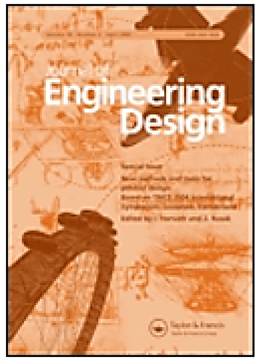

Exploring Graduate Students Collaborative Problem-Solving in Engineering Design Tasks

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Abstract: This study evaluated seven engineering graduate students' collaborative problem-solving (CPS) skills using a rubric designed to assess CPS while working in teams to solve problems. Students worked in two different interdisciplinary teams, in face-to-face and online environments, to solve complex manufacturing design challenges posed by their instructor. The students were assessed using the rubric's four dimensions: *peer interactions, positive communication, tools and methods*, and *iteration and adaption*, and scored via each dimension's associated attributes, and subsequently interviewed. Six students scored emergent or proficient in CPS and had slightly higher CPS scores during the second observation. One student demonstrated a limited ability for CPS and the observable CPS skills decreased during the project. Interviews revealed the importance of (1) relying on instructor and student chosen technologies for collaborative tasks, (2) recognizing and drawing on peer expertise early in the project, (3) building trust during and outside of team meetings, and (4) valuing off-site and online collaborative work. Findings advance the understanding of how instructors can create engineering design challenges developed for effective CPS skill-building and future teamwork.

Keywords: collaborative problem solving, engineering design challenges, peer interactions, communication, teamwork

The ability to collaborate while solving problems is considered a core competency in the 21st century and as such, has received significant attention from researcher and industry leaders with the rise of technology-enabled environments and increased emphasis on teamwork (Griffin, et al., 2011). Research demonstrates that the quality of solutions often improves when differing perspectives, innovative ideas, knowledge and experiences from a variety of group members working together are considered (Graesser et al. 2018). Much of the complex work in today's world is conducted in teams, but 'systemic training education and training on CPS is lacking for those entering and participating in the global workforce' (Graesser et al. 2018, 59). Teams are often defined as two or more members working interdependently toward a common goal (e.g., Salas et al. 1992). Industry and academia, particularly in STEM fields, identify collaborative problem solving (CPS) among team members as important yet acknowledge that many graduates entering the workforce lack collaboration skills (National Science and Technology Council, 2018). Interest in assessing skills associated with CPS, a critical component of preparing a STEM workforce, has led to numerous research efforts across fields including environmental science, STEM, math, the military, marketing and medicine (Care, Scoular and Griffin 2016). One important aim of this prior research includes defining the constructs of CPS in order to help instructors provide effective CPS opportunities and assist students in gaining CPS expertise to improve their future professional practice. With an increased desire to improve CPS proficiency in order to develop deeper knowledge and practical solutions for novel and difficult problems (Graesser et al. 2018), there is a need to support both students and instructors to create an environment where productive CPS occurs.

As part of a 5-year NSF funded engineering graduate traineeship program our research team facilitated industry-sponsored collaborative projects embedded in coursework for students to solve complex, multi-level human and systems manufacturing design challenges. Industry partners worked with the instructors and students on identifying specific projects that would be relevant to both the industry partner and the students. During their project work, we assessed the students' CPS ability while solving manufacturing design challenges and then garnered their perspectives on the collaborative work. The goal of our research is to offer a valid and practical way to identify and assess CPS behaviours in engineering students. We also gathered students' perspectives in order to assist researchers in understanding collaborative processes, and to inform instructors in ways that create opportunities for collaboration. Furthermore, the feedback from the assessment offers students a way to reflect on their individual CPS skills. Thus, our research questions are: 1. How proficient are graduate students in collaborative problem-solving when working in teams to solve engineering design challenges? and 2. What are the students' perspectives towards collaborative problem solving?

Literature Review

Much of the work done in science, technology, engineering, and mathematics (STEM) professions is performed by teams (Chang et al. 2017; Marra et al. 2016). At the same time, technological advances in the modern workforce has increased the ability to connect across time and discipline. This modern approach to teamwork has led to the need to understand collaborative problem solving (CPS), which includes social and cognitive skills where collective knowledge and skills can solve complex problems (Graesser et al. 2018; OEDC 2017). Moreover, educational institutions value CPS believing it to be a necessary skill that should be assessed (Care et al. 2016; Greiff, Holt and Funke 2013; Hao et al. 2015; Oliveri, Lawless and Malloy 2017; Rosen & Foltz 2014). In the field of engineering, the international Accreditation Board for Engineering and Technology (ABET) requires accredited engineering programs to have CPS as a student outcome. In fact, when considering the seven identified student outcomes to prepare engineering graduates to enter the practice of engineering, four of them are connected to CPS and include attributes such as: solving complex problems, communicating effectively and, functioning on a team (ABET 2020).

