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Exploring technical college student's collaborative problem solving and teamwork skills in multi-educational level engineering design teams

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ABSTRACT

Manufacturing engineers work in teams with a wide range of skills and credentials. Teamwork and collaborative problem solving (CPS) skills enable higher productivity and efficiency. However, these skills are largely absent from engineering education curricula and research in contexts involving multi-educational teams inclusive of technical college engineering students. We address this gap in research and practice through a qualitative case study exploring the contributions, experiences, and perspectives of technical college students working in multi-educational level teams to solve real-world engineering manufacturing problems. Data analyses resulted in six themes: (1) positive team culture, (2) valuing industry skills, (3) sharing responsibilities to iteratively make changes, (4) applying technical roles, (5) peer interactions, and (6) career preparation. Technical college students' perceptions of challenges and successes are also discussed. Results imply that to effectively promote CPS and teamwork in similar contexts educators and industry leaders should consider the importance of (1) valuing students'/workers' current professional identities while promoting productive conflict, (2) respecting differing team roles while encouraging skill development, and (3) fostering future career skills.

ARTICLE HISTORY

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KEYWORDS

Collaborative problem solving; engineering design tasks; teamwork; technical college students

Introduction

A team of five technical college and university students gathered in a small research-to-application factory workspace near a car frame that was propped up on a simulated vehicle assembly line. The team was part of a 5-year grant-funded engineering training programme that facilitated industry-sponsored collaborative projects with integrated coursework where technical college students (referred to as 'engineering technicians') and university students (all engineering majors; referred to as 'engineers') were asked to solve complex, multi-level human and systems manufacturing design challenges. We refer to the students as engaged in multi-educational level teams as they were working together in the training programme while enrolled in technical education, masters, and doctoral programmes from two different educational institutions. Throughout the training programme, industry partners worked with the instructors and students identifying specific projects relevant to both the industry partner and the students.

The team began discussing a problem they were solving related to using artificial agents, or cognitive robots, to correctly supply components for complex assembly line tasks. Sammi (all names are pseudonyms), an engineering graduate student and the informal leader of the group reminded

them, 'There is research and an applied phase to our project. First, we need to test our ideas with people to see how complex the object assembly tasks are. We need to determine how to best create panels with buttons for parts of the car that simulates a workstation on an assembly line, and then determine how taskwork and teamwork can be augmented with an artificial agent'. Reggie and Thomas, two team members from Fox Hill Technical College (FHTC) serving as engineering technicians, started discussing ways to improve the group's design. They suggested creating an assembly line diagram and commented on ways to make the simulation more aligned with a true assembly environment. Over the next hour they provided advice to the larger group on how to cut panels, affix doors, and consider the height of the vehicle and wiring options to allow artificial agents to pull the wires through the panel freely.

For one 16-week semester, five two-year technical college engineering technology students worked collaboratively with graduate level engineering students (two master's and four Ph.D. students) solving manufacturing engineering problems for 5-6 h per week. Each student received tuition remission through the funded project, however none were paid stipends other than the standard assistantships held by the Ph.D. students. Working in two separate teams of five and six students, with two and three FHTC students on each team respectively, they addressed different real-world problems currently faced by regional automotive manufacturers: (1) a problem related to using artificial agents in a workstation-based assembly process in manufacturing plants to determine how their use might impact assembly line performance (Figure 1); and (2) a problem focused on converting a fully manual seat connection task into an augmented task using a combination of sensing and artificial intelligence systems on the shop floor (Figure 2). Figure 2(a) depicts the actual automobile seats and wiring harnesses for the connectors. Figure 2(b) depicts a pressure measuring instrument, a digital read-out tool, and a breadboard connected to a computer running a programme that provided more pressure data.

During their project work, we observed the students working in teams to solve manufacturing design challenges and then gathered their perspectives on the collaborative work. The observations and data collection took place in an educational vehicle assembly line built through a partnership with an international automotive manufacturer. The environment includes a simulated vehicle



Figure 1. Workstation-based assembly.

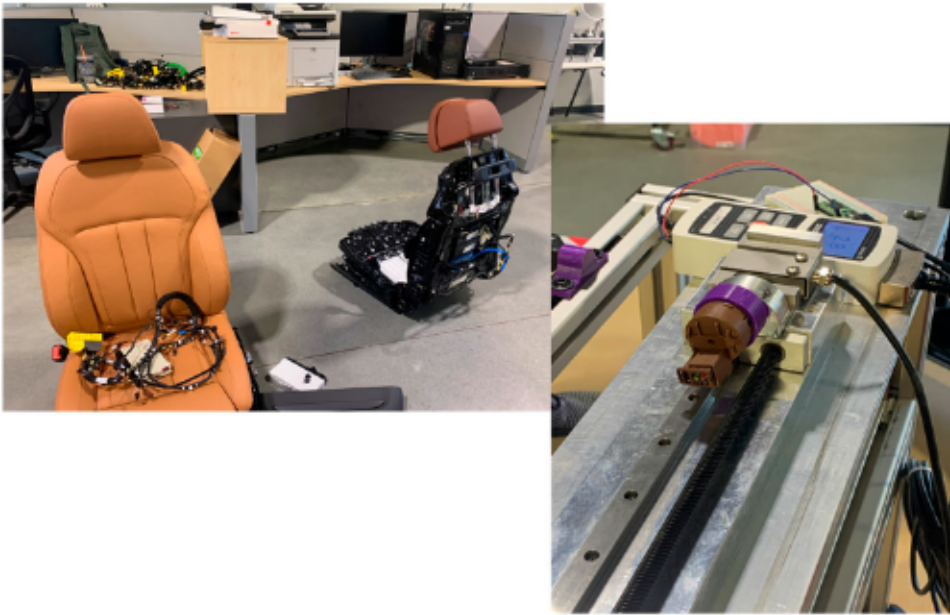


Figure 2. Manual seat connection.

assembly line with engineering design tools and testing facilities mimicking what might happen in a real manufacturing setting.

Purpose

The purpose of this case study is to explore the contributions and perspectives of technical college students working in multi-educational level teams to solve engineering manufacturing problems. In this training programme, the teams did not have a formal leader assigned and were encouraged to rely on one another's engineering and technical skillsets. Like other multi-functional engineering teams, they were organised to depend on team members' different yet complementary skills, mutual accountability, and interdependence (Horling and Lesser 2004). We draw on their experiences working and collaborating as team members in two separate project teams with graduate students (also referred to as 'university students' in this paper and as 'engineers') in order to understand ways they contributed, skills they acquired, and how they believed teamwork influenced their current work and what role it might play in their future careers. This case builds on our prior research detailing graduate students collaborating in engineering design tasks (see Herro et al. 2021). Our goal is to understand how technical college students perform in teams with students from varying education levels. This is a first step towards supporting other technical colleges and universities to consider ways to offer similar instruction and training that leverages the skills and needs of students at various levels of education to facilitate learning, better teamwork, and efficient problem solving.

