Team Effectiveness Theory from Industrial and Organizational Psychology Applied to Engineering Student Project Teams: A Research Review

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Abstract

Background Engineering student team projects are frequently used to meet professional learning outcomes. Industrial and organizational psychologists study teams in the industry settings for which we prepare students, yet this research does not effectively inform engineering education.

Purpose This research review sought to demonstrate the relevance of literature on teams literature from industrial and organizational psychology to engineering education and to identify implications for practice and future directions for research.

Scope/Method Phase 1 systematically reviewed 104 articles published from 2007 to 2012 describing engineering and computer science student team projects and sought to answer the following questions: What professional learning outcomes have been met by team projects? What negative student team behaviors have faculty sought to minimize? What literature has been used to inform development of teamwork outcomes? Phase 2 reviewed five team effectiveness constructs selected according to the results of Phase 1: social loafing, interdependence, conflict, trust, and shared mental models. Examples from Phase 1 articles and our own work explain how this research informs facilitation and assessment of engineering student teams.

Conclusions Engineering faculty sought to achieve a variety of outcomes through team projects, including teamwork, communication, sustainability, and consideration of global/societal design context. They sought to avoid social loafing and conflict while building trust to ensure equal team effort. That few Phase 1 articles engaged the literature about team effectiveness indicates there is great opportunity to apply industrial and organizational psychology research to engineering education.

Keywords psychology; systematic review; team

Introduction

Teamwork is the predominant mode of engineering professional practice, and engineering educators are increasingly emphasizing team learning outcomes and experiences for their students (ABET, 2012; International Engineering Alliance, 1989; Patil & Codner, 2007).

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Team projects are now fairly common in first-year and capstone undergraduate engineering courses (Froyd, 2005). Despite the clear emphasis on teamwork in engineering and the increasing use of student team projects, our understanding of how best to cultivate and assess these learning outcomes in engineering students is sorely underdeveloped (McGourty et al., 2002; Shuman, Besterfield-Sacre, & McGourty, 2005), particularly considering the deep knowledge of team effectiveness that has been accumulated in psychology and related fields.

This research review sought to better understand the negative student team behaviors engineering educators face in facilitating engineering student team projects and find ways to minimize these behaviors in the team effectiveness literature from industrial and organizational (I/O) psychology. The research was conducted in two phases. First, we performed a systematic review of recent literature on engineering student team projects. We used the results of this initial phase to guide selection of constructs from I/O psychology to guide research, assessment, and facilitation of engineering student teams. Phase 1 sought to answer these questions:

1. What professional learning outcomes have engineering and computer science educators sought to develop in engineering and computer science students through team projects?

2. What negative student team behaviors have engineering and computer science faculty sought to minimize?

3. What literature has been used to inform development of teamwork and related professional learning outcomes in engineering and computer science students?

Computer science was included in this analysis in part because the insights computing education offers outweigh the effort it would take to distinguish software engineering teams by whether their members were computer engineering or computer science majors. Many of these software development student team studies apply global and virtual teams literature in ways that can inform initiatives in other branches of engineering. This systematic review identified 104 journal articles published between January 2007 and June 2012 that described team projects conducted by engineering and computer science undergraduate and graduate students. These projects sought to meet a wide range of professional learning outcomes, such as those associated with teamwork, communication, lifelong learning, ethics, sustainability, and consideration of global and social context. The articles had reasonably good citations to student learning literature, including problem based learning (PBL), active and collaborative learning, and learning styles literature. However, while engineering educators identified a number of negative student team behaviors that could be minimized by recommendations from the I/O psychology literature, this literature was generally not used to inform the design of engineering team project experiences.

The most prominent negative student team behavior the articles identified was social loafing, a behavior in which some team members do not contribute their fair share to the project. Some articles additionally described conflict and how it arose from both social loafing and lack of trust. Collectively, the articles indicated that engineering and computer science faculty members wanted student projects to proceed smoothly and efficiently, with students managing their time and working together well, and each contributing their fair share of effort. In the I/O psychology literature, this concept is referred to as team effectiveness, which focuses on factors that influence a wide variety of team outcomes.

In the second half of this article, we describe I/O psychology theory of particular relevance to engineering education, given the emphases of the Phase 1 articles. First, we give an overview of how team effectiveness research is conceptualized. Then, we review five constructs selected according the results of the Phase 1 systematic review and existing team effectiveness models: social loafing, interdependence, conflict, trust, and shared mental models. For each, we define the construct and discuss its predictions and implications for facilitating engineering student teams. Then we use illustrations from Phase 1 articles and our own published and unpublished work to clarify how the constructs impact student team success.

Our contribution lies not only in summarizing recent practice in facilitating engineering student project teams but also in developing midrange theories of team effectiveness specific to engineering education settings. Many of the I/O psychology articles we cite describe general theories intended to be relevant to all types of teams. More specific theories have been developed for particular settings, including industrial, military and medical teams. Throughout this article, we describe our rationale for the relevance of these constructs and how specific relationships are likely to translate to educational settings. By giving specific pedagogical recommendations arising from I/O psychology literature, we bridge the gap between general theories of team effectiveness and specific studies in engineering education settings. In other words, we are beginning to develop a midrange theory of engineering student project team effectiveness (Pinder & Moore, 1979; Weingart & Cronin, 2009).

While it is clear that I/O psychology theory can inform engineering education, engineering education research can also help advance the study of project teams in a number of ways. Engineering education research is open to a range of qualitative and mixed methods that can complement the existing base of quantitative studies. Long-term studies can augment understanding of when particular team processes are most critical to overall team effectiveness. Engineering education research is often conducted in complex, authentic settings that may help identify relationships among variables and across individual, team, and organizational levels. New outcomes and contexts including innovation, creativity, and global and virtual teams are important new directions for both team research in general and engineering education specifically. These possibilities are explored in more detail in the Discussion section of this article.

In the sections that follow, we describe the methods and results of the Phase 1 systematic review. We then transition to an overview of team effectiveness research and descriptions of the five constructs. The article concludes with implications for practice and directions for future research.

Methods

Our methods followed accepted procedures for systematic reviews (Gough, Oliver, & Thomas, 2012; Petticrew & Roberts, 2006) and content analysis (Krippendorff, 2004). The goal of the first phase was to identify and characterize a representative set of recent articles describing team projects completed by engineering and computer science undergraduate or graduate students. We used EBSCO Host to simultaneously search four journal article databases: Education Research Complete, Academic Search Complete, Psychology and Behavioral Sciences, and Business Source Complete. As the names imply, these databases provide coverage of the primary journals in engineering and science education, psychology, management, and business, along with other fields.

Using the search terms *engineering*, *teams*, and *students* in any field, we searched for articles published in peer-reviewed journals between January 2007 and June 2012. We selected a 5.5-year period to focus on the most recent work about engineering student teams. These search parameters identified 713 unique results. To refine the search by identifying articles that could help answer the research questions, we examined the titles, abstracts, and full texts of each article as necessary to determine whether it met the following selection criteria (Petticrew & Roberts, 2006):

Studied engineering or computer science graduate or undergraduate students This criterion excluded teams in K–12 and practicing engineers.

Studied teams working on a specific project We followed Chiocchio and Essiembre's definition of project teams as "groups that perform a defined, specialized task within a definite time period, and whose members are generally cross-functional and disband after project termination" (Chiocchio & Essiembre, 2009, p. 392). This criterion excluded laboratories, peer-led team learning, paired programming in computing, and several studies of collaborative or cooperative learning outside project settings. The criterion also excluded general surveys of attitudes about teamwork, experimental studies comparing individual and team performance, and a small number of articles describing entire degree programs that were evaluated too broadly to draw conclusions about specific interventions.

Had at least a practical goal of developing professional learning outcomes in students In the engineering education literature, professional learning outcomes are not defined explicitly; they are only enumerated and contrasted with technical learning outcomes. We followed Shuman et al.'s (2005) categorization of ABET criteria which lists the professional learning outcomes as those related to multidisciplinary teamwork; ethics; communication; global, economic, environmental, and societal context; lifelong learning; and contemporary issues. Our analysis did not reveal additional non-technical learning outcomes that were unrelated to these (e.g., sustainability is a special case of environmental and societal context). Although design is considered a technical skill, we chose to include it in the initial criteria given its close relationship to team projects and global, economic, environmental, and societal context.

Evaluated with some effectiveness data from students, broadly defined This criterion excluded editorials, news items, and articles relying on faculty reflections if they included no data from students. A small number of articles focusing on how to assess team learning outcomes (for example by describing development of an instrument to assess a specific team skill) were included for their obvious relevance to answering the research questions.

We chose not to limit the country of origin of studies to reflect the international profile of engineering education research, including its journals and conferences. Criteria emphasizing projects and professional learning outcomes allowed us to focus on the types of teams most likely to be studied and informed by I/O psychology literature. This is not to say that other types of collaborative learning are not important. As our results revealed, though, the authors of the selected articles are reasonably familiar with the cognitive psychology and learning sciences literature underlying these pedagogies and are likely to apply the literature to all types of team activities. The greater need, and thus the focus of this analysis, is research on the processes and effectiveness of project teams.

Application of these criteria resulted in a final set of 104 qualifying articles, which were managed using an EndNote database. On the basis of the full text, we wrote brief summaries for each article that characterized the goals or outcomes for students, the literature cited, the intervention, the evidence to determine whether goals or outcomes had been met, and the conclusion regarding learning or team effectiveness. These summaries were used to create categories for content analysis in response to the research questions (Krippendorff, 2004). As necessary, the full text of the articles was consulted frequently to categorize the articles and write the results sections describing various aspects of the articles.

