2023-10-10

Teamwork Skills Development In Engineering Education: A Holistic Approach

Callum KIMPTON
Monash University, Australia, callum.kimpton@monash.edu

Nicoleta MAYNARD
Monash University, Australia, nicoleta.maynard@monash.edu

TEAMWORK SKILLS DEVELOPMENT IN ENGINEERING EDUCATION: A HOLISTIC APPROACH

C T Kimpton [1]
Monash University
Melbourne, Australia
0009-0002-2075-7644

N E Maynard
Monash University
Melbourne, Australia
0000-0001-7965-0716

Conference Key Areas*: Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Equality Diversity and Inclusion in Engineering Education*

Keywords*: Teamwork, Conceptual Framework*

ABSTRACT

Engineering is a profession grounded in teamwork with the need for engineering students and professionals to possess the ability to integrate their work efforts seamlessly and effectively towards a common goal. This in turn necessitates the need for a **comprehensive, tailored, and relevant overarching conceptual framework** to be constructed to ensure that our subsequent generations of engineers are equipped to efficiently tackle existential societal problems including anthropogenic climate change and the multi-faceted nature of sustainable development.

This paper motivates, details, and presents a conceptual framework for implementing successful engineering teams in tertiary engineering projects. The emergent conceptual framework presented is currently a work in progress based on the findings and recommendations of current literature. We plan to undertake student interviews with both first year and capstone students to refine our framework thereby ensuring the credibility of the framework.

[1] *C T Kimpton*

Callum.Kimpton@monash.edu

The final theoretical framework is composed of four key themes, these being team composition, team dynamics, creative leadership and team culture. The theoretical composition and relevance of their component sub-themes are discussed further in our work in addition to the unique interplay that occurs at the nexus of said themes and sub-themes. Ultimately this paper does not only define and outline a holistic conceptual framework to be used as a heuristic device for implementing successful engineering teams, but it additionally highlights current gaps in the relevant literature thereby provoking critical fields of future research.

1 INTRODUCTION

The 21st century, while still very much in its adolescence, has produced world shaping technologies that in combination with rapid globalisation have created fertile ground for complex and daunting engineering challenges. Such challenges include existential threats such as anthropogenic climate change which has irreversibly altered the complexion of modern engineering problems. Addressing these challenges requires successful collaboration among engineers, government regulators, entrepreneurs, and industry professionals. The effectiveness of this collaboration is vital to address increasingly complex challenges related to sustainable product development, innovation opportunities, and the progress of our society. Contemporary engineering graduates therefore must be equipped with drastically different skill sets from their predecessors including skills such as communication, leadership, creativity and capability to work in teams (Lappalainen 2009; Farr and Brazil 2009; Muñoz-La Rivera et al. 2020). This has necessitated research into the overarching theme of teamwork skills development and the need for students to be explicitly taught teamwork skills in a pragmatic and proactive fashion (Lingard and Barkataki 2011).

2 BACKGROUND AND MOTIVATION

There are prominent instances of tertiary engineering teamwork being used as a focus for the creation of conceptual frameworks. Such examples often investigate what constitutes effective or successful teamwork through the analysis of student attributes by drawing upon the current body of literature (Chowdhury and Murzi 2019). Further proposed conceptual frameworks are deeply pedagogically focused with highly specific applications (Zamora-Polo et al. 2019) or focused more so on the necessary and desired professional skills that our future engineers must possess in order to tackle new kinds of engineering problems (Kamaruzaman et al. 2019) including how to approach interdisciplinary engineering education (Van den Beemt et al. 2020). There is, however, a distinct lack of conceptual frameworks that incorporate all tertiary engineering education settings as well as encompassing both pedagogical and student-centred factors.

A significant focus of this research paper will be to develop a framework for effective team collaboration based on recent findings from team science research. With an estimated $1.5 trillion invested worldwide in sustainable development research, and an estimated $664 billion in the United States alone (OECD Data), establishing evidence for effective team science practices and policies is sorely needed (Hall et al. 2018). This includes addressing key features that research has identified as potential challenges: the diversity of the team's members; deep knowledge integration; team size; goal misalignment; permeable boundaries; geographic dispersion and high task interdependence (Cooke 2015). To address potential challenges, identified risks, and uncertainty associated with developing plastic-free paper-based point of care diagnostics, our project will be guided by principles of convergence science.

The proposed conceptual meta-framework therefore seeks to not only describe the state of contemporary research in the area of tertiary engineering teamwork education but also link this to pedagogical factors and strategies in order to provide a representation of not only what factors contribute to successful teamwork but also how this is achieved and what strategies educators have employed to achieve this. The construction of a holistic approach to detailing teamwork skills development in engineering education, therefore, motivates the following research question:

What individual, team based and pedagogical factors influence teamwork skills development in tertiary engineering teams and what is the interplay between them?

A conceptual meta-framework is an interconnected set of ideas about how a particular phenomenon functions or is related to its parts based on the synthesis of literature (Svinicki 2010). This conceptual meta-framework strives to elucidate our interpretation of teamwork within undergraduate engineering teams based on current, relevant literature. By qualitatively synthesising pertinent literature in the field and putting forth a framework composed of identified factors as well as the relationship between them we propose a heuristic for educators focusing on elements of teamwork that need to be considered in teaching and improving teamwork skills development.