The research questions guiding this study in the context of an educational activity are:

- (1) How do multi-educational level engineering design teams impact technical college students' collaborative problem solving and teamwork skills?
- (2) What are the technical college students' perceived benefits and challenges, towards collaborative problem solving and teamwork experiences?

Literature review

Productivity, efficiency, and the quality of engineering products and services are often increased by teamwork (Conde and Holgado 2020). Teamwork is essential for engineering students, therefore they need educational experiences that incorporate collaborative problem solving (CPS) and challenge them to develop teamwork skills (Murzi et al. 2020). One promising approach, Conceive Design Implement Operate (CDIO), is a global initiative encompassing standards-based curricula used to assist undergraduate students to integrate engineering coursework, real-world work environments, and teamwork through hands-on active learning (Kulkarni, Patil, and Pawar 2020). Yet despite promising initiatives such as CDIO, limited research explores how to integrate and assess CPS in technological education curriculum or across multi-educational levels. Furthermore, most research on teamwork has occurred in the workplace versus college or educational training endeavours (Han 2020). Siloed coursework and limited training in teamwork and communication have hampered student opportunities to gain practical engineering experiences (Hurst, Rennick, and Bedi 2019).

This study contributes to both research and practice. However, it is important to first provide a framework through which to understand teamwork and CPS more clearly in relation to engineering education and engineering technology contexts. We review literature to provide an overview of engineering technology skills and teamwork. Next, building on the understanding of teamwork, a foundational component of CPS, CPS is presented through the perspective of engineering technology. Finally, the literature review concludes with the conceptual framing for the research in this study. The conceptual framework focuses on conceptualising CPS and teamwork integration through real-world problems using a CPS framework drawn from elements of the Educational Testing Services (ETS) CPS framework that was adapted using skills specific to engineering design challenges.

Engineering technology skills and teamwork

Teams are essential to the practice of engineering in manufacturing environments. Engineering technicians play a vital role on engineering teams yet there is little research about their educational pathways, role, and capacity to contribute to the workforce overall (National Academy of Engineering 2017). In engineering teams, engineering technicians are the hands-on members who apply specialised knowledge of existing components and engineering systems. They work collaboratively with the engineers who focus on the theoretical design, development, and application of new technologies and engineering systems. All members of the team possess and apply similar foundations of knowledge and skills but differ in ways that they cope with levels of emphasis and complexity. For example, professional engineers often focus on theoretical and broad details, while engineering technicians focus on practical, specific details as they carry out tasks. In the United States engineering technology includes a clearly demarcated set of programmes. Internationally, in Europe for example, the 'technology' distinction is not used as often but the distinctions between theory-focused and practice, or application-focused engineering programmes are similar (Dyrenfurth et al. 2007). Internationally engineering technology roles and responsibilities focus largely on hands-on applied practice but may have specific nuances based on government policies and employer expectations in differing economies (Hussain et al. 2015).

Teamwork is defined as 'a process that describes interactions among team members who combine collective resources to resolve task demands' (Schmutz, Meier, and Manser 2019). Factors that can impact the effectiveness of teamwork may include team characteristics (composition, size, etc.), task type (routine versus non-routine), realism of the task (simulated versus real), and type of performance measures used (Maloney et al. 2016). Common teamwork competencies include knowledge (about the subject matter and teamwork), skills (in communication and feedback), attitudes (beliefs about teamwork), communication, commitment (dedication to teamwork),

standard (concern for quality of work and desire to excel), focus, team cohesion, team empowerment, team learning, self-management and self-leadership, and attitudes of open-mindedness, flexibility, and adaptability (Oliveria, Lawless, and Molloy 2017; Tang 2021). Many attributes of teamwork parallel attributes of CPS, as teamwork is an essential part of CPS.

Previous studies in engineering education have linked the importance of teamwork to professional identities (Tonso 2006). Engineering professional identity is the extent to which students view themselves as engineers and is important to persistence and retention in the field (Eliot and Turns 2011). While collaboration and teamwork are critical to engineering and workplace competencies, their role in developing professional identities in collaborative learning and team settings is often overlooked (Chen, Kolmos, and Du 2020). In engineering education, team-based projects have been found to support creative skill-building, enhance employability skills such as teamwork, and positively impact engineering professional identity (Chen, Kolmos, and Du 2020; Habib, Nagata, and Watanabe 2021). Moreover, helping students appreciate and reflect on diversity (social, cultural, and experiential) within teams through self-awareness of one's own and others' strengths and weaknesses (part of one's identity) must be taught for successful teamwork (Long, Rajabzadeh, and MacKenzie 2017). This also provides students the opportunity to recognise other multifaceted forms of diversity impacting team effectiveness including human capital (skills, knowledge, and expertise) and social capital (individual networks and relationships) (Tasheva and Hillman 2019). Similarly, exposing students to constructive conflict, where the benefit of the conflict outweighs its cost and can lead to improved understanding, integration of tasks, and productivity (Tjosvold, Wong, and Feng Chen 2014), is an important mindset to integrate across engineering curricula.

Collaborative problem solving in engineering technology

Collaboration, discussed here as CPS, is an approach where teams use critical thinking, problem solving, and decision making to work towards a common solution to an ill-structured problem (Care, Scoular, and Griffin 2016). Four primary components comprise CPS: teamwork, communication, leadership, and problem solving (Oliveria, Lawless, and Molloy 2017). CPS is defined as.

the capacity of individuals to effectively engage in a process where two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution by pooling their knowledge, skills, and efforts to reach that solution. (OECD 2017, 47)

Much research has been published about the need and benefits of integrating problem solving into engineering higher education curricula (Danaher and Schoepp 2020; Jonassen, Strobel, and Lee 2006; Passow and Passow 2017). This CPS research has demonstrated many benefits including increased student achievement, engagement, and development of higher order learning skills (Unal and Cakir 2021). Further, in engineering education, CPS has been used to explore engineering identity (Khosronejad, Reimann, and Markauskaite 2021), ways to tackle complex engineering challenges while promoting collaborative skill development (Zou and Mickleborough 2015), the use of asynchronous discussion boards and virtual learning environments (Danaher, Rhodes, and Kranov 2020), and even post COVID-19 virtual experimentation activities and online learning (Du et al. 2023). While this research notes many positive skill-building and learning benefits, limited studies focus on CPS in the context of technical and vocational education in areas of nursing, basic electricity, computer programming, mathematics, and English (Ozkara and Cakir 2020; Papantoniou and Hadzilacos 2017; Unal and Cakir 2021). These studies have found that integration of CPS significantly increased student knowledge retention, increased active learning engagement, and workforce readiness (Nwalo and Eze 2021; Oliveria, Lawless, and Molloy 2017; Unal and Cakir 2021). However, there are nearly no studies with a specific focus on technical engineering education (Jabarullah and Hussain 2019).