Phase 2 was a narrative review (Petticrew & Roberts, 2006) of the I/O psychology literature on five constructs that influence team effectiveness. The constructs were selected by considering the literature and negative student team behaviors identified in the Phase 1 articles and existing reviews of the team effectiveness literature (Kozlowski & Ilgen, 2006; Mathieu, Maynard, Rapp, & Gilson, 2008). We used EBSCO Host to search Psychology and Behavioral Sciences and Business Source Complete to identify review articles and recent studies. Finally, because these sources did not clearly describe how the constructs would be applied in an engineering class, we wrote descriptions of how we have applied them in our own research and teaching. Again, the primary contribution of this phase is beginning to build midrange theory bridging specific engineering education team projects with general theories of team effectiveness.

Methodological Validity: Connoisseurship Model

This study considers the "enacted curriculum" (Flinders & Eisner, 1994) through the voices of the literature and students as well as of the researchers (Oliva, 2000). As well, this study uses the educational connoisseurship model of Eisner (1998), in the same spirit as adaptations of the model in other studies. Briefly, the connoisseurship model has four overlapping dimensions (Flinders & Eisner, 1994):

Descriptive inquiry is the process of understanding one's topic through multiple forms of representation; in this study the articles in Phase 1 consider a broad range of types of professional learning outcomes as well as ways in which they are developed.

Interpretive inquiry is the process of making sense of the context described in the descriptive dimension. In this research review, the interpretive process is demonstrated through the analysis of Phase 1 results and development of the Phase 2 narrative review.

Normative inquiry recognizes that the values of the researcher influence the choice of questions asked. The description of the methods used (see Methods section above) and understanding of the limitations (see Limitations section below) also give the reader a window into the authors' effort to consider both the achievements and shortcomings of the field.

Thematic inquiry is the process of making the research useful by searching for and describing the recurring lessons learned regardless of the context of any given case. The process of using Phase 1 results to select Phase 2 constructs and the pedagogical recommendations summarized in the Discussion ensure the usefulness of this research.

Eisner (1998) completes his model with three tests of validity; these validity tests map to the qualitative legitimation model (Onwuegbuzie & Leech, 2006). Thus one mechanism we used for assuring rigor in this study is Eisner's three criteria (1998):

Structural corroboration is the demonstration that "multiple types of data are related to each other to support or contradict the interpretation and evaluation" (Eisner, 1998, p. 110). We accomplished structural corroboration in Phase 1 through the categorization and interpretation process seen in Tables 1 through 6 and in Phase 2 by using both undergraduate and graduate student data to triangulate the Phase 1 results.

Referential adequacy is the educational function of a study that allows readers to discover aspects of meaning that would otherwise remain hidden and that provides a guide for readers in their future work within the context considered. We show referential adequacy through the summary of constructs and illustrated definitions in Phase 2 as well as the discussion of implications for team-based instructional methods.

Consensual validity is established through the process of putting one's work in front of others knowledgeable in the area for review. We met consensual validity formatively through feedback from others during the writing stage as well as summatively through the peer-review process.

Additional validation procedures were conducted to understand the possible impact of the 5.5-year range on the final results. To consider a set of older articles, Web of Knowledge was used to search Science Citation Index and Social Science Citation Index for highly cited articles published from January 2000 (the year that ABET teamwork and related professional learning outcomes were adopted) through December 2006 (the cutoff for the current study). Searching the same terms (*engineering*, *teams*, and *students*), we identified 39 articles cited 10 or more times as of March 2013. On the basis of the abstracts, we identified 18 of these as potentially meeting the inclusion criteria, and on the basis of the full text, we determined that 13 met the inclusion criteria. Most of these articles were similar to those identified in the more recent sample in terms of journals represented (*International Journal of Engineering Education, IEEE Transactions on Education*, and *Journal of Engineering Education*), types of student teams (design projects, global and virtual software development, and service learning), and learning theories cited (Myers-Briggs Type Indicator and collaborative learning), as described further in Phase 1 Results. These articles generally did not cite team effectiveness literature, with two exceptions. First, Tonso (2006) integrated team effectiveness literature into the literature review for her ethnographic study of gender dynamics in student design teams. Second, these procedures identified an early use of the Team Effectiveness Questionnaire by the group that developed it (Varvell, Adams, Pridie, & Ruiz Ulloa, 2004), which was already well represented in the core dataset.

Limitations

There are several limitations to our approach. First, examining only five years of publications potentially excludes important prior work from the sample. However, we ran additional analyses to understand this limitation and concluded that five years adequately describes how team effectiveness literature has been applied in engineering education. Therefore, focusing on five years of recent publications is appropriate to answer questions focused on current interest and practice in engineering student team projects and the literature being cited. We note that the data reached saturation in the sense that the last several articles to be summarized and coded followed the pattern established earlier in the coding process, and few articles cited the literature of interest. Second, the authors of these articles made decisions, sometimes based on length constraints, about what to include and exclude; for example, individual publications may choose to describe just one aspect of a project. Some arguments and values were implicit, and we tried not to extrapolate in our interpretation. It was not always clear what the goals of a specific intervention or study were, and often the assessment instruments were not aligned to the stated goals.

Table 1 Summary Characteristics of Qualifying Articles

Journals (with 2 or more articles)	Countries (all)	Author affiliations (all listed in dataset)
International Journal of Engineering Education (31, high due to Mudd Design Conference special issues)	United States (approx. 45)	Engineering
European Journal of Engineering Education (8)	Australia (10)	Civil
Journal of Professional Issues in Engineering Education & Practice (7)	United Kingdom (9)	Mechanical
Journal of Engineering Education (4)	Spain (6)	Industrial
Advances in Engineering Education (4)	Turkey (6)	Electrical and computer
Journal of Mechanical Design (3)	Germany (4)	Engineering education
Australasian Journal of Engineering Education (2)	Panama (3)	Environmental
IEEE Transactions on Education (2)	South Africa (3)	Mining
Journal of STEM Education(2)	Denmark (2)	Systems
CoDesign (2)	Hong Kong (2)	Aeronautics and astronautics
Computers & Education (2)	Belgium (1)	Chemical
Computers in Human Behavior (2)	Botswana (1)	Petroleum
Issues in Informing Science & Information Technology (2)	Canada (1)	Materials science
	Colombia (1)	Agricultural
	Finland (1)	Biological
	France (1)	Architectural
	Mexico (1)	First-year
	Netherlands (1)	Manufacturing and design
	New Zealand (1)	Computer science
	Portugal (1)	Information technology
	Qatar (1)	Construction management
	Serbia (1)	Education
	Sweden (1)	Learning design
	Taiwan (1)	Educational psychology
	Trinidad and Tobago (1)	Educational leadership
	United Arab Emirates (1)	Technical communication
		English
		Writing
		Communication
		Psychology
		Industrial psychology
		Business
		Management
		Statistics
		Political science
		Agricultural leadership, education, and communication
		Engineering industry firms

Phase 1 Results

Before describing the industrial and organizational psychology literature and its relevance to engineering student project teams, we present the results of the Phase 1 systematic review of engineering education articles to understand the professional learning outcomes engineering educators sought to develop, the negative student team behaviors encountered, and the literature cited vis-à-vis facilitating student project teams.

As listed in Table 1, the 104 articles were published in 45 journals by authors from 27 countries. Authors had affiliations in nearly all branches of engineering, computer science, and a number of other disciplines that support development of professional learning outcomes. Nineteen articles described team projects in courses labeled as “capstone” by the authors, and 15 described team projects in first-year engineering courses. Many others were either not specified in terms of their location in a curriculum sequence or argued for a more general intervention with relevance across engineering education settings. The most frequently described interventions were in software engineering courses (taught frequently as distributed or online teams), sustainability projects taught in civil and environmental engineering and construction management (sometimes also as service learning and international projects), and design courses (most often taught by mechanical engineering faculty).

What professional learning outcomes have engineering educators sought to develop in engineering students through team projects? One way to characterize recent use of team projects in engineering education is in terms of the professional learning outcomes they were intended to develop. This characterization facilitates the Phase 2 mapping of I/O psychology outcomes (e.g., productivity and profit) to educational settings.

As listed in Table 2, the articles identified several professional learning outcomes, which align with those identified by ABET. The most commonly cited were teamwork and design, which were frequently cited together in the same article along with communication. Figure 1 represents these relationships. Only 18 of the articles did not list any of these three as outcomes. Fifteen articles were motivated by implicit goals; eight of these listed no explicit goals for students but cited industry needs or practices as their motivation. In other words, it is taken for granted in engineering education that team projects are valuable because they will prepare engineering students to work in industry.

Because so many articles cited teamwork outcomes ($n = 72$), we further analyzed and classified these into more specific categories, many based on the type of team or mode of interaction. The results are presented in Table 3. Although cultural competence, societal context, and distributed teams may seem closely interrelated, these 72 articles describing teamwork outcomes tended to use only one type of framing and related literature. Distributed teams articles were primarily published by computing instructors, while sustainability and societal context articles were primarily written by civil and environmental engineering faculty and directly discussed ABET outcomes. Cultural competence articles were more diverse; some of these articles had authors who primarily identified with engineering education. These results suggest that there may be multiple groups of engineering educators working in parallel toward similar goals who may not be aware of each other’s work. The results also suggest different keywords that might be searched and literatures that might be cited to better integrate these related topics within the engineering education teams literature.