3 METHODOLOGY AND METHODS

A scoping literature review approach was employed to understand, conceptualise and refine the individual, team based and pedagogical factors that have been seen to influence teamwork skills development as well as identifying potential research gaps (Boelt, Kolmos, and Holgaard 2022; Booth, Sutton, and Papaioannou 2016). This scoping literature review only included peer-reviewed journal articles and conference papers to ensure the manageability and rigor of included data. Further research outputs were gathered through citation searches of highly relevant sources to supplement the existing data corpus (Boelt, Kolmos, and Holgaard 2022).

Consequently, a qualitative content analysis design framework (Borrego, Foster, and Froyd 2014) was deemed to be the most appropriate due to the necessity of capturing meaning within and across literature as opposed to generating new theory through the construction of concepts and conceptual categories (Morelock 2017). A socio-constructivist paradigm was employed (Brown and Campione, 1994) whereby it is a team or group of learners who construct their own meaning and learnings which are dependent on what they experience to be true as a collective (Svinicki 2010). The conceptual framework presented in this work is a work in progress and therefore does not address validation of the framework nor teamwork assessment.

4 RESULTS AND DISCUSSION

Findings from our scoping literature review uncovered numerous pertinent factors that have been linked to the development of teamwork skills within cohorts of tertiary engineering students. Further analysis has since shown the emergence of four prominent categories of influencing factors with these being team composition, team dynamics, creative leadership and team climate. These categories will be elaborated upon further in the following discussion along with their component sub-factors.

4.1 TEAM COMPOSITION

Team composition is one of the most widely studied factors within the field of teamwork skills development with diversity, personality type, and team size being considered pivotal.

Gender and its implications in engineering, a famously male dominated field (Mubarak and Khan 2022), has been studied extensively with important findings related to the effectiveness of engineering teams being elucidated. Female students in engineering teams have been seen to not only exhibit less relationship variance (Zhou et al. 2019) but also provide higher peer ratings (Pasha-Zaidi et al. 2015) whilst receiving lower ratings themselves (Fajarillo, Moussa, and Li 2021). This disconnect between high teamwork skills and low peer feedback scores is symptomatic of a dominant male culture within engineering whereby underrepresented demographics such as women, particularly women of colour, experience great social pain related to being ignored, being the only one, being spotlighted and stereotyped amongst other factors (Ong, Jaumot-Pascual, and Ko 2020). Ultimately this is of great concern as the academic performance and persistence of women within engineering is held back by the overt discrimination that they face and is therefore a pivotal factor that needs to be considered when forming engineering teams.

Diversity of student grades, skills and ethnicity have similarly been identified as factors to consider when forming teams. **Academically diverse** teams have been associated with mixed results, showing no correlation to team enjoyment or effectiveness (Mostafapour and Hurst 2020), frustration from high achieving students (Michalaka & Golub, 2016) and a correlation to visible leadership (Marshall et al. 2016) as well as team effectiveness, positive peer feedback and course outcomes (Zhang et al. 2014; Vasquez et al. 2020). When it comes to the ethnic diversity, educators are encouraged to be mindful that team-based learning alone does not ameliorate the perceptions of low performance and poor decision-making skills that are harboured by students of minority ethnicities (Beneroso and Erans 2020). Although explicit instruction regarding team effectiveness and diversity has been shown to increase students' awareness of diversity, they also become less prone to support diverse and minority individuals (Kirn et al. 2018). This is supported by the work of Jimenez-Useche, Ohland, and Hoffmann (2015) where differences in culture were the leading cause of low team cohesion, satisfaction and high levels of conflict. As future engineers are required to work in diverse workplaces with people of various ethnicities and skill levels these issues must be overcome and tertiary

educators must temper the frustration that arises from vast skill disparities as well as nurture all students to support and avoid conflict with students of minority ethnicities.

Personality types have been used as a theoretical vehicle through which effective engineering teams can be formed and as a result there is a plethora of research focused on detailing these phenomena. Many of these works contend that an engineering team will be more successful and integrate work efforts in a more seamless manner if there exists a large variety of personalities within the team. Carl Jung and Isabel Briggs Mysers' personality test (MBTI) has been applied in a plethora of settings with results linking a greater distance between parametric test results to higher creativity, self-reported team capabilities and overall team achievement (DuPont and Hoyle 2015). Self-awareness of one's own MBTI can also lead students to recognise their particular strengths and weaknesses and improve their contributions to the team (Pieterse, Stuurman, and van Eekelen 2021). Similar personality-based tests such as the Enneagram test (Type Descriptions — The Enneagram Institute 2014) have highlighted students' improved ability to learn organisational skills, build relationships, resolve conflicts and emphasise higher standards (Havenga and Du Toit 2019). This sentiment is somewhat echoed by other studies where students have shown their willingness to work together and turn the discomfort of working with others into an opportunity when they are aware that there is a method behind the formation of teams (Michalaka and Golub 2016). Conversely, numerous other inquiries have shown no significant differences between MBTI diverse and randomly allocated teams (Michalaka and Golub 2016) which also holds true for the 'big five' personality traits with the exception of the adventurous trait which is negatively correlated with teamwork competencies (Tang 2020). Ultimately these contrasting findings make it difficult to identify the 'perfect' mix of personalities or whether such a phenomenon even exists. As a result, educators need to use these tools in different ways and apply them to their specific contexts whilst ensuring that their processes are as transparent as possible to ensure the perceived fairness of these teams and elicit student self-awareness.