Integration of CPS in problem-based design courses can lead to more efficient use of peer reviews, better co-construction of knowledge and shared ideas, and increased collaboration skills

(Bissett-Johnson and Radcliffe 2019). In fact, many studies suggest that in engineering education technical competence and effective collaboration cannot be separated and are essential elements of the curriculum (Passow and Passow 2017). Still, across these studies, very few examine technical college engineering education application of CPS problem-based design and teamwork, and none examine the impact of a multi-educational level team. Thus, a gap exists in research exploring engineering technology students' CPS working in multi-educational level teams. In this project, one way that we addressed this gap was by intentionally posing problems for students to solve that encouraged them to gain content knowledge and technical skills through collaboration, communication, and digital and non-digital tools regularly facilitated through teamwork.

In sum, CPS encompasses many skills and is critical to educational success and career sustainability (Nelson and Squires 2017). Integration of CPS into postsecondary two-year college technological education can better prepare students for jobs that entail challenges that are complex and require solutions from multi-functional teams. When considering engineering design projects involving CPS, there is a need to address the gap in the literature understanding and describing ways that multi-functional teams, including multi-educational level teams, might collaborate to effectively solve common manufacturing problems (Chowdhury and Murzi 2020).

Conceptualising teamwork and CPS integration through real-world problems

As engineering and engineering technology careers become more diverse in title, role, and responsibilities; skills including teamwork, communication, and problem solving are becoming increasingly more critical to success in the labor market (Durkin 2016). Using real-world problems better prepares students for industry; therefore, authentic projects should be presented in cooperation with industry to improve student motivation, teach real-world problem-based design, and promote CPS and teamwork (Murzi et al. 2020; Zhou, Kolmos, and Nielsen 2012). While there are multiple frameworks for CPS, most notably the Organization for Economic Co-Operation and Development (OCED) Programme for International Student Assessments (PISA) and the Educational Testing Services (ETS) frameworks, all contain a collaborative social element and teamwork. The ETS CPS framework assesses CPS broadly and includes four skills: sharing resources/ideas, assimilating and accommodating knowledge/perspective taking, regulating problem-solving ideas and maintaining positive communication (Liu et al. 2016).

These CPS frameworks informed our conceptualisation of CPS, however they assess skills in a general manner, removing all context from the operationalisation of the construct, which makes sense for large organisations. In smaller contexts, such as students working in engineering design teams, there are often educational approaches that incorporate collaboration specific to content and tasks. Therefore, we developed a framework and accompanying CPS assessment rubric (utilised in a prior study and further described below; see Table 2) which identifies skills, or attributes, specific to engineering design challenges under the broad dimensions of *Peer Interaction*, *Positive Communication*, *Tools and Methods*, and *Iteration and Adaption*. This CPS rubric also guided our observations when collecting data.

Methods

We use qualitative intrinsic case study to explore the experiences and perspectives of the technical students working within two multi-educational level manufacturing engineering teams. Intrinsic case studies are often exploratory and emphasise reconstructing experiences to capture the complexity of the problem while focusing on interpretation and meaning (Stake 1995). Intrinsic case study allows researchers and readers to learn while drawing their own interpretations. Our case is bound by the technical college students participating in the collaborative team manufacturing engineering program during the 2021–2022 academic year. This case allows us to answer 'how', 'why' or 'what' occurred in the context of the environment (Stake 1995). In this circumstance we

were interested in understanding how technical students participate in manufacturing engineering teams and what occurred related to CPS and teamwork during their participation.

The context

Participants

Five two-year technical college students participated in this study, 4 male and 1 female; 4 were in the Mechatronics Technology Associate in Applied Science program, and 1 student was in the Electrical Engineering Technology Associate in Applied Science program with an intention to transfer to the university programme for an Electrical Engineering Bachelor of Science (Table 1 includes participants' demographic information).

One participant was 19 years old, three were 22 years old and one student was 32 years old. Four of the five were non-traditional students meaning they held other jobs while simultaneously attending technical college. Students were recruited through their technical college instructor based on potential fit (above average GPA, student interest, current skill level) as part of a funded project designed to encourage student training within multi-educational level engineering manufacturing teams to prepare for continued or future careers in manufacturing. We acknowledge that this convenience sample, where students were selected based on overall fit for this programme, may not typify students in all technical and university programmes or the make-up of industry teams. The study was approved by the sponsoring university's Institutional Review Board (IRB) and all students participated with informed consent.

Industrial challenges posed to project teams

Technical college students met with university students to learn about the projects two months before the spring semester and project work began. After each project challenge was explained, teams visited the associated manufacturing plant and observed the current assembly in order to outline and visualise current operations and note opportunities for possible integration of solutions. Two instructors, who were not a part of the research team, met weekly with the project teams for 30–45 min for check-ins to discuss their progress, receive updates or briefings and assist with problem-solving. Occasionally an industry partner or guest speaker would also attend the check-ins. Each weekly meeting with the instructors was followed by approximately three hours of lab time where the project teams held their own meetings specific to each industrial challenge and worked independently of the instructors. Each team created a set of future visions of the operation as it could be in 10 years with the inclusion of automated sensing and/or artificial agent assistance systems. Teams defined the scope of their project, created and tested hypotheses of what might work, and defined metrics to measure their performance. They also made supply lists of resources needed for each task. Throughout each project the teams updated the instructors, industry partners – several who were engineers, and one another about their progress and to ask for feedback. Both teams engaged in tasks related to building the physical systems, designing/sourcing the software systems, and designing performance tests. Students' grades were not directly based on CPS or teamwork contributions, or roles such as coaching or mentoring.

Table 1. Technical college student demographic data.