What negative student team behaviors have engineering and computer science faculty sought to minimize? Teamwork, leadership, project management, and others listed in Tables 2 and 3 are positive outcomes of team projects that several authors sought to cultivate in their students. Some articles framed the outcomes as ways to prevent negative student team behaviors, many of which can be counteracted using the I/O psychology literature summarized in Phase 2.

The most prominent negative student team behavior described in these articles was the issue of “free-riders,” or team members who do not contribute their fair share to the project. For example, Gransberg (2010) explains, “This paper addresses the issue of furnishing a mechanism for rewarding students who actively participate in construction team projects, while disciplining those who fail to meet their team-assigned responsibilities” (p. 3). This specific issue was described in five articles (Burd, Hatch, Ashurst, & Jessop, 2009; Chen & Chong, 2011;

Table 2 Learning Outcomes Identified in Phase 1 Articles

Outcome or goal	No. of articles	Example citations
Teamwork	72	Cerato, Elton, and Shannon (2012); P. D. Johnson, Johnson, and Shaney (2008); Oladiran, Uziak, Eisenberg, and Scheffer (2011)
Design	37	Al-Rizzo et al. (2010); Booker (2011); Gruenther, Bailey, Wilson, Plucker, and Hashmi (2009)
Communication skills	30	Borg and Zitomer (2008); Chao and Brown (2009); Tubaishat (2009)
Innovation and creativity	11	Elizalde et al. (2008); Linsey and Viswanathan (2010); Oehlberg, Leighton, Agogino, and Hartmann (2012)
Implicit: learning experiences similar to industry	8	Dahm, Newell, Newell, and Harvey (2009); Luque Ruiz and Gómez-Nieto (2012); Soares, Jacobs, Brunier, Chapellier, and Dejean (2012)
Life-long learning or self-directed learning	7	Brodie (2011); Cinar and Bilgin (2011); Krishnan, Gabb, and Vale (2011)
Research studies to understand teams, no learning outcomes	5	Dinsmore, Alexander, and Loughlin (2008); D. Johnson and Gardner (2007); Leicht, Hunter, Saluja, and Messner (2010)
Ethics	4	Brodie (2009); Chau (2007); Mehalik, Lovell, and Shuman (2008)
Efficacy, motivation and/or retention in engineering[a]	4	Goff et al. (2010); McIntyre (2011); Purzer (2011); Schaffer, Xiaojun, Xiumei, and Oakes (2012)

[a]These articles were included in the analysis because they also addressed professional skills, e.g. teamwork.

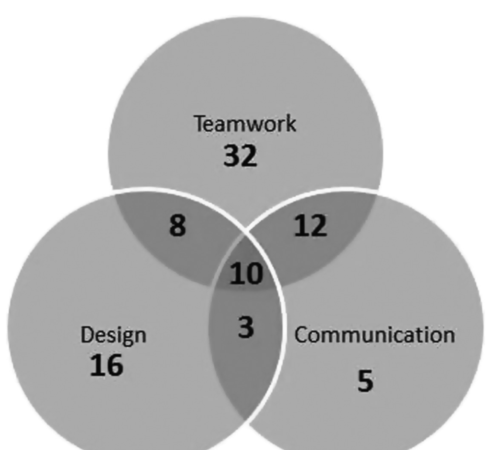

Figure 1 Number of articles describing teamwork, design, and communication learning outcomes.

Table 3 In-depth Analysis of Teamwork and Related Outcomes

Outcome or goal	No. of articles	Example citations
Global/cultural competence (clients or team members in other countries)	14	Mohtar and Dare (2012); Serçe, Swigger, Alpaslan, Brazile, Dafoulas, and Lopez (2011); Swigger, Hoyt, Serçe, Lopez, and Alpaslan (2012)
Project management	11	Eggermont, Brennan, and Freiheit (2010); Geske (2009); Schroeder (2008); Yakhno and Ekin (2011)
Interdisciplinary teamwork	10	McNair, Paretti, and Kakar (2008); Oden, O'Malley, Woods, Kraft, and Burke (2012); Oehlberg et al. (2012)
Context/constraints: sustainability, societal, with no global or cultural aspects (international projects labeled service learning or sustainability by authors)	8	Bhandari, Ong, and Steward (2011); Cardella, Hoffmann, Ohland, and Pawley (2010); Reid and Estell (2011)
Distributed teamwork, no global or cultural aspects	7	Marquez, Martinez, Romero, and Perez (2011); Paretti, Richter, and McNair (2010); A. Wodehouse, Eris, Grierson, and Mabogunje (2007)
Leadership	7	Gnanapragasam (2008); Ramirez Cajiao, Carvajal Diaz, and Hernandez Penaloza (2010); Ras, Carbon, Decker, and Rech (2007)
Time management	2	Gary (2008); Keefe, Glancey, and Cloud (2007)

Gransberg, 2010), but only two (Pieterse & Thompson, 2010; M. C. Yang & Yan, 2008) used the technical term from psychology: *social loafing*. Yang and Yan (2008) found that social loafing was the top concern among members of both local and distributed teams. Likewise, Pieterse and Thompson (2010) and Chen and Chong (2011) described social loafing as a cause of conflict in student teams.

In addition to social loafing specifically, conflict was also studied more broadly. Karn and Cowling (2008) explored conflict in student software engineering teams. Rebollar, Lidon, Cano, Gimeno, and Qvist (2010) developed the Teamwork Failure Prevention questionnaire to avoid conflict and other sources of team project failure. Yang and Yan (2008) and Paretti, McNair, and Holloway-Attaway (2007) described the need to build trust in distributed teams to avoid conflict.

In sum, engineering faculty want student team projects to proceed smoothly and efficiently. Their efforts are frequently directed at ensuring that students manage their time, work together well, and each contribute their fair share of effort. In the I/O psychology literature, this idea is referred to as team effectiveness. Team effectiveness research focuses on the study of factors that influence a wide variety of team outcomes. Therefore, the literature on engineering student teams is already connected to several effectiveness factors, including social loafing, conflict, and trust, which are promising directions for future engagement with the I/O psychology literature. These constructs are described in more detail in the second half of this article.

What literature has been used to inform development of teamwork and related professional learning outcomes in engineering students? With a few exceptions, the articles analyzed did not engage deeply with the literature or relevant theories. That is, the literature was used to draw attention to the importance of the topic, but in many cases it was not used to directly inform the assessment instruments, and in others, it was unclear whether it was being used to directly inform the interventions themselves.

Four notable exceptions were articles closely aligned with the relevant literature describing tools for assessment (Davis et al., 2010; Schaffer, Xiaojun, Xiumei, & Oakes, 2012), assigning students to teams (Layton, Loughry, Ohland, & Ricco, 2010), or diagnosing potential team dysfunctions (Rebollar et al. 2010).

Another notable example of using the literature is how three articles used self-managed work teams literature from I/O psychology to further describe teamwork in industry and associated learning outcomes, for example, as do Luechtefeld, Baca, and Watkins (2008):

> A self-managed team is one that is empowered to determine structure, processes, assessments and corrections as it performs assigned tasks (Hackman, 1987). Such a team is highly autonomous. The guidance functions that are provided by management in more hierarchical organizations are performed by the team itself. (p. 1139)

Their intervention was designed using self-managed work teams and other related literature. Zafft, Adams, and Matkin (2009) used self-managed work teams literature to justify their use of shared leadership models and roles. McNair, Newswander, Boden, and Borrego (2011) used self-managed work teams literature as the context for their discussion of identity development in ill-structured interdisciplinary project teams. Each of these author teams explained that rather than have instructors assign a leader to a team, it was more appropriate for them to focus on using facilitation pedagogies that help students develop skills for thriving in the face of complexity. These are three notable examples of how the engineering education community with its strong value of preparing students for industry work has applied the I/O psychology literature to advance engineering education thinking about what it means to be an effective team member.

Even if it was not always clear exactly how the literature was informing instructors' design of team project assignments, the other articles in this dataset demonstrated reasonably good citation of student learning perspectives and theories. Table 4 summarizes how learning, pedagogy, and other literatures were cited in the articles in this dataset. Since the focus of this review is on team effectiveness literature from I/O psychology, these particular findings will not be discussed further. Rather, we sharpen our focus on team effectiveness.

In an attempt to improve team effectiveness, some topics from psychology literature were used in these articles to assign students to teams or help them understand team dynamics, including the Myers-Briggs Type Indicator (Douglas-Mankin, 2008; Knobbs & Grayson, 2012; Williams, He, Elger, & Schumacher, 2007) and learning styles (Bermejo, Sanchez, Gutierrez, & Perez, 2011; Dahm, Newell, Newell, & Harvey, 2009; Dahm, Riddell, Constans, Courtney, Harvey, & von Lockette, 2009; Fiegel & Denatale, 2011; Lau, Beckman, & Agogino, 2012). Four articles proposed other alternatives to assigning teams (Borges, Dias, & Cunha, 2009; Gunderson & Moore, 2008; Layton et al., 2010; Sahin, 2011). Two others used Tuckman's stages of team development (forming, norming, storming, performing) as a starting point in developing their own ideas and interventions (Minocha & Thomas, 2007; Sahin, 2011). As can be seen, most of these interventions focus on only the inputs to teams, rather than team processes and development of transferable skills that students can apply to future team projects. This emphasis is certainly the case in strategies for assigning teams. Other approaches to using psychology literature to inform team projects (e.g., Tuckman's stages) may help students anticipate conflict but do not give them the skills to negotiate with each other and manage conflict.