Team size can be easily overlooked and arbitrarily set, there exists however lessons which can be garnered from the current body of research. Despite some research showing no particular correlation between team size and team effectiveness (Iacob and Faily 2020), large teams of over six members often cause an issue for both students and educators alike as both groups are not able to intervene, communicate and develop capabilities as effectively (Kearney, Damron, and Sohoni 2015). Team members often feel that such large groups stunt their ability to communicate effectively and make decisions which may be countered by the construction of component sub-teams according to expertise and interest (Murzi et al. 2020). Whilst there is no 'one size fits all' solution here, educators should be wary of forming large teams and in such cases consider forming smaller sub-teams within them.

4.2 TEAM DYNAMICS

Team composition is not however the be all and end all of effective team functioning. Healthy team dynamics are crucial in ensuring the ongoing functioning of a team which centres around communication, conflict, psychological safety, team cohesion and motivation.

Whilst **communication** may not be considered to be as important as technical contribution amongst students (Robal 2018), it is a challenge for engineering students (Senna Fouché and Müller 2021) and a skill that is sought after by industry (McHenry and Krishnan 2023). Consequently, the perils of poor communication have been outlined with findings highlighting the consequent lack of feedback, progression towards deliverables, contribution from peers and poorer work quality (Lucietto et al. 2017; Eggert et al. 2014; Petkovic et al. 2014). Regular team communication therefore is key to project success (Presler-Marshall, Heckman, and Stolee 2022) and something that along with individual motivation impacts less satisfied teams proportionally more (Dzvonyar et al. 2018) thereby creating a negative feedback loop where poor communication, **motivation** and low team satisfaction perpetually increase the magnitude of the others. To break this loop, educators must consider the inclusion of explicit pedagogical techniques that relate to mature communication, a method of communication in which ideas are put forth, justified and feedback is provided constructively (Murzi et al. 2020). Additionally, the poor motivation of students must simultaneously be targeted as the antecedent of poor communication (Pertegal-Felices et al. 2019) through various emerging pedagogies tailored to increasing student motivation including point-concept-review (CPR) pedagogies (Lee et al. 2022).

Despite the logical connection between **team conflict** and poor team effectiveness (Mostafapour and Hurst 2020), it is the manifestations of how this occurs that are crucial to understanding conflict. Personal tensions over unequal work distribution (Lucietto et al. 2017) as well as more overt disagreements within a team (Eggert et al. 2014) can stifle the learning and teaching opportunities of other students. The work of Mostafapour and Hurst (2020) further outlines the root causes of such conflict including differences in expectations, lack of communication, poor quality or lack of effort and internal disagreements. Much of this stems from a lack of **constructive controversy** or the process of working towards an agreement when one initially holds an incompatible opinion or ideological position to their counterpart (Johnson, Johnson, and Smith 2000). Constructive controversy should be seen as a growth opportunity for students where conflict is acknowledged and used to fuel progress, something which can be taught to engineering students (Abbasi, Wolfand, and Vijlee 2022).

Psychological safety arises in environments where team members collectively believe that risk taking is a safe practice (Edmondson 1999) and is a concept that lends itself to the study of teamwork in engineering. The lack of psychological safety has been seen to be a persistent issue within the field whereby students feel insecure and as though they are not heard within their teams (Lescott 2022).

Psychological safety is a key pillar in the construction of creative learning environments for engineering students (Zhou 2012) as well as overcoming barriers to students' creativity. Consequently, psychological safety presents itself as a prosperous avenue for future research whereby the forming of psychologically safe environments should be prioritised to ensure team dynamics promote mutual trust and respect (Murzi et al. 2020).

Engineering students value building rapport with their fellow team members and getting to know one another (Thompson 2017) which is inextricably linked to the construction of a supportive, welcoming and successful team environment (Abreu and Read-Daily 2020). This is frequently referred to as **team cohesion** which can be seen as the agglomeration of personality, conflict and communication within teams, acting as the intermediary between team rules and team performance (Avila, Van Petegem, and Libotton 2021). Whilst the importance of both conflict and communication are outlined above, team cohesion in this application refers to the importance of interpersonal relationships built between team members necessitating social networks and trust. Such personal relationships within engineering teams are crucial (Zaugg and Davies 2013) and pedagogical approaches to foster this should ensure the consistency of team membership (Luna and Izu 2023; Vasquez et al. 2020) without neglecting to consider fostering effective communication and conflict management skills.