Literature on CPS in Engineering in Higher Education

Researchers aptly point out that, 'there are few studies that investigate whether students can be successfully trained to collaborate' (Lai 2011, 24). Training instructors to provide students with explicit instruction in how to communicate, interact, help others, and negotiate when solving a problem is necessary as today's engineering challenges are complex, ill-defined and ill-structured (Jonassen, Strobel and Lee 2006). At the same time, it is difficult because engineering preparation is rarely interdisciplinary, (Zou & Mickelborough 2015), practical or relevant to how an engineer behaves (Jonassen, Strobel and Lee 2006). Zou and Mickleborough

(2015) argue that many courses simply assign students in a group, which does not inherently lead to the development of collaborative skills (Kavanagh and Crosthwaite 2007).

With the call to increase CPS skills in education from the Organisation for Economic Co-operation and Development (OCED) and ABET, engineering education has incorporated CPS into their curriculum, research, and assessment (Passow and Passow 2017). For example, Todorovich, Marone and Vazquez (2012) used collaborative problem solving as a methodology to teach programmable logic to engineering students in an introductory design course. The course was structured to allow work across teams to find solution to complex projects. Results indicated students valued the hands-on experience and found it potentially useful for future engineering work (Todorovich, Marone and Vazquez 2012). Marra et al. (2016) argued for better support of collaborative skill development in engineering students using embedded collaborative technologies (i.e. Google Drive) and found 'quantitative evidence that the use of the environment was significantly correlated to improved student learning outcomes' (p. 14). Furthermore, qualitative results indicated students believed the collaborative technologies improved their work.

Students CPS abilities may also depend on their social or personal relationships with team members. One study on CPS in higher education examined the within-team and extended networks of 80 computer science engineering students (de Montjoye et al. 2014). The research demonstrated the students' problem-solving ability was a function of the strength of both networks. The authors suggest that the structure of social interactions, which includes advice, expertise, contextualised knowledge and experience, matters when solving complex problems as it assists in accessing the right pieces of information. The study found a positive correlation between strong expressive ties (i.e. friendship, affective connections) and instrumental ties (i.e.

professional in nature, to exchange information) towards team performance in that the strongest ties between both mattered.

Researchers have also extended CPS studies evaluate the impact on students' performance after analyzing their collaborative practices. Meneske, Purzer and Heo (2019) examined types of verbal episodes students used in collaborative groups looking at how the interactions occurred at the individual and team level. Results indicated that effective CPS teams need balanced participation from group members and should include active listening skills, which may need to be developed (Meneske, Purzer and Heo 2019). More recently, Mabley and colleagues (2020) argue that scaffolding and structure is needed in the early stages of a CPS pedagogy, especially if prior instruction and learning was primarily offered through traditional lectures.

An extensive systematic review of engineering competencies summed up ways that collaborative problem solving is used in engineering education. Passow and Passow (2017), looked at engineering materials and research from 1990 to 2013 to determine what competency(s) engineering education should give focus. Their results indicated that technical competence was inseparable from effective collaboration. The diverse field of engineering is 'too complex and interdisciplinary for one person to fully know' (Passow and Passow 2017, 491). Therefore, collaborative social interactions are needed to solve real world ill-structured problems faced by both professionals and students.

Theoretical Framework

We draw on socio-constructivist theory (Vygotsky 1980) to position our research as our focus is on understanding how language, human interactions and available technologies during collaborative relationships might assist in solving relevant problems (Squire 2004). Socio-constructivist theorists recognise cognition as social and often support the theory using situated cognition, in which knowledge is 'situated' within the activity, context, and culture in which it is developed, where knowing and doing are considered entwined activities (Brown, Collins and Duguid 1989). The pedagogical implications for socio-constructivist learning and situated cognition suggest that situating problems in relevant or real world practices may engage people in creating solutions. This ostensibly can be extended to students collaboratively solving problems in engineering design environments, hence it is well aligned with our research.

Method

We used qualitative case study (Merriam 2009), to understand graduate students' CPS while working in collaborative teams to solve manufacturing design challenges. Case study is appropriate as it relies on multiple sources of evidence and theoretical propositions when searching for meaning or developing deeper understandings. In this study, case study assists us in studying the phenomena of collaboration in its natural setting to make sense of and then describe, via our analysis of observations and interviews, how collaboration occurred in engineering students' project work. Our case was bound by students enrolled an advanced manufacturing course during the spring semester of 2020. Our participants were seven graduate students who attended the same university in the southeast United States and moved through each course within the manufacturing trainee program together. Eight students were enrolled in the program and all of them were selected to participate, however one student was not present for all of the observations and data collection, and thus was not included in the final analysis. During our research, we paid particular attention to students' actions aligned with dimensions and attributes using the Traineeship Evaluation CPS rubric (pseudonym used; further described below).

