogy to teach teamwork

Previous research has noted that curriculum design considerations with respect to teaching teamwork have rarely been addressed in the literature (Riebe *et al.*, 2016). Designing curriculum that teaches teamwork requires considerable effort, where the primary intention of teamwork may be to make a course more manageable (e.g., by reducing grading) or may be to engage teamwork as a pedagogical approach to improve learning outcomes associated with course content. Loughry *et al.*, (2014) lay out sample learning goals using tools built around the CATME assessment that include knowledge (e.g., "students will understand the factors necessary to work in teams") and skills (e.g., "students will demonstrate improvement in team-based skills over time") that may be desirable. Ettington and Camp (2002) and Riebe *et al.*, (2010) also introduce basic curricula. Davis and Ulseth (2013) provide a curriculum spanning a 4-y undergraduate engineering program. Efforts to provide extensible curricula must match common

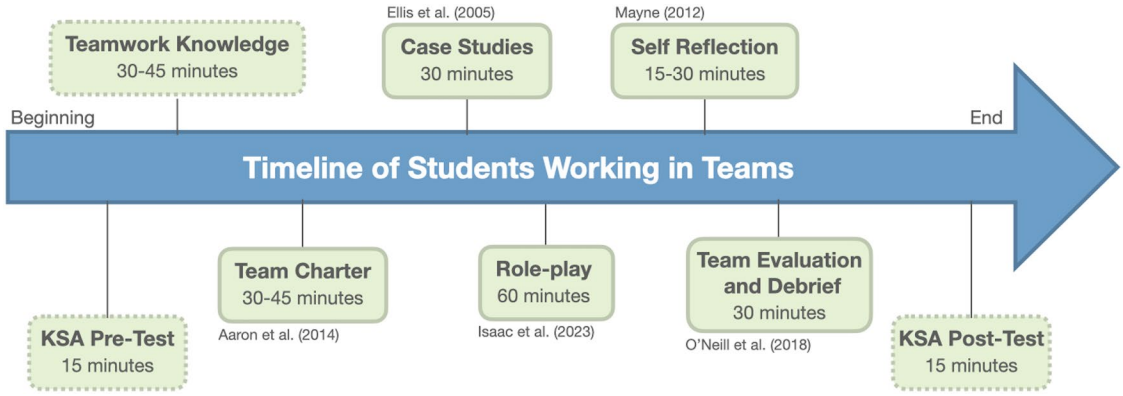

FIGURE 3. A generalized timeline for teaching teamwork in a PBL or CURE STEM classroom that engages students in small teams over the course of an entire semester. Activities that we identify as important, but for which we were unable to identify a robust approach in the literature, are indicated with dashed boxes. The total estimated amount of in-class time for the proposed activities is ~4 h.

approaches to teaching in STEM (e.g., longer independent projects, project-based learning [PBL], or course-based undergraduate research experiences [CUREs] carried out in teams), must consider the total amount of time that an instructor will be willing to allocate to teaching teamwork in comparison to other intended learning outcomes, and should be carried out in the context of a broader teamwork curriculum map that creates breadth and depth over time (Figure 3).

If we ultimately build generalized curricula, then we must empower instructors to use it effectively. Much as simply doing teamwork will not necessarily lead to better teamwork KSAs among students, simply providing instructors teamwork curriculum and pedagogy alone is insufficient (Burbach *et al.*, 2010). We need to teach instructors about teamwork.

CONCLUSIONS

There is an exceptionally large body of literature addressing teamwork from different educational and professional settings across a number of different fields. Moreover, teamwork engages a number of different complex competencies and processes that are often described using different terminology depending on the discipline from which the research originates. However, when one focuses on interventions designed, implemented, and assessed in the context of higher education, the research is considerably more limited and focused more on the administration of teamwork than the pedagogy of teamwork. These complications create a significant barrier for STEM instructors who are almost exclusively trained to teach in their discipline, rather than trained to teach professional skills. By providing insights into the competencies necessary for teamwork, the pedagogies that have been used to teach teamwork, and the instruments available to assess it, we can begin to understand the challenges and the priorities that are needed to teach our students how to work together successfully.

ACKNOWLEDGMENTS

This work was supported by postdoctoral fellowships to M.L.A., H.C.A., K.D., D.L.G., and M.S. from the Grand Challenges Initiative at Chapman University. The authors thank the reviewers for constructive feedback.

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