Student	Race	Gender	Major	Student Status	Years in Current Job
Student A	White	Male	Mechatronics	Full-time	12
Student B	White	Male	Mechatronics	Full-time	4
Student C	White	Male	Mechatronics	Full-time	4
Student D	Hispanic	Female	Engineering Transfer	Full-time	1
Student E	White	Male	Mechatronics	Full-time	4

Procedure

Although the research project spanned the entire academic year 2021-2022, most of the data was collected in the 2022 spring semester. The lead university faculty member collaborated with a two-year college faculty member to schedule visits and data collection. Before the semester began two members of the research team visited the educational factory to contextualise the study and better understand where the teams would be working. At the beginning of the semester (early January), researchers collected initial interview data and observed the students working in teams. Approximately 1 ½ months into the semester (late February) researchers returned and observed the two project teams. As noted above, observations were guided by an evaluation rubric that focused on CPS. After groups completed their work for the day, the post-observation interviews were conducted. Finally, near the end of the semester (April) there was a final observation, again using the CPS rubric, and a final interview. Artifacts were collected throughout the semester.

Observations

Four members of our research team observed the technical college students three times over the semester, for approximately 90 min each time. The researchers used an observation rubric designed to capture attributes related to four dimensions of CPS including: *Peer Interaction*, *Positive Communication*, *Tools and Methods*, and *Iteration and Adaption*. Attributes of the dimensions included items such as ‘monitors tasks and checks for shared understanding with peers, divides work to complete tasks, may assign or negotiate roles, listens and takes turns, provides peer feedback, uses tools collaboratively’, etc. (See Table 2 for abbreviated rubric). The rubric includes a space for notes to justify each rating as ‘not evident, emerging or proficient’. To ensure consistency in observations, one researcher who developed the rubric and used it frequently trained the other researchers. Students were observed individually, using a separate rubric for each student during each observation. To increase accuracy, two research team members observed the same team and met to discuss and collectively interpret the observations. The rubric was modified from a prior validated rubric with a Fleiss kappa = .65 indicating substantial agreement (Landis and Koch 1977; see Herro et al. 2017) used to assess students CPS in STEM-related challenges. This type of rubric was designed to provide a relatively quick observation of the students’ ability to collaborate and is consistent with what often happens in industrial settings where workers are assessed based on their ability to work with others, communicate effectively, and use appropriate tools.

Semi-structured group interviews

Two members of our research team interviewed students, in groups of two and three, three times over the course of the semester: within the first two weeks, midway through the semester and in

Table 2. Abridged CPS evaluation rubric.

Dimension: Peer interaction
Monitors tasks and checks for shared understanding with peers
Divides work to complete tasks; may assign or negotiate roles
Provides peer feedback, assistance and/or redirection
Dimension: Positive Communication
Respects others’ ideas and compromises
Uses socially appropriate language and behaviour
Listens and takes turns
Dimension: Tools and Methods
Identifies and defines task(s) Negotiates relevant method or material to solve the problem
Uses tools collaboratively to complete the task(s)
Dimension: Iteration and Adaption
Demonstrates iterative thinking
Tests designs, prototypes or solutions
Develops and directs revisions in designs and/or prototypes

the final week. Interviewers assured the students their individual responses would not be shared with the instructors or impact their grades. Each group interview lasted between 45–60 min; they were conversational in nature and designed to elicit responses related to describing and reflecting on ways they worked as a team and collaboratively solved problems. In each interview, students were asked questions such as, ‘How would you describe your project? Can you tell me about ways your team communicated? How would you describe your interactions with peers? Are there any skills you brought to this project? Do you think you will use anything you learned in the future?’

Artifacts

Each team shared the presentations that they developed and added to throughout the project, folders with documents related to the project, grading assessment guides, project overviews and pictures. The artifacts helped us to understand the scope of the project, expectations, and process in developing their final products and were used as secondary sources to assist in describing and understanding the case.

Data analysis

Two members of the research team independently conducted an intensive reading of all qualitative data creating memos of the participants actions, statements, and perceptions (Charmaz 2003) related to understanding and describing their work and role with each team. Initial, broad patterns in data were discussed to guide a priori and open coding. Data were imported into Maxqda (<https://www.maxqda.com/>) software for organisation and analysis. We used a thematic analysis doing a second reading of the data beginning with transcribed interviews and observations and drawing on a priori codes from the CPS rubric, including the notes at the bottom of each CPS rubric, and our memos to code and categorise all data and note emergent codes. Data were coded and triangulated across data sources until reaching saturation (Saunders et al. 2018). Our team met several times to compare and winnow codes, discuss and form categories, and reach consensus (Cascio et al. 2019), and included a third member of the research team to check the codes for accuracy. The categories were then analysed and developed into themes. Finally, the artifacts were analysed as secondary sources to better understand the project expectations and processes during the problem-solving challenges. Table 3 provides representative examples of theme, data source and related codes.

Results

Our analysis resulted in six primary themes related to the technical college students’ experience, which assisted us in answering research question one. They include (1) positive team culture, (2) valuing industry skills, (3) sharing responsibilities to iteratively make changes, (4) applying technical roles, (5) peer interactions, and (6) career preparation. We discuss each finding below and acknowledge some natural overlap between the themes.

(1) Positive team culture

Before the project teams worked together, several technical college students voiced interest in participating with diverse teams (in terms of skills and education) but also concerns over how their team might work together, saying things such as ‘I don’t know how much help I am going to be’ and ‘I don’t know how much PLC work we are actually going to be using for this’ (referring to his interest in programmable logic controllers). However, as the semester wore on, all FHTEC students commented on how quickly the team gelled believing the culture was positive, accepting, and assisted in their productivity. It appeared the engineering technicians expected to feel intimidated by the engineers, or that they would be treated with less respect because of their different skill set,

Table 3. Representative examples of themes and coded data.