4.3 CREATIVE LEADERSHIP

In the context of engineering, it is important that leaders understand how to facilitate both idea generation and implementation particularly in design projects. Consequently, leadership within tertiary engineering settings must be considered in terms of student leadership style as well as educator or project manager influence.

Leadership styles are extensively studied in fields such as management, however their application to engineering education particularly in the context of teamwork can yield important results. **Integrative leadership** and conflict management styles involve the consideration of all parties with a view to finding a truly 'win-win' solution for the team (Individual and Team Performance Lab Department of Psychology 2016) and have been correlated with overall team satisfaction (Maliashova, Sultanova, and Sanger 2022). The key to integrative leadership is being able to adapt and compromise without dominating or avoiding team discourse. Leadership within engineering teams is often prescribed however many students do not see the value in effective leadership and only employ suggested leadership structures when absolutely necessary or when approaching deadlines require the effective functioning of a team (Murzi et al. 2020). Ultimately this necessitates the early and effective implementation of pedagogical strategies in team-based units to instil within students the importance of and direct the practice of integrative leadership. **Project managers**, mentors, teaching associates and faculty members have been employed across a variety of team based applications with generally excellent feedback highlighting their crucial role as an intermediary between theory and

practice (Kearney, Damron, and Sohoni 2015). The work of Kearney, Damron, and Sohoni (2015) further provides a heuristic framework for the involvement of project managers in team development, initially providing strong team direction through their leadership position which the students gradually take ownership of themselves as their work progresses. This process allows students to recognise the importance of teamwork through improving their ability to communicate, set expectations and support one another (Fajarillo, Moussa, and Li 2021). Such examples are beneficial when managers simply act as **mediators of team dynamics** (Lescott and Tevaarwerk 2022) without being overly casual and not task specific in their interactions (Lucietto et al. 2017; Presler-Marshall, Heckman, and Stolee 2022). Furthermore, when applied in team-based design work the presence of project managers aids in mitigating performance costs associated with teamwork through fostering higher levels of semantic similarity (Gyory, Cagan, and Kotovsky 2019). Thus, it is necessary to consider how to best implement project managers or **mentors** within team-based programs, considering their role as a mediator between educators and students, instilling leadership structures and their importance as well as lessening the prevalence of performance costs.

4.4 TEAM CLIMATE AND CULTURE

Team climate and culture dictates how a team organises themselves, manages work efforts and forms norms. Oftentimes this involves pedagogical activities involving goal setting, team expectations and time management thereby precipitating the need to synthesise these findings in a way that presents educators with an overarching heuristic with which to implement teams with healthy cultures and climates.

Team climate and culture has proved to be an influential factor for team creativity and innovation (Hülsheger, Anderson, and Salgado 2009; Peretz, Levi, and Fried 2015; West 2002). Climate refers to “the set of norms, attitudes, and expectations that individuals perceive to operate in a specific social context” (Pirola-Merlo et al. 2002). Culture refers to beliefs, values, and ideologies shared by members of an organisation or discipline (Schneider, Ehrhart, and Macey 2011). Careful consideration should be given to ensure our engineering team projects opportunities and team environment encourage our students to value **innovation** and **collaboration** not only as a starting process but throughout the implementation process and communication of project **progress**. A unique benefit of this approach to teamwork would be the inclusion of team members belonging to diverse engineering **disciplines**. We are aware that this might be a very challenging logistic approach, however, if we merge concepts, theories, and approaches from multiple disciplines, as well as the principles, practices, and structures of different cultures we develop models that address team members’ vision, participative safety, task orientation, and support for innovation.

Team norms or expectations are critical first steps in instilling a healthy team culture (Løvold, Lindsjørn, and Stray 2020) and is something that is taught widely to varying degrees of success. Integration of team contract drafting as part of broader instruction regarding team management and leadership has been seen to reduce

conflict whilst improving motivation, even distribution of workload, satisfaction and responsibility (Pertegal-Felices et al. 2019). Furthermore, when students are prompted to scaffold how they plan to resolve conflict within their teams in conjunction with creating a team contract, similar teamwork skills development is observed in addition to higher levels of trust and conflict resolution (Abreu and Read-Daily 2020). Students struggle however, when creating their own team norms and expectations during the early stages of their project citing difficulties regarding knowing their team members and specific requirements of their project (Presler-Marshall, Heckman, and Stolee 2022). Ultimately student construction of team norms and expectations through generating team contracts is associated with student teamwork skills development across the board. There are however some important pedagogical considerations that should guide this practice. Students should be given some explicit instruction regarding the necessity and purpose of these contracts as well as being given the opportunity to understand their project requirements and fellow team members before undertaking this task.