Table 4 Citation of Educational Literature in Teams Articles

Literature	No. of articles	Example citations
Problem-based learning	18	Ardaiz-Villanueva, Nicuesa-Chacón, Brene-Artazcoz, Sanz de Acedo Lizarraga, and Sanz de Acedo Baquedano (2011); Mitchell, Dori, and Kuldell (2011); Neal, Ho, Fimbres-Weihs, Hussain, and Cinar (2011)
Globally distributed teams	9	Di Marco, Taylor, and Alin (2010); Glier, Schmidt, Linsey, and McAdams (2011); Serçe, Swigger, Alpaslan, Brazile, Dafoulas, and Lopez-Cabrera (2011); Walthall et al. (2011)
Active learning	7	Dederichs, Karlshoj, and Hertz (2011); Elizalde et al. (2008); Layton, Loughry, Ohland, and Ricco (2010)
Distributed teams	6	Bermejo, Sanchez, Gutierrez, and Perez (2011); Minocha and Thomas (2007); Paretti et al. (2010)
Learning styles	6	Bermejo et al. (2011); Fiegel and Denatale (2011); Lau, Beckman, and Agogino (2012)
Kolb's experiential learning cycles and associated learning styles	5	Hey, Van Pelt, Agogino, and Beckman (2007); Linsey and Viswanathan (2010); Steiner, Kanai, Cheng, Alben, and Gerhardt (2011)
Collaborative learning	3	Gunderson and Moore (2008); Korkmaz (2012); Schäfer and Richards (2007)
Constructivist perspective on learning	3	Daniels, Cajander, Pears, and Clear (2010); Gibbings and Brodie (2008); A. J. Wodehouse et al. (2010)
Cooperative learning	3	Borges, Dias, and Cunha (2009); Knobbs and Grayson (2012); Luque Ruiz and Gómez-Nieto (2012)
eLearning	3	Brodie (2009); Brodie and Porter (2008); R. A. Ellis, Goodyear, Calvo, and Prosser (2008)
Interdisciplinary learning and interdisciplinary teams	3	McNair, Newswander, Boden, and Borrego (2011); Paretti et al. (2010); Tafa, Rakocevic, Mihailovic, and Milutinovic (2011)
Myers-Briggs Type Indicator (MBTI)	3	Douglas-Mankin (2008); Knobbs and Grayson (2012); Williams, He, Elger, and Schumacher (2007)
Technical communication	3	Dahm et al. (2009); Fredrick (2008); Paretti, McNair, and Holloway-Attaway (2007)
Research methods for collecting data from student teams	3	Chen and Chong (2011); Leicht et al. (2010); Purzer (2011)
Communities of practice and apprenticeship	2	Chen and Chong (2011); Manuel, McKenna, and Olson (2008)
Efficacy	2	Purzer (2011); Schaffer et al. (2012)
Learning sciences	2	Ge, Huang, and Dong (2010); Svihla (2010)
Reflection and metacognition	2	Dahm et al. (2009); Hirsch and McKenna (2008)

These uses of the psychology literature are a good starting point for educators to help students understand and anticipate the challenges of teamwork. Yet the I/O psychology literature on team effectiveness is much richer, more directly relevant, and suggestive of more productive interventions for engineering student teams. A small number of Phase 1 articles did utilize this literature, and they are cited in the appropriate sections below.

Team Effectiveness Literature

As mentioned above, team effectiveness focuses on factors that influence various team outcomes. The I/O psychology literature contains cross-sectional studies and laboratory experiments that involve a large number of teams to achieve statistical robustness (Austin, Scherbaum, & Mahlman, 2008; Berdahl & Henry, 2005). These studies have attempted to isolate a single factor or small set of factors (while controlling for others) to ask, "Does X matter in team effectiveness?" where X may be, for example, trust, information sharing, or a specific training intervention. This approach is influenced by McGrath's (1964) input-process-output (IPO) model (Figure 2), which has long characterized the I/O psychology approach to studying teams (Wheelan, 2005). Inputs are what members bring to the group, processes are the interactions among team members, and outputs are the products created by the team (Guzzo & Shea, 1992). Synthesis methods including meta-analysis (Mullen, Driskell, & Salas, 1998) have helped to develop an understanding of the strength and consistency of effects across many studies.

Although the IPO model remains the foundation of I/O psychology, it has been criticized for not fully capturing the dynamic, emergent, and adaptive nature of teams (Mathieu et al., 2008). As Kozlowski and Ilgen (2006) state, "teams are complex dynamic systems that exist in a context, develop as members interact over time, and evolve and adapt as situational demands unfold" (p. 78). Figure 2 compares the classic IPO model with the more recent input-mediator-outcome model. Teams research has expanded the IPO model to allow for more interactions between inputs (organizational context, team context, and team members); more feedback loops between inputs, processes, and outcomes; and greater consideration of time scales. As a result, the processes portion of the model has been expanded to include both team processes and emergent states under the collective label "mediators" (Mathieu et al., 2008). Emergent states develop over time as team members interact and can include such constructs as conflict, trust, and a common understanding of how the team's goals will be met. Research findings reinforce the idea that team processes aligned to team goals ensure team effectiveness (Kozlowski & Ilgen, 2006). This shift in emphasis also clarifies that attending to team processes may have a more significant impact on outcomes than focusing on fixed inputs, such as personality types, when assigning team members.

While many researchers dedicate their careers to understanding a particular construct and its influences, engineering educators have a tendency to combine a plethora of constructs into an overall model of team effectiveness (e.g., Sheppard, Dominick, & Aronson, 2004). Among the Phase 1 articles describing engineering student teams, four team effectiveness models were cited and used to inform interventions or assessments. References to these models and their components are listed in Table 5. Yang and Yan (2008) used Alexander's (1985) team effectiveness model and survey that was developed for teams in industry. Adams, Zafft, Molano, and Rao (2008) built on their seven-component team effectiveness model (Adams et al. 2002). Luechtefeld et al. (2008) used Hackman's (1987) model of team effectiveness along with double-loop learning and self-managed teams literature. Douglas-Mankin (2008) and Davis et al. (2010) both described the model

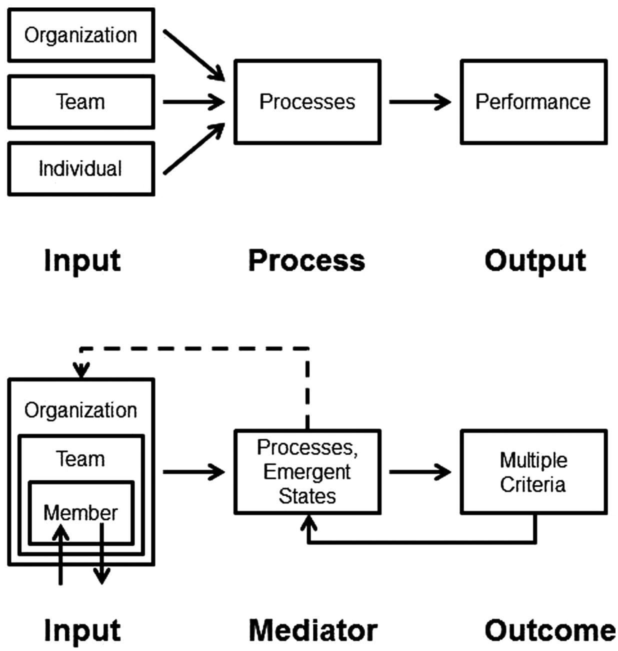

Figure 2 The classic input-output-process model has been expanded to accommodate interactions between inputs, emergent states such as trust, multiple success criteria, and feedback loops. After Mathieu et al. (2008).

underlying transferable integrated design engineering education (TIDEE) assessments (Beyerlein, Davis, Trevisan, Thompson, & Harrison, 2006). (The TIDEE project used teams literature to develop assessments of engineering student design teams. Although it is not labeled a team effectiveness model, it shares many of the same characteristics and components as these others.)

We caution that there is much more to team effectiveness, particularly measurement of these constructs, than is evident from these effectiveness models. Given the limited prior engagement of engineering education with I/O psychology literature, we have chosen to give an overview of the many potential interactions between inputs, processes, emergent states, and outcomes (Figure 2), and then to focus on a subset of specific constructs. A number of practical suggestions for facilitating and assessing teams can be extracted from this literature. Focusing on constructs and their specific pedagogical recommendations may lead to more effective change than effectiveness model, since these models necessarily sacrifice depth for breadth.