Theme	Source	Coded Data
Team Culture	Observation	The FHTC joke around with everyone on the team and are respectful. One asks questions of the university students such as 'How are we going to vary the wiring? What were we thinking about for the structure actually having that piece? How are we going to affix it so it doesn't stick out?' There is clearly a lot of respect for all of the team members evidenced by the respectful and easy conversation, occasional joking around and way that they listen to one another.
	Interview	'Everyone kind of accepted each other and everything that came with it. It is open communication through the whole group. If you have a question, just ask and someone will give you an answer if they know it. If not, they will figure it out and let us know. It is kind of open communication between six people'.
Perceived Skills	Observation	Reggie suggests that they use an assembly diagram (to show the students who will be testing their structure with buttons). He also explains why it would make sense to work together to test the device and not do it separately after Thomas discusses testing it with 'high variability and low variability' based on his past experiences.
	Interview	'We don't all have the book smarts like engineers, like how to design things in a certain way. I could probably pick up anything and put anything together. Within reason, obviously'.
Changes and Iterations	Interview	'XXX (the company) is having a technical problem with motor connections from electrical plugs so we are trying different solutions. We came up with possible solutions based on testing, we are working through six different ideas kind of at the same time ... we decided we can give them data and the knowledge that this might work'.
	Artifacts	FHTC students created several prototypes of the door panels with buttons after repeatedly testing them with the full team.
Project Roles	Observation	Riley seems to be respected and valued by the team and listens attentively. He stands back much more than Tammi but is a productive team member – getting tools and resources, asking Tammi and the university students questions. He also mentions how work is addressed at XXX (the company) differently where they both work.
	Interview	'I'm task oriented. I like to know that I am going to do and just go do it. When Sammi said 'go do this' it was just the perfect thing to do. I'd say the engineers, they kind of do the behind-the-scenes stuff and we are actually doing more of the physical stuff'.
Peer Interaction	Observation	Thomas checks in with Sammi and the other graduate students often and provides feedback to team. He refers to a problem a student had when they tested the ability to assemble parts to affix to a door. Thomas mentions she struggled to use all of the parts and suggest the process isn't 'true' to an assembly environment at all. He clarifies how many buttons and panels should be on the door. Thomas takes redirection (and asks for it) from Sammi often. Sammi appears to be the informal team leader.
	Interview	'Today, I just appreciated the clarification that the grad students gave us. I've made a connection with Scott (grad student) because we share a lot of common interests. We kind of all just get along'.
Career Preparation	Interview	'One of the biggest things I've learned is how to interact with people that we go and visit (referring to industry tours). The university students are friendly, but professional and they communicate extremely well. I've learned from that and can use it'.
	Interview	'When it comes to building and fixing stuff, I can do that. When it comes to coding and crunching numbers and stuff, I've learned a lot that I can take with me from this programme. This programme is more conceptual where we gather a ton of data and see how we can use it to solve problems. I'll carry that with me'.

but instead were integrated into the team. For example, one student noted, 'none of us knew each other, but there were no butting heads on ideas, we are all on kind of a level playing field'. Another FHTC student discussed the usefulness of Friday 'team meetings' to go over their tiered approach to problem solving, believing it set the tone for positive culture and productivity. A third student commented, 'we joke around and have fun with it, I mean we are not in a super serious environment, we are free to say what we want'. At the same time, they also noted how the teamwork was much more 'professional than what you see in a factory setting', indicating that while they had the freedom to behave and say whatever they wanted, there was an unspoken level of respect for one another as professionals.

During observations we noted how the teams appeared to divide tasks based on perceived skills yet functioned well together and checked in with one another often. We noted that positive team culture and open-minded discussions impacted the technical students' CPS and teamwork skills

by making the students feel valued and professional, and therefore appeared to make them want to work harder to solve problems and draw on appropriate expertise.

That said, while the team members shared goals, they continued to primarily contribute based on their current skillset. Thus, despite getting along well and sharing goals, the team culture also posed a limitation in that the technical college students rarely brought forth any viewpoints that diverged from the graduate students' problem-solving approach or perspectives.

(2) Valuing industry skills

The FHTC students recognised their skill set was different from the university students and perceived their skills as more technical and practical in nature, in particular when it came to using tools. One student explained,

They (referring to the university students) have great knowledge of theory and concepts, but they also have slightly different skill sets. They like to tell us how to stay organized and managed, they can manage their professional relationships extremely well ... but they sorta brought us in because we worked in factories, we know how that stuff goes.

One student commented that before he worked at his current job (an automotive manufacturing company) he bounced around as a mechanic for his father and worked construction jobs. He believed this provided knowledge across fields and made him think constructively when using tools and solving problems. He explained, 'Being a person from the workforce or field, I've seen and done some stuff that they haven't. So, I feel like I just bring a different perspective when it comes to tackling a task'.

In week five, one student summed up their skill set and utility on the project team based on their current progress at FHTC saying,

Going through the mechatronics program, we've learned pretty much the basics of hydraulics and pneumatics, robotics, PLCs, and electrical engineering. You know, the four basic types of engineering. I am not exactly sure how we will use these skills with the team, but this will give me experience working with engineers and this will give them experience working with maintenance technicians which is important for them.

Several of the FHTC students discussed how they were brought in to provide a 'real world connection' since they 'worked in factories and stuff like that and actually know how things go'.

During observations we noted how the FHTC students often checked with a university student, who tended to be the informal group leader, but then partnered up with another FHTC to do more technical work such as taking measurements, affixing panels, checking the voltage of batteries etc. In each observation, separate members of the research team noted how the FHTC students directed the use of the materials and tools, but often checked in with the university students to ask questions and confirm they were on the right track. The project roles were not assigned, however the students typically identified with their role (see section below) based on their perceived skills. While valuing industry skills is important, it also posed a limitation in that the FHTC students had difficulty seeing themselves outside of the role of technical workers, which greatly reduced their task conflict, and may have limited their consideration of alternative solutions (Rexhepi et al. 2019).

(3) Sharing responsibilities to iteratively make changes

In several of our observations we noted how comfortable the students were in discussing problems to solve and making changes after trying initial ideas or after testing portions of their prototypes. For example, one team was testing a motor connection with electrical plugs that were often incorrectly seated and trying to find a way to ensure the loose connection would not get overlooked on the assembly line. After several team meetings to pitch, sketch, and revise their ideas, the team came up with an initial concept to use an IR (infrared) camera or thermal camera to detect the heat signature between the two connections. After creating a mock-up and prototype of how it might

work, they eventually abandoned the idea in favour of a proof-of-concept solution that involved a small camera that would train software that was less expensive and viable to present to the company. Several FHTC students commented on the value in their morning meetings, which were held at least once a week, to help them revise their thinking or approach. This excerpt from a FHTC student exemplifies this idea:

So, we pretty much had one of the morning meetings and Scott (a graduate student) said, 'hey we need to pare back, let's gather around the whiteboard and talk about the list of tears (referring to the prototype not working correctly) and what is going on, and what to repair', so we made changes based on data and Scott explained the rationale and we were all there to hear it.