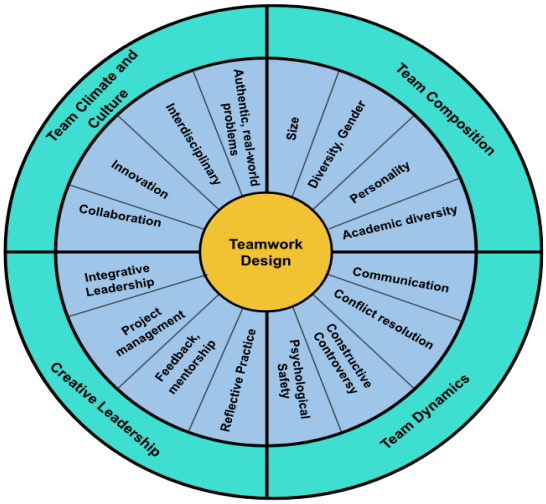

Fig. 1. Teamwork Skills Development Conceptual Framework

5 CONCLUSION

Sustainable development challenges are strongly connected to **increased complexity and integration challenges** (Phillips, Harrington, and Srai 2017). To address these challenges, we will need to lead our student teams across all disciplines in embracing the inherent complexity of the task, using it as inspiration to develop innovative and practical solutions. Further, as educators, we will need target aspects that consider the need to embrace this complexity and influence team effectiveness: *team composition, team dynamics, creative leadership and context (climate and culture)*. As this starting point of this research, will provide a clear framework for improving team collaboration and effectiveness *with the context of sustainable development in mind,* adding significant insights to the results provided so far by our research. Therefore, we recommend explicitly studying and optimising: 1) team composition; 2) team dynamics; 3) creative leadership; 4) team climate and culture. Figure 1 summarises the elements that will be considered in developing and refining our framework, based on further investigations.

REFERENCES

Abbasi, Shaghayegh, Jordyn Wolfand, and Shazib Vijlee. 2022. 'Constructive Controversy: Optimizing Decision Making in Engineering Design Teams'. In *2022 ASEE Annual Conference & Exposition*.

Abreu, Jean Carlos Batista, and Brenda Read-Daily. 2020. 'Effectiveness of Techniques to Develop and Assess the Teamwork Skills of First-Year Engineering Students'. In *2020 ASEE Virtual Annual Conference Content Access*.

Avila, Daymy Tamayo, Wim Van Petegem, and Arno Libotton. 2021. 'ASEST Framework: A Proposal for Improving Teamwork by Making Cohesive Software Engineering Student Teams'. *European Journal of Engineering Education* 46 (5): 750–764. https://doi.org/10.1080/03043797.2020.1863339.

Beneroso, D., and M. Erans. 2021. 'Team-Based Learning: An Ethnicity-Focused Study on the Perceptions of Teamwork Abilities of Engineering Students'. *European Journal of Engineering Education* 46 (5): 678–689. https://doi.org/10.1080/03043797.2020.1865879.

Boelt, A. M., A. Kolmos, and J. E. Holgaard. 2022. 'Literature Review of Students' Perceptions of Generic Competence Development in Problem-Based Learning in Engineering Education'. *European Journal of Engineering Education* 47 (6): 1399–1420. https://doi.org/10.1080/03043797.2022.2074819.

Booth, Andrew, Anthea Sutton, and Diana Papaioannou. 2016. *Systematic Approaches to a Successful Literature Review*. 2nd ed. Thousand Oaks, CA, US: Sage Publications, Inc.

Borrego, Maura, Margaret J. Foster, and Jeffrey E. Froyd. 2014. 'Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields'. *Journal of Engineering Education* 103 (1): 45–76. https://doi.org/10.1002/jee.20038.

Brown, Ann L., and Joseph C. Campione. 1994. 'Guided Discovery in a Community of Learners.' In *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice.*, 229–70. Cambridge, MA, US: The MIT Press.

Chowdhury, Tahsin, and Homero Murzi. 2019. 'Literature Review: Exploring Teamwork in Engineering Education'. In *Research in Engineering Education Symposium*.

Cooke, Nancy J. 2015. 'Team Cognition as Interaction'. *Current Directions in Psychological Science* 24 (6): 415–19. https://doi.org/10.1177/0963721415602474.

DuPont, Bryony, and Christopher Hoyle. 2015. 'Automation and Optimization of Engineering Design Team Selection Considering Personality Types and Course-Specific Constraints'. In *2015 ASEE Annual Conference & Exposition*, 1–14. https://doi.org/10.18260/p.23612.

Dzvonyar, Dora, Lukas Alperowitz, Dominic Henze, and Bernd Bruegge. 2018. 'Team Composition in Software Engineering Project Courses'. In *Proceedings of the 2nd International Workshop on Software Engineering Education for Millennials*, 16–23. https://doi.org/10.1145/3194779.3194782.

Edmondson, Amy. 1999. 'Psychological Safety and Learning Behavior in Work Teams'. *Administrative Science Quarterly* 44 (2): 350–383.

Eggert, Ryan, Joshi, Aditi, Mehrotra, Saarth, Zastavker, Yevgeniya V, and Darer, Veronica. 2014. 'Using Discourse Analysis to Understand "Failure Modes" of Undergraduate Engineering Teams'. In *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 1–5. https://doi.org/10.1109/FIE.2014.7044436.

Fajarillo, Meghan Leigh, Angie Moussa, and Yanfen Li. 2021. 'Impacting Team-Based Learning of First-Year Engineering College Students via the Creation of an Upperclassman Project Management Course'. In *2021 ASEE Virtual Annual Conference Content Access*. https://peer.asee.org/37291.