Phase 2 Review of I/O Psychology Constructs

Table 6 summarizes the five constructs discussed in the second half of this article. We used the constructs emphasized in Phase 1 articles, team effectiveness models employed in Phase 1 articles, and general reviews of team effectiveness literature (Kozlowski & Ilgen, 2006; Mathieu et al., 2008) to identify a small number of constructs of particular relevance to

Table 5 Team Effectiveness Models Used in Engineering Education Publications

Model	Components
Alexander's team effectiveness model[a] – cited by Yang and Yan (2002)	1. The team's ability to understand and agree on commonly understood goals. 2. Utilization of resources. Team member resources are recognized as well as utilized. 3. Trust and conflict. The degree of trust among team members, and ability of team to handle conflict openly. 4. Leadership. Sharing of leadership roles among team members. 5. Control and procedures. Effective procedures for team functioning that team members support and use to regulate team function. 6. Interpersonal communication. Communication between team members is open and individuals participate. 7. Problem solving/decision making. Established procedures for group problem solving. 8. Experimentation/creativity. Ability to try new or different ways of doing work as a team. 9. Evaluation. The frequency with which a team examines their own functions as a team. 10. Cohesion. The level of enjoyment of working together as a team.
Adams' team effectiveness model[b] – cited by Adams et al. (2008)	1. Common purpose 2. Clearly defined goals 3. Psychological safety 4. Role clarity 5. Mature communication 6. Productive conflict resolution 7. Accountable interdependence
Hackman's model of team effectiveness[c] – cited by Luechtefeld, Baca, and Watkins (2008)	Stage 1: Prework 1. What is the task? 2. What are the critical task demands? 3. Will the team be manager-led, self-managing, or self-designing? 4. Overall, how advantageous is it to assign the work to a team? How feasible is it? Stage 2: Creating performance conditions 5. How should the team be composed and the task structured? 6. What contextual supports and resources must be provided? Stage 3: Forming and building the team 7. How can a team be helped to get off to a good start? Stage 4: Providing on-going assistance 8. How can opportunities be provided for the team to renegotiate its design and context? 9. What process assistance can be provided to promote positive team synergy? 10. How can the team be helped to learn from its experiences?
Transferable integrated design engineering education (TIDEE) model[d] – cited by Davis et al. (2010) and Douglas-Mankin (2008)	Team relationships Inclusive climate: Building an inclusive supportive climate for all members. Member commitment: Gaining buy-in and interdependence of all members. Conflict resolution: Resolving conflicts to enhance teamwork. Joint achievements Goal establishment: Establishing shared team goals. Planning and management: Managing tasks to achieve team goals. Joint work products: Producing competent consensus outputs.

Table 5 (continued)

Model	Components
Member contributions	
Work allocation: Allocating responsibilities fairly to members.	
Performance quality: Achieving quality work from all members.	
Member growth: Facilitating team member growth.	
Team information	
Internal communication: Achieving effective in-team communication.	
Stakeholder communication: Managing other stakeholder communication.	
Knowledge assets: Building shared knowledge assets.	

[a]Alexander (1985). [b]Adams, Simon Vena, Ruiz Ulloa, & Pereira (2002). [c]Hackman (1987). [d]Beyerlein, Davis, Trevisan, Thompson, & Harrison (2006).

engineering student teams. In the sections below, we first define the construct and discuss its predictions and implications for facilitating engineering student teams. If relevant, we describe how Phase 1 articles employed the construct. We then use illustrations from our own published and unpublished research and teaching to clarify how the constructs impact student team success and learning.

Social Loafing

Social loafing was the single most frequently cited negative student team behavior in Phase 1 engineering education articles. As stated above, social loafing is the tendency of individuals to exert less effort when working collectively than when working individually. Social loafing is fundamentally a motivational issue, so it is no surprise that the motivation theories that have been applied to engineering student retention have also been adapted to social loafing. Specifically, Karau and Williams (1993) adapted the expectancy-value model and validated their collective effort model through a meta-analysis of 78 social loafing studies.[1] Although social loafing is a major concern of teaching faculty, publication of social loafing studies in psychology journals has dropped off precipitously since the 1990s.

Several factors are likely to reduce social loafing. Evaluation is one of the most significant (Price, Harrison, & Gavin, 2006). When individual contributions can be identified on the basis of information from the instructor, peers, or self reports, social loafing is likely to disappear altogether, at least in controlled laboratory experiments involving simple tasks (Karau & Williams, 1993, 1995). Peer evaluations were used in approximately 15 of the Phase 1 articles. For example, Williams et al.'s (2007) peer evaluation form included items on participation and fulfillment of roles, while Rebollar et al.'s (2010) instrument included items on team member contributions. These articles (particularly Gransberg, 2010) tended to focus on the mechanics of calculating the best peer evaluation measure; they sometimes reviewed the literature on calculating peer evaluation measures, without deeply engaging with underlying theory about why group grades or group projects are important to student learning and development.

[1]Although this meta-analysis was conducted in 1993, the collective effort model has emerged as the definitive theory for social loafing. Subsequent research has validated the model (Huguet, Charbonnier, & Monteil, 1999; Smith, Kerr, Markus, & Stasson, 2001) and begun to apply social loafing principles to virtual teams (e.g., Martins, Gilson, & Maynard, 2004), which are beyond the scope of this review.

Table 6 Summary of Constructs[a] Discussed in this Research Review

Construct	Definition	Pedagogical recommendations	Key references	Phase 1 papers
Social Loafing (avoid)	The tendency of individuals to exert less effort when working collectively than when working individually	Compelling project with inherent value Peer evaluation of individual effort Complex tasks Small teams	(Karau & Williams, 1993)	(Chen & Chong, 2011; Pieterse & Thompson, 2010; Yang & Yan, 2008)
Interdependence (promote)	The level of reliance one person, group, or organization has on others in order to complete their work	Complex projects Group processing Group grading	(Ito & Peterson, 1986; Thompson, 1967)	(S. G. Adams et al., 2008; Davis et al., 2010)
Conflict (avoid, promote conflict management)	Perceived incompatibilities or discrepant views among the parties involved in a project or team	Clear goals and values Discuss conflict as a source of creativity Time and activities for teams to develop consensus Grading that promotes collaboration Class time for team meetings Balance project workload with other student demands Training on situational awareness for effectively dealing with different levels of conflict	(Crittenden, Gardiner, & Stam, 1993; Jehn & Bendersky, 2003; Worthen, 2004)	(Chen & Chong, 2011; Karn & Cowling, 2008; Pieterse & Thompson, 2010)
Trust (promote)	Confidence in the ability of others; faith in the trustworthy intentions of others	Teambuilding, e.g., social Minimize monitoring behaviors Grading requirement to know all aspects of project	(Webber, 2008)	(L. A. Ellis & Petersen, 2011; Yang & Yan, 2008)
Shared Mental Models (promote)	Shared knowledge structures that enable a team to form accurate explanations and expectations of the task, to coordinate their actions, and to adapt their behavior	Clarity of project assignment Goal setting together in teams Group processing	(Edwards, Day, Arthur, & Bell, 2006; Kozlowski & Ilgen, 2006; Mohammed, Ferzandi, & Hamilton, 2010)	(Bierhals, Schuster, Kohler, & Badke-Schaub, 2007; Lee & Johnson, 2008)

[a]Technically, these are constructs, inputs, and emergent states (Figure 2), but we refer to them as constructs to minimize confusion.

Given real-life complexities, evaluation alone is unlikely to eliminate social loafing altogether. Also highly significant to social loafing was task valence, or the inherent value of the task to the individual (Karau & Williams, 1993); when the inherent value of the project is high for students, they are less likely to socially loaf. A number of recent changes in engineering education seek to increase task valence (with the consequence of reducing social loafing) by engaging students in community service projects with social justice underpinnings (Adams et al., 2011; Baillie & Catalano, 2009). Karau and Williams (1993) also found that social loafing was reduced in groups that typically value collective outcomes, such as women and people from East Asian cultures.

Social loafing is also reduced when team members perceive their contributions to be unique and not redundant of other students' skills or efforts (Karau & Williams, 1993, 1995). Designing team projects that require unique student contributions can be particularly difficult in first-year engineering projects, in which students have few prior experiences directly relevant to the assignment (because these projects are often intentionally designed to be accessible to all students). Social loafing may be reduced in interdisciplinary teams, to the extent that students feel accountable for representing their own disciplinary knowledge to others. In a related study, one of the few simulation-based studies designed to measure team learning as an outcome, members of teams with more distributed workloads learned more (A. P. J. Ellis et al., 2003), so projects that call for unique contributions from each team member have additional benefits beyond simply reducing social loafing. Finally, when all other factors are controlled, smaller groups tend to experience less social loafing than larger groups (Karau & Williams, 1993); however, the literature generally does not quantify small or large teams. Since social loafing was the negative student behavior most commonly mentioned in Phase 1 articles, we can conclude that typical project assignments are not sufficiently large or complex to reduce social loafing in engineering student project teams of four or more students.

Only one Phase 1 article used the social loafing literature. Pieterse and Thompson (2010) reviewed some of the relevant literature and applied it in the design and interpretation of their team project experiment. The authors assigned engineering students to teams with narrow or wide ranges of grade point averages. They found that academically unbalanced teams (i.e., with the most variation in grade point averages) were at greater risk of social loafing and other unprofessional behaviors that lead to conflict.

An example of social loafing from our own experience is a digital portfolio project in a graduate-level course (McNair & Borrego, 2010) that did not follow recommendations from the literature to minimize social loafing; the students were assigned in large groups to complete a complex and difficult task, and the tasks were not differentiated among members (who mostly had the same set of skills). This loose project organization led to frustration for the students who worked hard on the difficult task and to disengagement and loafing among others who may have felt redundant. Nonetheless, this scenario resulted in unanticipated learning outcomes (e.g., conflict management skills), and the instructors were able to identify missed opportunities for planned learning outcomes. In the next iteration, the instructors reduced team size and provided more instructional scaffolding for working with clients and working in teams, for example, so that the overall assignment was divided into smaller tasks for which individuals or small groups of students were responsible. The tasks remained challenging, but the smaller groups were able to focus on client needs. Ultimately, students from each group collaborated on an eight-author article that documented the assessment process (Kajfez et al., 2013). As described in the next section, the literature has extensively documented that conflict is normal and, at certain levels, is healthy; thus, it is better to provide students with strategies for dealing with social loafing and related conflict than to attempt to avoid it altogether.