Another FHTC student devised a work-around to get a more accurate reading from a computer program by unplugging the USB cord on the pressure measuring machine to freeze the program as soon as the part 'clicked' and connected. He checked in several times with an engineering student who encouraged him to use the data to make changes and suggested he was 'on to something'. Similar to several observations, in this exchange we noticed how the FHTC students relied on the university students for feedback to direct the iterative process of problem solving, resulting in the FHTC students taking a more data-driven approach to trying again.

(4) Applying technical skills

Regarding how FHTC students perceived their role in the project, a recurring theme from the observations and interviews was that they wanted to contribute and feel like an 'equal' to their teammates, and also believed their role was more task-oriented than conceptual or organisational. Before working with the team several FHTC students expressed concerns about exactly what they would do and how they would be treated, but after one meeting they noted that everyone on their team seemed open to new ideas and 'nice'. As they began working with their team, they often discussed the fact that while completing tasks they were able to learn from others. During the project, two FHTC students described their relationship with the university students by saying, 'they are like having a mentorship relationship sometimes. It is really helpful to help guide us ... they helped guide us through'.

Another FHTC student commented:

I think my favorite part of the project was trying to code like Natasha (a university student). And then when we had our first meeting, Natasha was like, 'you set up this hardware.' Her telling me to do that was perfect because it was exactly what I needed to do, and I enjoyed setting it up (referring to what he learned by setting it up and working with Natasha).

One FHTC student commented that, 'engineers – they kind of do more of the behind-the-scenes stuff, and we are actually doing more of the physical stuff', another explained, 'we have more implied roles and we're all designing together and bouncing ideas off of each other, but it depends on who has the most expertise'. He went on to suggest that the graduate students tend to be the ones who 'keep the momentum going and supply the ideas'. The FHTC students made no distinction between the master's and PhD students, they seemed to consider all of them as 'engineers'. Furthermore, the students did not comment about their interactions between other engineering technicians other than to say they got along well together. This may be attributed to the structure of the interview as they responded alongside other engineering technicians. Despite the positive outcomes when dividing work based on areas of specialty or expertise, here, we also noted the application of technical skills with little discussion (much of how they believed they should contribute was 'implied') between the technical and graduate students contributing to a missed opportunity to articulate and clarify their positions (Rahim 2023).

(5) Peer interactions

In observations and discussions, it was evident that peer interactions were positive within both teams. It is important to note that although prior research indicates that women in engineering education programmes deal with intended and unintended micro-discrimination during group work (Abey et al. 2019) our study was not designed to specifically capture these behaviors. All FHTC students described their satisfaction with the make-up of each team and believed the positive interactions were key in helping them learn more and contribute positively. Some pointed to the Friday project team meetings as an opportunity to understand one another's reasoning and knowledge about ways to solve problems and manage conflict constructively (Tjosvold, Wong, and Chen 2019). The FHTC students felt free to ask questions and gain deeper understanding of theories regarding why processes made sense, and often applied this learning to the team's solutions.

All five of the FHTC students seemed genuinely surprised and happy that the teams meshed and interacted easily. One FHTC described his interactions with the university students as 'I feel like an equal, and Scott... he feels like an older brother'. When referring to the university students, another FHTC revealed, 'I like the insights they can bring, like they looked at my code and showed me things I didn't understand before. I like how quickly we can figure something out [together]. I think I will know more coming out of the programme'. Several of the FHTC students discussed how their opinions seemed to matter and they felt valued because the peer interactions were positive.

This excerpt from a final interview exemplifies their thoughts regarding their interactions:

It's open communication throughout the whole group, honestly. I mean if you have a question, ask it. They will give you an answer if they know it. If not, someone will figure it out and let us know, it is kind of an open communication between six people. They take our ideas into consideration and that comes with a level of respect.

This quote points to the *emergence* of a coaching role for the engineers, where the engineering technicians felt free to ask questions but looked for direction to help deconstruct issues and solve problems. This finding also indicates the FHTC students were, at times, exposed to new, different, or conflicting ideas and found it rewarding to discuss the ideas with their team.

(6) Career preparation

The FHTC students were intentional about participating in this industry sponsored project to improve their future skills and position them for advancing in their careers. In pre-interviews they discussed wanting to improve their skills as an engineer and have insight into problem solving. A couple of FHTC students were interested in improving PLC skills or learning more about artificial intelligence and robotics in particular, and one mentioned that 'watching organisation and communication skills evolve on a team might be useful'. An interesting finding related to career preparation was how useful the FHTC students believed the collaboration, communication, and process of working as a team to solve problems would be to their future career. They described the project as helping them learn much more than the technical skills they were trained in for the current work or through the technical college programme. They pointed to tools used for communication and problem solving such as using Microsoft Teams efficiently, getting code from GitHub (<https://github.com/>), sharing files collaboratively, and using data effectively. They also believed knowing how to write an email using proper etiquette were important skills that would help them in their future. One student summed up the importance of the skills they would use in their future by explaining:

Our project isn't as technical like what we do at work. What we do at work is literally things break, we go fix it. Pretty simple. It's electrical problems, mechanical problems ... just go take care of it. This was more conceptual. Let's gather a ton of data and see how we can use that data to solve the problem. That has also given us exposure to 'please and thank you' as well (referring to soft skills useful in the future).

Perceived successes and challenges

To answer research question two, we detail the technical students most commonly discussed perceived benefits and team challenges when working with project teams to assist other wishing to promote multi-educational level teams to solve engineering problems.

All five students expressed appreciation for being invited to participate in the programme and felt satisfied with the level of support from the industry partners and university, and in learning from one another. They identified several successes from their involvement such as: learning how to problem solve more effectively by using data and talking through ideas, strengthening their understanding of PLCs, learning to code from others with more experience, honing their communication skills, discussing the theory and process behind ideas (such as heat transfer, chemical reactions when soldering, how audio and cameras might work together), and practicing professionalism (several students referred to how 'crass' workers were on the factory floors of their current jobs compared to working in these project teams).