Farr, John V., and Donna M. Brazil. 2009. ‘Leadership Skills Development for Engineers’. *Engineering Management Journal* 21 (1): 3–8. https://doi.org/10.1080/10429247.2009.11431792.

Fouché, Lauren, and Erika Müller. 2021. ‘Exploring Formative Assessment Possibilities: Building a ‘Teamwork Discourse’ with First-Year Engineering Students Online’. In *7th International Conference on Higher Education Advances (HEAd’21)*, 37–45. Editorial Universitat Politècnica de València. https://doi.org/10.4995/head21.2021.12927.

Gyory, Joshua T., Jonathan Cagan, and Kenneth Kotovsky. 2019. ‘Are You Better off Alone? Mitigating the Underperformance of Engineering Teams during Conceptual Design through Adaptive Process Management’. *Research in Engineering Design* 30 (1): 85–102. https://doi.org/10.1007/s00163-018-00303-3.

Hall, Kara L, Amanda L Vogel, Grace C Huang, Katrina J Serrano, Elise L Rice, Sophia P Tsakraklides, and Stephen M Fiore. 2018. ‘The Science of Team Science: A Review of the Empirical Evidence and Research Gaps on Collaboration in Science.’ *American Psychologist* 73 (4): 532–548. https://doi.org/10.1037/amp0000319.

Havenga, Marietjie, and Hannes Du Toit. 2019. ‘Integrating Diverse Team Capabilities as Part of Problem-Based Learning in a First-Year Engineering Course’. In *PAEE ALE 2019*.

Hülsheger, U.R., N Anderson, and J.F. Salgado. 2009. ‘Team-Level Predictors of Innovation at Work: A Comprehensive Meta-Analysis Spanning Three Decades of Research’. *Journal of Applied Psychology* 94 (5): 1128–1145. https://doi.org/10.1037/a0015978.

Iacob, Claudia, and Shamal Faily. 2020. ‘The Impact of Undergraduate Mentorship on Student Satisfaction and Engagement, Teamwork Performance, and Team Dysfunction in a Software Engineering Group Project’. In *Proceedings of the 51st ACM Technical Symposium on Computer Science Education*, 128–134. https://doi.org/10.1145/3328778.3366835.

Jimenez-Useche, Isabel Cristina, Matthew W Ohland, and Stephen R Hoffmann. 2015. ‘Multicultural Dynamics in First-Year Engineering Teams in the US’. In *2015 ASEE Annual Conference & Exposition*, 1–11. https://doi.org/10.18260/p.24514.

Johnson, David W., Roger T. Johnson, and Karl A. Smith. 2000. ‘Constructive Controversy: The Educative Power of Intellectual Conflict’. *Change: The Magazine of Higher Learning* 32 (1): 28–37. https://doi.org/10.1080/00091380009602706.

Kamaruzaman, Fathiyah M, Roszilah Hamid, Azrul A Mutalib, and Mohamad S Rasul. 2019. ‘Conceptual Framework for the Development of 4IR Skills for Engineering Graduates’. *Global Journal of Engineering Education* 21 (1): 54–61.

Kearney, Kerri S, Rebecca Damron, and Sohum Sohoni. 2015. ‘Observing Engineering Student Teams from the Organization Behavior Perspective Using Linguistic Analysis of Student Reflections and Focus Group Interviews.’ *Advances in Engineering Education* 4 (3): 1–29.

Kirn, Adam, Allison Godwin, Nelson Pearson, Hector Enrique Rodriguez-Simmonds, Jacqueline Ann Rohde, Dina Verdín, and Monique S Ross. 2017. ‘Building Supports for Diversity through Engineering Teams’. In *2017 ASEE Annual Conference Proceedings*, 1–10. https://doi.org/10.18260/1-2--27918.

Lappalainen, Pia. 2009. ‘Communication as Part of the Engineering Skills Set’. *European Journal of Engineering Education* 34 (2): 123–29. https://doi.org/10.1080/03043790902752038.

Lee, Chorong, Hyun Jin Cho, Michael R. Melloch, and Chantal Levesque-Bristol. 2022. ‘What Worked for the Engineering Students to Learn? Students’ Learning