Interdependence

Interdependence was part of the two team effectiveness models developed for engineering education (Table 5, Adams et al., 2002, and Beyerlein et al., 2006) and cited in Phase 1 articles. None of the articles described interdependence as a primary construct; nonetheless, it is an important one, closely related to the motivational issues underlying social loafing and other negative student behaviors identified in Phase 1 articles.

Interdependence (or workflow interdependence) is the level of reliance one person, group, or organization has on others in order to complete a task. This reliance could be in the form of tangible or intangible resources, materials, or organizational outputs (Daft, 2007; Thompson, 1967). In engineering education, the organizational unit of interest is typically the student team. Members of the team rely on one another to complete team assignments; resources include course content knowledge, process knowledge (e.g., technical writing or how to use a particular machine), class notes, and time. Within the student team, members may opt to structure themselves with varying levels of interdependence. Unfortunately, the default for most engineering students is not as much interdependence as instructors would hope for. In this section, we review four types of interdependence (pooled, sequential, reciprocal, and intensive) that can be used to understand and distinguish the interdependence of engineering student teams and to set goals for the type of interdependence desired.

Pooled interdependence is a form of workflow in which people or subgroups work independently, often in parallel, to achieve the organization's goal (Tesluk et al., 1997; Thompson, 1967). A typical pooled interdependence student team would divide its assignment into discrete tasks among the members, complete tasks individually, and then combine the outputs (e.g., report sections) just before the deadline. Levels of communication between the team members are low. For guidance, student teams practicing pooled interdependence tend to rely heavily on the assignment specifications provided by the instructor rather than on one another (Van de Ven, Delbecq, & Keonig, 1976). The design of the team assignment may unintentionally allow the students to each complete their own portion of the work with little or no coordination among members. Although engineering students often default to this efficient means of completing group assignments, this level of interdependence is unlikely to result in the types of experiences or coordination skills required for success in engineering industry teams.

Sequential and *reciprocal* interdependence are seen when the workflow occurs in series, the output of one person or subgroup becoming the input of the next person or subgroup (Tesluk, Mathieu, Zaccaro, & Marks, 1997). Like a moving assembly line, sequential work flows only in one direction, with no reverse dependency as in an iterative design process (Thompson, 1967). A team using this form of interdependency would have one student begin the assignment, hand the partly completed material off to the next student to add more work, and so on, until each student had added a contribution to the assignment. This mode of teamwork is sometimes referred to as "throwing it over the wall" to indicate the limited communication between team members as they hand off the assignment to one another. While feedback may sometimes flow "backwards," it is often too late to impact the team goals (Ito & Peterson, 1986). *Reciprocal* interdependence is similar in terms of its linear sequence, but with more feedback loops (Tesluk et al., 1997).

Intensive interdependence is usually what engineering instructors envision when they assign projects to student teams. Here, the outputs and resources of each team member are also among the inputs of each other team member; this process occurs in a nonlinear manner (Tesluk et al., 1997). These teams have intense coordination among the members, who make adjustments to their individual work based on the results and knowledge of the others (Daft, 2007). Feedback is much more timely and flows in all directions. For example, in a hospital, patients and information about their condition and treatment move between departments, sometimes repeatedly, such as occurs when a patient returns to the primary medical team so they can make decisions based on test results. A significant amount of planning and training occurs before patients arrive, but the team is structured for continual feedback and problem solving (Naik, 2006). In a student team, this planning is often an initial meeting to discuss logistics, communication mechanisms, and the variety of roles to be played by the team members. In addition to encouraging students to take the time up front to create these norms and roles, instructors can provide supplemental training or resources to aid students in creating infrastructure aimed at improving their ability to multidirectionally coordinate information and decisions. These resources for coordination may include meeting times and locations, project meeting and storage space, and various communication and coordination technologies, such as wikis, cloud-based collaborative spaces (e.g., Google Docs), virtual meeting spaces (e.g., Skype), and virtual team workspaces (e.g., Basecamp).

Instructor decisions and project characteristics play a significant role in students' choices of interdependency levels. These characteristics include the geographical location of team members (e.g., Dudley, 2000; Kumar, van Fenema, & von Glinow, 2009), the level of telecommuting or virtual teaming within the organization (e.g., Alcover, Sanchez-Manzanares, & Gil, 2009; Turetken, Jain, Quesenberry, & Ngwenyama, 2011), social networking – both on- and offline – among students (e.g., Cross, Rice, & Parker, 2001), and goal interdependence as seen through the balance between group and individual rewards (e.g., Hirst, 1988; Wageman, 1995). For a student team, another important characteristic of the project is the contribution of individual tasks and group tasks to individual students' grades and the students' perception of this contribution. Industry research implies that grading structure can influence students to operate at higher levels of interdependence by inviting their input in setting goals and success measures (Scott & Tiessen, 1999). Arguing for complex, realistic projects in marketing education, Skilton, Forsyth, and White applied industry-based research to student teams and demonstrated with their own data that high interdependence encouraged learning and that complex projects promoted (but are not a requirement for) interdependence. They concluded that "If educators focus on creating interdependence between students in addition to content related design, abstract project team assignments will be much more likely to do what we want them to" (p. 64).

The findings described above are nearly identical to those advocated by D. W. Johnson, Johnson, and Smith (1991) for positive interdependence in cooperative learning settings. To help students develop transferable skills for future team experiences, they also suggest that students engage in group processing, or "reflecting in a group session to describe what actions of the members were helpful and unhelpful and to decide what action to continue or change . . . to clarify and improve the effectiveness of the members in contributing to the . . . goals" (p. 22).

One interdisciplinary senior design course from our own research serves as an example of efforts to facilitate interdependence. The faculty team, in collaboration with the evaluator, developed a pedagogical model of disciplinary balance intended to ensure that students in interdisciplinary teams adopted roles as experts yet worked hands-on in other disciplines (K. Kim & McNair, 2011; Martin et al., 2012; Martin et al., 2013; McNair et al., 2011).

The instructor team designed discipline-specific, hands-on workshops in which students acted as leaders and resident experts in their home disciplines, while students in other disciplines participated in activities outside of their area of expertise. Workshop modules included sketching “minute drawings” that emphasize communication of ideas over aesthetic skill, analyzing target markets and designing “product boxes” to promote technologies to stakeholders, and programming Arduino™ electronics kits to perform simple but interactive functions. These activities were designed not to build expertise in multiple disciplines but rather to improve integrative teamwork by developing and expanding appreciation of each discipline’s role in the project. This appreciation led to awareness of the level of interdependence necessary in interdisciplinary processes. In this model, the instructors combined open-ended design with scaffolding modules that situated students as resident experts while engaging others in hands-on learning. Building interdependence through appreciation of other disciplines made the projects more cooperative, because throughout the project the students realized each other’s value and contributed to tasks or processes, not just the contributions of their own discipline. This interdependence resulted in higher levels of investment in the project. These high levels of student investment in all aspects of their projects created a high potential for conflict but also high potential for creativity. The autonomy of students also contributed to learning gains in managing interdependence in teams. The instructors adopted roles as facilitators rather than hands-on managers: they set target dates for project milestones, encouraged students to self-select and self-manage small teams, and combined formal grades with input from a professional panel of entrepreneurs. Other instructors can apply these principles by including activities in which students discuss the unique strengths they bring to a team project.

Conflict

Conflict was specifically mentioned as a situation to be avoided in several Phase 1 articles, while other articles appeared to use learning styles or Tuckman’s stages to prepare students to expect conflict. Broadly defined, conflict is “perceived incompatibilities or discrepant views among the parties involved” (Jehn & Bendersky, 2003, p. 189). Many studies separate relationship conflict (personal differences between members) from task conflict (disagreements about the nature of the task or how to complete it) and find that relationship conflict reduces productivity and satisfaction while task conflict may promote team effectiveness under certain conditions (de Wit, Greer, & Jehn, 2012). Moderate levels of conflict are associated with increased productivity (De Dreu & Weingart, 2003) as well as creativity (Pondy, 1968). Encouraging a team to approach and manage conflict using healthy, creativity-inducing behaviors begins with understanding the core sources of team conflict: task interdependence, goal incompatibility, differentiation, and limited resources (Cramer, 1991; Rahim & Mace, 1995). Essentially, conflict management (through understanding and negotiating these sources of conflict) is of far more practical importance than acknowledging that conflict exists in nearly every team situation.

*Task (*or *workflow) interdependence* is the level of reliance one person, group, or organization has on others in order to complete assigned tasks; a general rule is that the higher the level of task interdependence, the greater likelihood of conflict. When conflict is managed well, higher interdependence will lead to more innovative team results (Jaffe, 2000). *Goal incompatibility* results from differing objectives between individuals or groups who must work together. A grading incentive system that encourages the top student in the group to tolerate a severely under-performing group member in order to assure, through his or her own additional work, that the group grade is an A is an example of a goal incompatibility imposed by the structure of the course. *Differentiation* arises from the functional, social, emotional, and cognitive orientations of the individuals and their organizational subcultures. For example, team members may come from departments or disciplines with very different values, attitudes, and communication styles. The perception of *limited resources* such as money, time, physical space, equipment, and knowledge is also a core source of conflict (Worthen, 2004). Conflict resolution strategies are still being conceptualized and researched in order to understand the impact of specific situations on the most appropriate approaches for minimizing unproductive conflict (Jehn & Bendersky, 2003).