In terms of challenges, the FHTC students typically pointed to processes or prototypes not working correctly or struggling to understand concepts but did not see their work within the team as challenging. One student suggested that it was advantageous to have so many 'personalities and backgrounds from maintenance and from engineering students' and then said there were not any real challenges with their team and referred to the 'advantage of practicing collaboration and teamwork skills'. The only challenges the FHTC students specifically identified were understanding some of the programming concepts, how to use particular electrical equipment or the best way to approach solving a problem. One FHTC student discussed the tool they were developing (a glove with a camera and microphone) as having several attachments and trying to determine what time and resources had the 'most promise' to devote to fixing the problem. Another FHTC said, 'we had many good challenges, but not in a bad way. At least the ones I feel like I am facing are in terms of understanding the material' (referring to required book work as part of understanding the project). The general lack of challenges identified by FHTC students may appear positive, however we also saw the limited challenges they discussed as a missed opportunity for the FHTC and graduate students to realise the importance of identifying challenges within teams that may lead to innovation in their resolution. Broadly, this implies a need to teach multi-education teams about friction, constructive conflict, and resolution as important principles of healthy teamwork. One way forward is to use scenario-based practices and simulations and reflect on team roles and conflict (Mathieu et al. 2000); another tactic is to consider ways team mindfulness may assist in reflexive processes and the reduction of false consensus (Selart et al. 2020).

Discussion

Our findings detailed through the six themes above and successes and challenges make three unique contributions related to better understanding how multi-educational level engineering design teams impact technical college students CPS and teamwork skills in the context of project work. To effectively promote CPS and hone teamwork in similar contexts educators and industry leaders should consider the importance of (1) valuing students'/workers' current professional identities while promoting productive conflict (2) respecting differing team roles while encouraging skill development; and (3) fostering future career skills. We acknowledge the similarities between identities and roles as identity can influence an individual's role(s). However, identity typically describes 'who you believe you are' and roles describe 'the part that you play' (Walsh and Gordon 2008).

Valuing professional identities while promoting productive conflict

Throughout the project duration, technical college students continued to have a tight professional identity around practical/technical skills and real-world experiences, and believed their contributions

mattered. In early interviews several FHTC students discussed their professional identity as maintenance engineers at their respective manufacturing factories and seemed genuinely surprised that the university students valued their manufacturing experiences and skills. They expressed who they were and what they could contribute during assembly line processes where they often took the lead in manually fixing electrical or mechanical issues. Their tight professional identity did not wane, but instead strengthened as the project and problem-solving became more complex (several iterations did not work as planned and they had to ideate, test, and try again) and required rethinking their approach after receiving input from the team.

To some extent, the FHTC students grew their identity beyond technical skill experts and acknowledged building new problem solving and teamwork skills and mindsets that contributed to a stronger identity as a professional engineer. Working in multi-educational level teams may contribute to more positive professional identities where technical education students view themselves as both technicians and engineers (Chen, Kolmos, and Du 2020), which in turn may increase persistence and retention in the workplace (Khosronejad, Reimann, and Markauskaite 2021). This seems particularly important for technical college students who are likely to already have a work identity they can draw on and extend to productively contribute during problem solving yet may initially feel less professional than the engineers they work alongside. That said, this finding of valuing professional identities may also limit team members ability to expand their profession identity if educational, skill, and interest-based diversity are not fully recognised and team members feel confined to their current, perceived professional identity. For instructors this points to the importance of helping students make their diverse, growing skillsets and disciplinary knowledge explicit through continuous assessments such as checklists or rubrics. These useful tools might guide team meetings and nurture positive collaborations.

Feelings of empowerment and cohesion were evidenced in ways FHTC students talked about being on a level playing field, joking around, feeling confident in the skills they brought to the project, and believing that their ideas were heard during team meetings. This positively impacted feeling valued and seemingly impacted skills such as team empowerment, cohesion, and open-mindedness (Oliveria, Lawless, and Molloy 2017). The morning meetings served to bring to light issues the whole team was facing, and the motivation to find a new solution was shared by the entire team. However, the team member who identified as the expert in 'doing' technical work, based on their experience working in a factory, or using data-driven or conceptual approaches based on their university coursework, typically weighed in. In each project, the team culture and natural division of roles (discussed in greater detail below) based on prior expertise fostered an openness for, and acceptance of, different skill sets and respect for expertise – whether it be technical or theoretical. This finding implies that working within multi-educational level engineering teams that function similarly, wherein technical skills and real-world experiences are seen as an important contribution, openly discussed, and used to drive problem solving, may foster productive collaborations. Similar to documented findings from other practice-related learning opportunities, multi-educational level engineering teams where students work in authentic learning situations via internships, innovation hubs, or on company projects, may provide excitement and motivation to increase relevant teamwork and CPS skills (Hadgraft and Kolmos 2020). Despite the level of empowerment and motivation the FHTC students expressed, an important future research consideration is the inclusion a broader selection of students to better represent and mimic workforce teams.

Our research also implies that the environment (simulated factory setting) in addition to the multi-educational level teams may contribute to professional identity. While simulated assembly lines are not possible in many educational settings, integrating multi-educational teams in real factories through internships or industry, technical college and university partnerships may be feasible. However, our findings also suggest a general lack of team friction, other than some constructive controversy when trying to understand how to apply new ideas between the engineers and engineering technicians. This is likely not the norm in many factory or industrial settings and may be a limitation when trying to promote productive multi-functional teams. For engineering educators wishing to

promote multi-educational level teams, our research points to the need to consider and integrate models of open-minded discussions in coursework to assist students in identifying the productive benefits of conflict versus acquiescing to other team members (Tjosvold, Wong, and Feng Chen 2014). Models to conceptualise how to bring forth and discuss conflicts (e.g. express, understand, integrate, and agree) and manage team performance and effectiveness offer good starting points for curriculum integration and workplace learning (Murzi et al. 2020; Tjosvold, Wong, and Feng Chen 2014).

Respecting differing team roles while encouraging skill development

Throughout the duration of each of the projects, the team culture of professionalism for *all* workers assisted in feelings of respect for one another's roles and expertise. Technical college students had a strong desire to make a significant contribution and not be in the 'backseat', yet they often seemed to take semi-subservient roles to the university team members. Similarly, each team's leadership roles were informal meaning they were not assigned but instead they emerged – yet they were typically held by the university students. There was an unspoken but shared understanding that the technical college and university students would pool their knowledge, skills, and efforts to solve each problem, akin to OECD's (2017) definition of CPS. However, this 'pooling of knowledge' often constrained the students at all education levels to stay within their implied roles and limited their ability to contribute to the team. We noted more leadership and mentoring skills from the university students that mirrored informal coaching or cognitive apprenticeship (Bockarie 2002) to increase subject matter, design and planning knowledge to assist the engineering technicians. In interviews, the FHTC students suggested solving these complex problems using teamwork provided opportunities to expand upon their prior knowledge and experiences, yet the FHTC students typically only contributed technical skills.