Experiences through Concept-Point-Recovery'. *European Journal of Engineering Education* 47 (6): 1243–1259. https://doi.org/10.1080/03043797.2022.2147051.
Lescott, Chamille, and Emma Tevaarwerk. 2022. 'Increasing Students' Group Processing Ability in a First-Year Engineering Design Course Through Scaffolded Team Reflection Exercises'. In *2022 ASEE Annual Conference & Exposition*.
Lingard, R., and S. Barkataki. 2011. 'Teaching Teamwork in Engineering and Computer Science'. In *2011 Frontiers in Education Conference (FIE)*, F1C-1. https://doi.org/10.1109/FIE.2011.6143000.
Løvold, Henrik, Yngve Lindsjørn, and Viktoria Stray. 2020. 'Forming and Assessing Student Teams in Software Engineering Courses'. 298–306. https://doi.org/10.1007/978-3-030-58858-8_31.
Lucietto, Anne M, Andrew Simon Scott, Kenneth A Connor, and Frederick C Berry. 2017. 'Initial Survey of Engineering Technology Capstone Courses and Teamwork Building Using CATME'. In *2017 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--28532.
Luna, A., and C. Izu. 2023. 'Using IF-AT Cards to Engage Students in Deeper Learning of Course Content'. *IEEE Revista Iberoamericana de Tecnologias Del Aprendizaje* 18 (1): 136–145. https://doi.org/10.1109/RITA.2023.3251182.
Maliashova, Anna, Dilbar Sultanova, and Phillip A. Sanger. 2022. 'Characteristics of Team Dynamics Influencing Success in Engineering Student Teams'. In *Mobility for Smart Cities and Regional Development - Challenges for Higher Education*, edited by Michael E. Auer, Hanno Hortsch, Oliver Michler, and Thomas Köhler, 13–20. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-93904-5_2.
McHenry, Robert, and Siva Krishnan. 2022. 'A Conceptual Professional Practice Framework for Embedding Employability Skills Development in Engineering Education Programmes'. *European Journal of Engineering Education* 47 (6): 1296–1314. https://doi.org/10.1080/03043797.2022.2164255.
Michalaka, Dimitra, and Michael Golub. 2016. 'Effective Building and Development of Student Teamwork Using Personality Types in Engineering Courses'. In *2016 ASEE Annual Conference & Exposition*, 1–14. https://doi.org/10.18260/p.26902.
Morelock, John R. 2017. 'A Systematic Literature Review of Engineering Identity: Definitions, Factors, and Interventions Affecting Development, and Means of Measurement'. *European Journal of Engineering Education* 42 (6): 1240–1262. https://doi.org/10.1080/03043797.2017.1287664.
Mostafapour, Mehrnaz, and Ada Hurst. 2020. 'An Exploratory Study of Teamwork Processes and Perceived Team Effectiveness in Engineering Capstone Design Teams'. *International Journal of Engineering Education* 36 (1): 436–449.
Mubarak, Hamisi Ramadhan, and Md. Shahadat Hossain Khan. 2022. 'Variations in Students' Conceptions of Good Teaching in Engineering Education: A Phenomenographic Investigation'. *European Journal of Engineering Education* 47 (6): 865–885. https://doi.org/10.1080/03043797.2022.2049216.
Muñoz-La Rivera, Felipe, Pamela Hermosilla, Jean Delgadillo, and Dayan Echeverría. 2020. 'The Sustainable Development Goals (SDGs) as a Basis for Innovation Skills for Engineers in the Industry 4.0 Context'. *Sustainability* 12 (16). https://doi.org/10.3390/su12166622.
Murzi, Homero G, Tahsin M Chowdhury, Jurij Karlovšek, and BC Ruiz Ulloa. 2020. 'Working in Large Teams: Measuring the Impact of a Teamwork Model to Facilitate Teamwork Development in Engineering Students Working in a Real Project'. *International Journal of Engineering Education* 36 (1): 274–295.

Ong, Maria, Nuria Jaumot-Pascual, and Lily T. Ko. 2020. 'Research Literature on Women of Color in Undergraduate Engineering Education: A Systematic Thematic Synthesis'. *Journal of Engineering Education* 109 (3): 581–615. https://doi.org/10.1002/jee.20345.

Pasha-Zaidi, Nausheen, Ernest Afari, Jaby Mohammed, Samuel Cubero, Ameera Shoukry, and Wael Sokkary. 2015. 'Gender-Based Teams: Perceptions of Team Satisfaction and Effectiveness among Engineering Students in the United Arab Emirates'. *International Journal of Engineering Education* 31 (4): 953–966.

Peretz, Hilla, Ariel Levi, and Yitzhak Fried. 2015. 'Organizational Diversity Programs across Cultures: Effects on Absenteeism, Turnover, Performance and Innovation'. *The International Journal of Human Resource Management* 26 (6): 875–903. https://doi.org/10.1080/09585192.2014.991344.

Pertegal-Felices, M. L., A. Fuster-Guilló, M. L. Rico-Soliveres, J. Azorín-López, and A. Jimeno-Morenilla. 2019. 'Practical Method of Improving the Teamwork of Engineering Students Using Team Contracts to Minimize Conflict Situations'. *IEEE Access* 7: 65083–65092. https://doi.org/10.1109/ACCESS.2019.2916343.

Petkovic, D., M. Sosnick-Pérez, S. Huang, R. Todtenhoefer, K. Okada, S. Arora, R. Sreenivasen, L. Flores, and S. Dubey. 2014. 'SETAP: Software Engineering Teamwork Assessment and Prediction Using Machine Learning'. In *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 1–8. https://doi.org/10.1109/FIE.2014.7044199.

Phillips, Mark A., Tomás S. Harrington, and Jagjit Singh Srai. 2017. 'Convergent Innovation in Emerging Healthcare Technology Ecosystems: Addressing Complexity and Integration'. *Technology Innovation Management Review* 7 (9): 44–54. https://doi.org/10.22215/timreview/1105.