Instructors facilitating student teams can significantly mitigate these sources of conflict. Goal incompatibility can be minimized by providing students with clear goals and grading criteria for the project (which may include giving them time to discuss goals or write their team's own). Similarly, the balance between individual and group grading should encourage collaboration. Differentiation can arise from disciplinary values and prior experiences, which provides an opportunity for students to learn to develop consensus within their teams. Instructors can provide clear information about project expectations and structure time and activities for consensus building on teams. Finally, limited resources such as time can be mitigated by balancing the team project workload with other course requirements and considering other demands of student workloads (e.g., midterms and finals weeks). Allowing course time for team meetings, as well as training on how to plan and conduct effective meetings, may also help. When conflict does arise, instructors should discuss it as a potential source of creativity and guide students through developing their own solutions rather than providing top-down decisions.

Tasks that require greater creativity or diversity are also likely to have higher levels of conflict. Instructors can help students learn to discern the levels of conflict inherent in a task and different behaviors that are most likely to be effective. Where there are lower levels of conflict, most teams exhibit rational model behaviors, such as centralized decision making (i.e., within the group), relatively free access to information, and group norms that enforce orderly, efficient processes (Louis, Taylor, & Douglas, 2005; Daft, 2007).

Again, in just one Phase 1 article did the authors use the conflict literature to guide their methods and interpretation. Using the psychology literature to differentiate between constructive and destructive types of conflict, psychologists Karn and Cowling (2008) developed and applied an observation template to explore conflict in student software engineering teams. They concluded that both types were present in the teams and that the template is a useful research and evaluation tool. We note that in the field of conflict research, categorizations of positive and negative conflict are under debate, both because it is unclear that two categories are sufficient and because constructive strategies for dealing with destructive conflict are unclear (Tjosvold, 2008).

In our own work, we observed high levels of conflict in the case of an industry cross-functional team that was tasked to design and manufacture a product for a marketing event deadline (Paretti & McNair, 2012). The team included members from three separate divisions: marketing, manufacturing, and design. As the three core organizational divisions within a horizontal linkages model, they had high workflow interdependence while their functional differentiation led to incompatible goals. For example, the marketers needed to have a product ready for an annual demonstration targeted to consumers; the designers needed to specify physical constraints in order to produce an effective, efficient, and safe product; and the manufacturers needed to schedule enough time to produce the physical product without over-costing the process. All of these goals existed within an unrealistic timeline, and the team members had little cross-functional understanding of each other's work processes, requirements, and constraints. The team members were working, then, within a framework of limited resources – primarily lack of time. The resulting behaviors included decentralized and sometimes conflicting decision making due to shifting coalitions of team members as well as their sharing or withholding of information as a weapon for strategic advantage.

Trust

As with interdependence, only a few Phase 1 articles included trust as part of a larger framework of team effectiveness (M. C. Yang & Yan, 2008) or leadership (Ellis & Petersen, 2011); they had little direct engagement with the trust literature itself. Trust is closely related to other constructs discussed in this article (e.g., social loafing and conflict; de Wit et al. 2012), but we have chosen to discuss it separately to highlight additional specific pedagogical approaches that can enhance team effectiveness. Trust has been defined several ways in the literature; some definitions include a positive expectation for others' intentions and a willingness to be vulnerable to others (Costa, Roe, & Taillieu, 2001; Mayer, Davis, & Schoorman, 1995).

Trust is a complex and multifaceted construct that sustains the attention of researchers and managers because work teams are becoming increasingly distributed and self-managed (Al-Ani & Redmiles, 2009; Muethel, Siebdrat, & Hoegl, 2012; Wilson, Straus, & McEvily, 2006). Researchers are still working to develop and validate instruments to measure trust (Costa & Anderson, 2011). Numerous studies demonstrate a positive relationship between trust and productivity or satisfaction in teams (e.g., Bromiley & Cummings, 1995; Butler, 1991; Dirks, 1999; Kirkman, Rosen, Tesluk, & Gibson, 2006; McAllister, 1995; Polzner, Crisp, Jarvenpaa, & Kim, 2006). More recent studies have included creativity and innovation as team outcomes promoted by trust (Barczak, Lassk, & Mulki, 2010).

Many researchers are exploring cognitive and affective components of trust. Cognitive trust is "confidence in the ability of others" and affective trust is "faith in the trustworthy intentions of others" (Cook & Wall, 1980, p. 40; Webber, 2008). Affective trust is thought to be more important for effectiveness than cognitive trust, particularly at stressful times when errors and performance shortfalls could reduce cognitive trust. Webber (2008) studied cognitive and affective trust in 78 teams of four students completing a three-month project in organizational psychology courses at a Canadian university. Using several measures at three different times, she found that early trust was based on prior familiarity, since team members have not had a chance to base trust on anything else. Affective trust develops over time through "citizenship behaviors" such as "doing extra things for team members, willingly helping each other, and taking a personal interest in the team" (p. 762). Development of cognitive trust was based on the interaction of high reliable performance and high early trust; without both, cognitive trust was unlikely to develop. Webber found that *monitoring* behavior such as "tracking the work of others, creating backup plans and working around team members to get tasks done" had a negative effect on the development of trust (p. 753). Both types of trust were correlated with performance, but only affective trust was statistically significant. Mat and Jantan (2009) found a similar result, namely that affective (but not cognitive) trust positively impacted new product development team satisfaction.

Instructors facilitating student team projects can put these research findings into practice by including team-building activities as a part of team projects. Pritchard and Ashleigh (2007) compared teams with and without team-building activities and found there was greater trust in the team-building group. Instructors should also make efforts to reduce monitoring behaviors, such as asking about team dynamics in interim meetings or using reporting and grading practices that require all team members to be conversant in all aspects of the project. Instructors who have taught first-year engineering courses will sympathize with the difficulty in assigning projects that are simple enough for freshmen to complete yet large and complex enough to discourage high-achieving students from practicing monitoring behaviors that undercut the potential contributions of other students. These low-trust team experiences unfortunately cause many engineering students to develop a negative attitude toward team skills and projects. Instructors should provide concrete steps for promoting trust among student team members.

There are several reasons why trust is particularly important to interdisciplinary teams but also more difficult to build among members from different disciplines. Early trust can be based on group membership, i.e., members with the same department or disciplinary affiliation are more likely to trust each other (Kim, Ferrin, Cooper, & Dirks, 2004). Since cognitive trust requires early trust in order to develop, interdisciplinary teams may be at an inherent disadvantage in building cognitive trust. On the other hand, it may be more difficult for interdisciplinary team members to engage in monitoring behaviors that damage trust if the team member to be monitored is the only link to particular disciplinary knowledge and working around the member is impracticable.

An example of trust from our own work is from an engineering technical communication course. McNair assigned students a semester-long team project in which they were asked to design a business idea and write and present a series of documents that included a proposal and business plan. After observing several team conflicts, the instructor designed assignments that would be completed by the teams parallel to their project work in future semesters. These assignments were designed to promote trust early in the semester and to make expectations transparent. The first assignment prompted students to discuss their own previous team experiences, both positive and negative. Early in the semester – before any problems occurred – the teams had been assigned to write and sign working agreements that included both logistical agreements (e.g., how quickly one should respond to e-mails from the team) and guidelines for managing problems (e.g., how to deal with someone not meeting a deadline). Structuring the tasks in this way is also a method of reducing conflict. In another assignment later in the semester, students revisited these agreements and made adjustments to the guidelines if necessary. By making expectations and consequences explicit, the students were better able to collaborate. The initial discussions of prior team experiences made it clear that almost everyone had both positive and negative prior experiences in working in teams.

Shared Mental Models

Only two Phase 1 articles used the terminology or literature of mental models, and these studies were conducted by nonengineers (Bierhals, Schuster, Kohler, & Badke-Schaub, 2007; Lee & Johnson, 2008). Nonetheless, as these two articles show, the concept of shared mental models is useful in understanding how teams approach complex, ill-defined projects, and may be particularly useful for understanding interdisciplinary team effectiveness. Shared mental models or team mental models are knowledge structures that enable a team to form accurate explanations and expectations of the task, to coordinate their actions, and to adapt their behavior to demands of the task and other team members (Cannon-Bowers, Salas, & Converse, 1993). Team mental models also allow members to facilitate information processing, provide support, and diagnose deficiencies; they influence both team processes and team products (Edwards, Day, Arthur, & Bell, 2006; Mohammed, Ferzandi, & Hamilton, 2010).

The degree to which team members share mental models impacts their productivity and success (Edwards et al., 2006; Kozlowski & Ilgen, 2006; Langan-Fox, Anglim, & Wilson, 2004; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005). Teams can develop shared mental models through activities that encourage them to discuss and clarify their task and how it will be completed, and that encourage them to reflect at different points during the project (Mohammed et al., 2010; Yang et al., 2008). Early assignments can require members to set goals and define responsibilities. Later on, group processing time can allow team members to reflect on their interactions. Additionally, some degree of clarity of the assignment can also help members of student teams develop shared mental models. However, overprescribing how students should complete a team project is at odds with some of the recommendations for promoting shared mental models and other constructs such as interdependence. An appropriate balance between providing clarity and micromanaging may be clear goals and values that allow flexibility for exactly how teams complete their projects.