The FHTC students appeared to have a sense of agency in the CPS process allowing them opportunities to persist and build confidence during the problem solving. For example, in making decisions regarding iterating several prototypes the FHTC valued the university students' expertise and continual reminders to use data-driven approaches, and simultaneously felt they were listened to when they pitched, sketched or revised ideas based on their expertise with motors, tools, cameras etc. The technical college students were aware of the different skill sets from the outset of the project and while working they acknowledged the 'great knowledge of theory and concepts' the university students held, suggesting they wanted to learn from them. This finding also aligns with the idea and importance of role clarity, where team members' common understanding of others expected role helps minimise misunderstandings in assigned tasks (Adams 2002). Assigning and respecting roles based on diversity of human capital (skills, knowledge, and expertise), versus emphasising the need for each team member to learn and apply tasks they may be less familiar with, can minimise role confusion and lead to a more natural division of labour and productivity (Tasheva and Hillman 2019). This implies that educators working with multi-educational teams may want to help students to reflect upon and discuss their roles and teammates roles. Intentional reflection may assist in understanding the importance of diversity on teams (Long, Rajabzadeh, and MacKenzie 2017) and formalise cognitive apprenticeship and mentoring roles. This may be accomplished, in part, by developing mentoring and mentee checklists with criteria aimed at self-monitoring CPS skills, role diversity, and productive team friction.

Despite the fact that the FHTC felt comfortable contributing and felt valued when their roles were respected, at times, this hindered growth (i.e. leadership growth for FHTC students; technical skill growth for university students). In this case, role clarity could be balanced with accountable interdependence (mutual dependence by team members towards the quality and quantity of individual work), and mature communication (articulating ideas concisely, providing reasons, listening and clarifying ideas) (Murzi et al. 2020). Murzi and colleagues suggest that teamwork competencies help students feel more prepared for professional work. This implies a general need to help students across

levels of education understand attributes of effective teamwork models to positively impact workplace contributions. Instructors could help students understand teamwork models before reflecting on the project goals and incorporate peer review of team member's goals and roles (Murzi et al. 2020). In this way, students could reflect on their current skillset before setting goals to expand their skillset while contributing to collective problem solving.

Fostering future career skills

Analogous to research with university students, in this study we observed how the ill-structured nature of each problem, along with gaining some teamwork competencies, helped the FHTC students feel more prepared for their current professional engineering work environments (Murzi et al. 2020), but also for their imagined future career. The FHTC described their skills as 'comfort in using tools, tackling hands-on tasks like taking measurements or checking voltage, and helping their team understand how a proposed solution might play out in a real factory'. They saw these skills as different than the engineers and relevant to solving the problem, but also wanted to learn from the university students for their own professional benefit. Although they gravitated toward those skills and identities, as the project progressed, their identities and skills expanded to include more professional engineering skills such as communication and problem solving which are critical to employment and career success (Durkin 2016).

While current literature points to the integration of CPS as key in increasing knowledge retention, engagement, and workforce readiness for technical college students (Nwalo and Eze 2021; Unal and Cakir 2021), this case demonstrated how the students' interest in retaining knowledge, engaging in problem solving and garnering workforce skills was seen as a personally beneficial. Essentially, the technical college students perceived the transfer of knowledge and learning on several levels (theory, technical skills, soft skills) as critical to their future career possibilities. The inclusion of industry and guest speakers during weekly class time check-ins may have also contributed to a desire to advance the FHTC students' future careers. One student even identified the importance of the growth of these skills in supporting her educational pathway as she had plans to transfer to a four-year engineering degree programme.

An important part of CPS and teamwork is self-management and self-leadership while maintaining an open mind (Oliveria, Lawless, and Molloy 2017). The FHTC students expressed their desire to 'simply work with engineers', to better understand them, and to acquire conceptual, technical, and soft skills to help them manage and lead in the future. We noted that the FHTC students achieved greater insight into how a team functions and what a complex project entails and gained CPS skills, however it is unclear if the students acquired teamwork skills that will easily transfer to future projects. Again, this necessitates instructors' intentionality towards teaching and including students in the evaluation of teamwork competencies.

The FHTC students came to the programme because they wanted to improve their skills in order to advance their careers and were explicit in mentioning the importance of 'getting ahead'. They believed it was important to watch, participate in, and reflect on the CPS and teamwork processes, seeing it as a way to become a respected leader in either their current (four of them held factory jobs they hoped to advance in) or future jobs. With much of the focus of CPS and teamwork research on workplace readiness (Nwalo and Eze 2021; Unal and Cakir 2021), this finding extends workplace readiness to considering the importance of each individual's workplace advancement.

Limitations

We acknowledge several limitations with this research. First, the sample size is small and consisted almost exclusively of white men with students selected to fit within this programme, which limits generalisability. However, the goal of this qualitative research is to better understand the context of technical college students working in multi-educational level teams as a first step towards

proposing what might strengthen collaboration and problem solving in similar circumstances. Second, the technical college students had above average GPAs which might have influenced their engagement and positive participation in this project. Similarly, they may have been motivated to participate in the engineering training programme and industry challenges, which is not always the case when workers or students are assigned projects or tasks, and this may have influenced the findings. Furthermore, their desire to participate may have limited the amount of constructive conflict and differing perspectives they choose to offer towards solutions. Third, despite triangulating our data sources the observation rubric was designed to capture specific attributes related to CPS and may not have fully captured the variety of ways CPS is experienced. Finally, observing students and collecting more data over longer periods of time may provide insight into the progression of CPS over time. In this case our data collection was constrained by the length of the funded training programme.

Conclusion

In sum, our research proposes several benefits when students are working in multi-educational level teams where professional identities are valued while promoting productive conflict, differing roles are respected and skill development is encouraged, and career skills are honed. For technical college students these benefits include engagement, motivation, feelings of empowerment and cohesiveness (Oliveria, Lawless, and Molloy 2017) and the potential to advance in their careers. Our research also points to need to make teamwork competencies overt and assist multi-educational teams in self-reflective practices. For other members of the team and industry the benefits include the integration of real-world experiences and technical expertise during problem solving and the likelihood of increased productivity. Importantly, this case answers the call to extend what we know about educational pathways, roles, and workforce contributions by engineering technicians (National Academy of Engineering 2017). It also extends the literature informing ways to effectively hone CPS skills such as teamwork, communication, problem solving, and the ability to work in diverse teams (Long, Rajabzadeh, and MacKenzie 2017).

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