Pieterse, Vreda, Sylvia Stuurman, and Marko CJD van Eekelen. 2021. 'Using Jungian Personality Types for Teaching Teamwork in a Software Engineering Capstone Course'. In *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*, 239–245. https://doi.org/10.1145/3408877.3432455.

Pirola-Merlo, Andrew, Charmine Härtel, Leon Mann, and Giles Hirst. 2002. 'How Leaders Influence the Impact of Affective Events on Team Climate and Performance in R&D Teams'. *Emotions and Leadership* 13 (5): 561–581. https://doi.org/10.1016/S1048-9843(02)00144-3.

Presler-Marshall, Kai, Sarah Heckman, and Kathryn T Stolee. 2022. 'What Makes Team [s] Work? A Study of Team Characteristics in Software Engineering Projects'. In *Proceedings of the 2022 ACM Conference on International Computing Education Research-Volume 1*, 1:177–188. https://doi.org/10.1145/3501385.3543980.

Robal, T. 2018. 'Fair and Individualized Project Teamwork Evaluation for an Engineering Course'. In *2018 28th EAEEIE Annual Conference (EAEEIE)*, 1–9. https://doi.org/10.1109/EAEEIE.2018.8534256.

Schneider, Benjamin, Mark G. Ehrhart, and William H. Macey. 2011. 'Perspectives on Organizational Climate and Culture.' In *APA Handbook of Industrial and Organizational Psychology, Vol 1: Building and Developing the Organization.*, 373–414. APA Handbooks in Psychology. Washington, DC, US: American Psychological Association. https://doi.org/10.1037/12169-012.

Svinicki, Marilla D. 2010. 'A Guidebook on Conceptual Frameworks for Research in Engineering Education'. *Rigorous Research in Engineering Education* 7 (13): 1–53.

Tang, Kuok Ho Daniel. 2020. 'Personality Traits, Teamwork Competencies and Academic Performance among First-Year Engineering Students'. *Higher Education, Skills and*

Work-Based Learning 11 (2): 367–385. https://doi.org/10.1108/heswbl-11-2019-0153.
The Enneagram Institute. n.d. ‘Type Descriptions — The Enneagram Institute’. The Enneagram Institute. https://www.enneagraminstitute.com/type-descriptions.
Thompson, A. 2017. ‘Fostering Development of Teamwork Skills in an Introductory Engineering Course’. In *2017 IEEE Frontiers in Education Conference (FIE)*, 1–4. https://doi.org/10.1109/FIE.2017.8190551.
Van den Beemt, Antoine, Miles MacLeod, Jan Van der Veen, Anne Van de Ven, Sophie van Baalen, Renate Klaassen, and Mieke Boon. 2020. ‘Interdisciplinary Engineering Education: A Review of Vision, Teaching, and Support’. *Journal of Engineering Education* 109 (3): 508–555. https://doi.org/10.1002/jee.20347.
Vasquez, Erick S, Matthew J Dewitt, Zachary J West, and Michael J Elsass. 2020. ‘Impact of Team Formation Approach on Teamwork Effectiveness and Performance in an Upper-Level Undergraduate Chemical Engineering Laboratory Course’. *International Journal of Engineering Education* 36 (1): 491–501.
Walker, James. 2016. ‘Conflict Management Styles’. Departement of Psychology University of Calgary. https://www.itpmetrics.com/resources/report_samples/en/ConflictManagement_EN.pdf.
West, Michael A. 2002. ‘Sparkling Fountains or Stagnant Ponds: An Integrative Model of Creativity and Innovation Implementation in Work Groups’. *Applied Psychology* 51 (3): 355–387. https://doi.org/10.1111/1464-0597.00951.
Zamora-Polo, Francisco, Amalia Luque Sendra, Francisco Aguayo-Gonzalez, and Jesus Sanchez-Martin. 2019. ‘Conceptual Framework for the Use of Building Information Modeling in Engineering Education’. *International Journal of Engineering Education* 35 (3): 744–755.
Zaugg, Holt, and Randall S Davies. 2013. ‘Communication Skills to Develop Trusting Relationships on Global Virtual Engineering Capstone Teams’. *European Journal of Engineering Education* 38 (2): 228–233. https://doi.org/10.1080/03043797.2013.766678.
Zhang, D., N. Yao, L. Cuthbert, and S. Ketteridge. 2014. ‘A Suggested Strategy for Teamwork Teaching in Undergraduate Engineering Programmes Particularly in China’. In *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 1–8. https://doi.org/10.1109/FIE.2014.7044077.
Zhou, Chuhan, Sunjae Choi, Behzad Beigpourian, Siqing Wei, Daniel M Ferguson, and Matthew W Ohland. n.d. ‘The Difference between Teams with No Female Students and Teams with Female Students for Peer Evaluation Behavior in Engineering Education’. In *Proceedings of the International Conference on Industrial Engineering and Operations Management 2019*, 609–619.
Zhou, Chunfang. 2012. ‘Fostering Creative Engineers: A Key to Face the Complexity of Engineering Practice’. *European Journal of Engineering Education* 37 (4): 343–353. https://doi.org/10.1080/03043797.2012.691872.