As noted, two articles from Phase 1 made meaningful use of the shared mental models literature. Bierhals et al. (2007) studied mental models of the members of mechanical engineering student teams. Using observations, a questionnaire, and comparisons with an interdisciplinary automotive industry team, the researchers concluded that team performance was better when the teams agreed more on their mental models about team members' skills and their interactions (i.e., mental models were more "shared"; Bierhals et al., 2007). Lee and Johnson (2008) used a quantitative questionnaire approach to measure the shared mental models of manufacturing engineering students completing a complex, ill-defined project. Mental models describing both the team members and their assigned task changed over the course of the project, in both structure and degree (Lee & Johnson, 2008).

Disciplines have characteristic ways of organizing knowledge, which can shape the mental models of team members from different disciplines, for example, in terms of how a project should proceed. Therefore, shared mental models may be particularly important for interdisciplinary teams. One interdisciplinary graduate student team we studied had a large and complex project with interrelated subgroups that organized the students on specific tasks or aspects of the system (Beddoes & Borrego, in press). This complex, interdisciplinary team structure contributed to faculty and students having a wide range of different mental models (i.e., mental models were not shared), which inhibited their progress toward goals. In this extreme case, students could not consistently list who was and was not a member of their project team, let alone comfortably draw a diagram of the team's structure. Since these were long-term projects, a few new students joined each year at different times, so it was not obvious when or how new members could be formally oriented to the group and its structure. We contrast this with a more cohort-based interdisciplinary graduate program, which made extensive use of orientation and team development activities such as those described throughout this article. These students could confidently diagram their team mental models, which were consistent among the students. Although productivity is difficult to compare between these two types of teams that differed in size and goals, we observed satisfaction with interdisciplinary team projects to be higher in the latter case.

Discussion: Implications for Facilitating Engineering Student Teams

The results of Phase 1 demonstrated that engineering educators are dedicated to providing students with learning experiences to help them develop skills to work effectively on design and problem-solving teams, which may include sustainability, global, distributed, and interdisciplinary contexts. Yet instructors struggle with negative student team behaviors that can be minimized by teams research that I/O psychologists have been conducting for years. Phase 1 articles identified a number of negative student team behaviors that engineering and computer science faculty members seek to minimize in facilitating student teams. The I/O psychology literature is an important source of guidance for designing team projects that minimize these negative behaviors and increase learning. While a few Phase 1 articles cited the I/O psychology literature and used it to inform interventions and evaluations, much of the potential for applying I/O psychology to engineering education remains unfulfilled.

Psychology researchers emphasize that teams should not be formed if a project can be completed by individuals working independently (Kozlowski & Ilgen, 2006; Steiner, 1972), and much of this literature emphasizes or assumes members' skills and knowledge are complementary. While there are several examples of interdisciplinary undergraduate engineering team projects (Richter & Paretti, 2009), the norm is that organizing projects across departments is fraught with disincentives and obstacles for both faculty and students (McNair et al., 2011). Most project courses are taught in one department for students in one major. In these single-major settings, it is difficult to envision how students might be expected to bring different skills to a team or to otherwise complement each other. This situation raises the question of whether team project assignments are sufficiently complex or authentic to develop meaningful team skills. If projects are not sufficiently complex, students may lose motivation and disengage, especially if they have experienced conflict, social loafing, or lack of trust in previous team projects. Fortunately, the I/O psychology literature we have reviewed contains several constructive suggestions. It is worth emphasizing that more complex, interdisciplinary, and authentic projects, although difficult to implement in higher education institutions, are likely to better prepare students for industry work and foster their sustained interest in engineering careers.

Industrial and organizational psychology research provides several reasons to design learning experiences around authentic, complex engineering problems. First, training in team skills such as coordination and communication should take place in teams (Mathieu et al., 2000). Second, complex projects that challenge team members to work hard and coordinate their efforts reduce social loafing and increase interdependence. As members of a profession, engineering educators value authentic training experiences that emulate industry teams, which are composed of members selected for the diverse and complementary expertise they bring to a complex, real-life problem.

This review may seem repetitive because there is much convergence in the practical implications of the five constructs. Examples of specific pedagogical strategies from our own teaching and research provided

activities for setting goals, targets, and interaction rules for team members,

structures that scaffold students toward success without micromanaging them,

explicit discussion items for teams, including interaction rules, expectations, and how to deal with conflict,

guidelines for forming smaller teams, allowing students to self-select and even switch teams after a trial period (for longer or more intensive projects),

exercises for interdisciplinary team members to develop understanding and mutual respect, and

grading schemes that motivate participation in team projects.

Lastly, it is worth noting that among the four articles that used the I/O psychology literature to guide their investigations, only one (Pieterse) had an engineering or computer science faculty member as the first author. The others were written by psychologists and information technologists and did not always include course instructors as coauthors. Many more Phase 1 articles cited teams literature and constructs but generally did not align learning outcomes to assessment nor use the literature to inform the design of their intervention. This superficial use of I/O psychology literature by engineering and computer science faculty underscores the need for collaboration by engineering faculty with those trained in relevant disciplines to access the literature and theories that will advance training of engineering students in teamwork.

Future Research: Complementing I/O Psychology

Given the consistency and depth of pedagogical recommendations for minimizing negative student team behaviors discussed here, it is clear that engineering education research would benefit from I/O psychology theory and literature. Theory describes what is happening and why it is happening; theory predicts changes that are likely to improve outcomes. It also guides in selecting what to focus on from among a seemingly infinite selection of potential factors. At the same time, there are opportunities for engineering education research to inform I/O psychology research on teams.

Industrial and organizational psychology research about team process still tends to isolate one construct at a time without sufficiently synthesizing relationships between several variables (Mathieu et al., 2008). There have been several calls to expand perspectives and methods beyond investigations of individual constructs in order to move toward a more integrated theory of group research (Berdahl & Henry, 2005; Paletz & Schunn, 2010; Weingart & Cronin, 2009).

Engineering education is open to a wider range of research approaches than I/O psychology (Borrego, Douglas, & Amelink, 2009), including qualitative and mixed methods that allow for in-depth studies of a smaller number of teams as they evolve over time. Observations over extended time periods can help us understand

> *when* the respective team processes are most critical in explaining performance. . . . For example, once a team is formed, how long does it take for shared perceptions of collective efficacy to form and solidify? How vulnerable to transgressions are shared perceptions of trust? Does it matter when such transgressions occur? (Mathieu et al., 2008, p. 433)

Engineering education researchers also greatly value studying students in naturalistic settings, such as real classrooms. In contrast, a large portion of I/O psychology research still takes place in artificial laboratory situations, albeit with increasingly sophisticated simulations (Kozlowski & Ilgen, 2006). Engineering education researchers can respond directly to Mathieu et al.'s (2008) call to "embrace the complexity" (p. 461) of real teams to better understand complex interactions in their dynamics. Specifically, studies of engineering student teams can contribute to an understanding of training in the context of teams and their work environments so educators can "recogniz[e] the linkages among factors crossing the individual, team/unit, and organizational levels of analysis" (p. 448).

Time is also an important consideration, both the duration of the study and the life expectancy of the team. The majority of I/O psychology studies rely on data collected at one or two points in time; however, more longitudinal studies are emerging (Paletz & Schunn, 2010). Cognitive psychology and learning sciences are emphasizing new perspectives on learning teams and learning organizations (e.g., Senge, 1997), but researchers generally assume that, with some allowances for employee promotion and turnover, the team is relatively stable over time. Undergraduate student teams are certainly not stable over the same long periods of time because projects often span one academic term or less. At the graduate level, teamwork is also frequently taught through courses (Borrego & Cutler, 2010), but long-term dissertation research and lab group settings could mimic industry teams in interesting and productive ways (Crede & Borrego, 2012). In research labs, the notion of research "productivity" (e.g., publications) is also clearer than at the undergraduate level and perhaps easier to translate to productivity as described in the psychology literature.

In psychology, creativity is now seen as an outcome of teamwork (Mathieu et al., 2008; Paletz & Schunn, 2010). Given the expansive design cognition and design pedagogy research and the longstanding emphasis on innovation and creativity in engineering education, new linkages between creativity and teamwork are another opportunity for engineering education researchers to inform psychology research. Some research on team innovation is already underway (Schippers, West, & Dawson, 2012; Sears & Baba, 2011).

It is noteworthy that distributed and virtual teams, whether they include an international component or not, are an important new direction for engineering student teams and teams research in general. A wealth of research literature can be translated into recommendations for facilitation of such teams; these recommendations are already being integrated into software engineering student team projects in particular (as shown by Phase 1 results). Although detailed discussion of that literature was beyond the scope of this review, additional opportunities for interdisciplinary research in this domain exist as well.

Conclusion

Theory and findings from psychology expand the knowledge base from which engineering educators can draw to focus on factors most likely to positively influence student teamwork outcomes. By drawing on the team effectiveness literature in psychology, engineering and computer science instructors can develop ways to minimize negative team behaviors. Some researchers are using this literature to understand engineering and computer science student teams, but few of the articles that used I/O psychology to inform their team interventions included engineering or computer science faculty among the authors. Opportunity abounds for greater connection of I/O psychology teams theory and practice in facilitating engineering student teams. The primary goal of this review was to assist engineering educators and researchers in understanding and applying teams research to refine and improve the engineering student teamwork learning outcomes that are important transferable skills for engineers in today's global economy.

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