The context

The seven participating students applied to participate in the trainee program after it was broadly advertised via academic media outlets; applications were reviewed by participating researchers and students were selected based on the achievements and the fit of their interdisciplinary background within the trainee program. All students identified as White or Caucasian, five were male and two were female (students are referred to as Student A-G and genders as s/he in this paper to protect their anonymity). Three students were earning their PhD in Computing, one was earning his PhD in Automotive Engineering, and three students (both of the females) were enrolled in the Mechanical Engineering MS program. The goal of the program was to recreate experiences in which researchers, engineers and technicians collaborated on projects in actual factories. Graduate students took advanced coursework together in three key areas – manufacturing, data management, and human technologies, and then developed projects and solutions while working collaboratively. For this study, students were in the first year of the program and taking a capstone course focused on interdisciplinary collaboration on applied manufacturing projects relating to advanced manufacturing capabilities. Within the projects, they conducted research, imagined solutions, planned and created prototypes, tested their prototypes and iterated their designs before presenting them to peers, instructors and industry partners.

In one project team, four students worked on problem-solving an applied manufacturing project, attempting to measure shear and normal forces with a novel sensor designed for handheld use cases, while also integrating IoT (Internet of Things) data collection capabilities. A second project group of four students focused on developing a smart manufacturing system capable of integrating environmental and machine data to create a more complete picture of the manufacturing environment that could be used to predict future maintenance and workforce concerns.

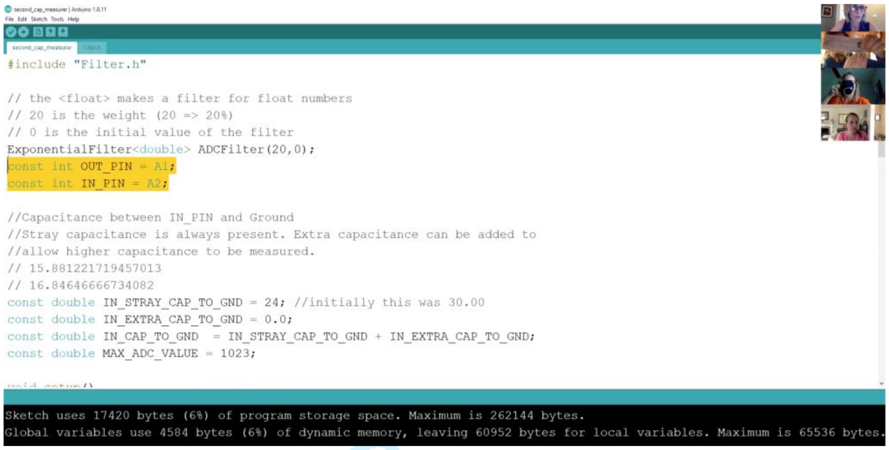


Figure 1: Students meeting online to share code before testing and iterating capacitor sensors.

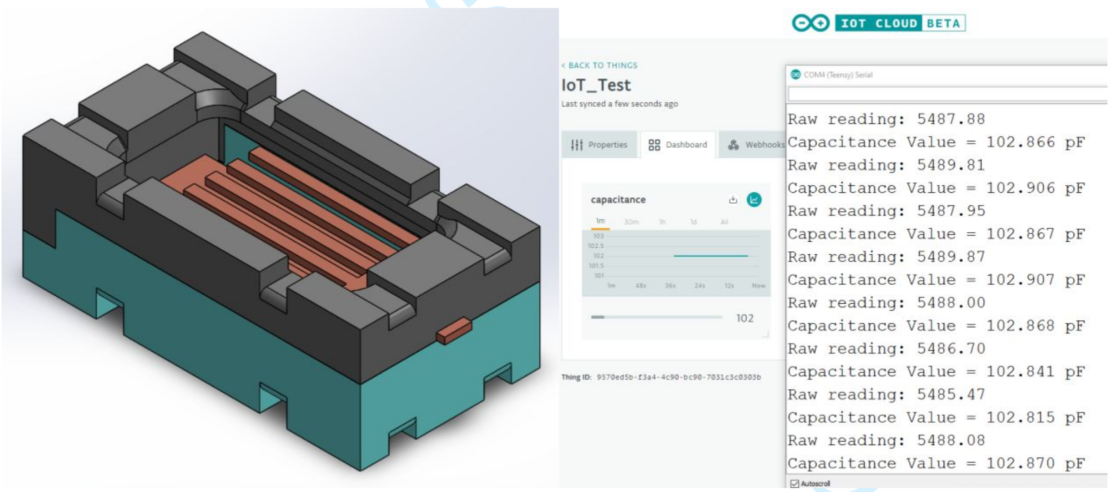


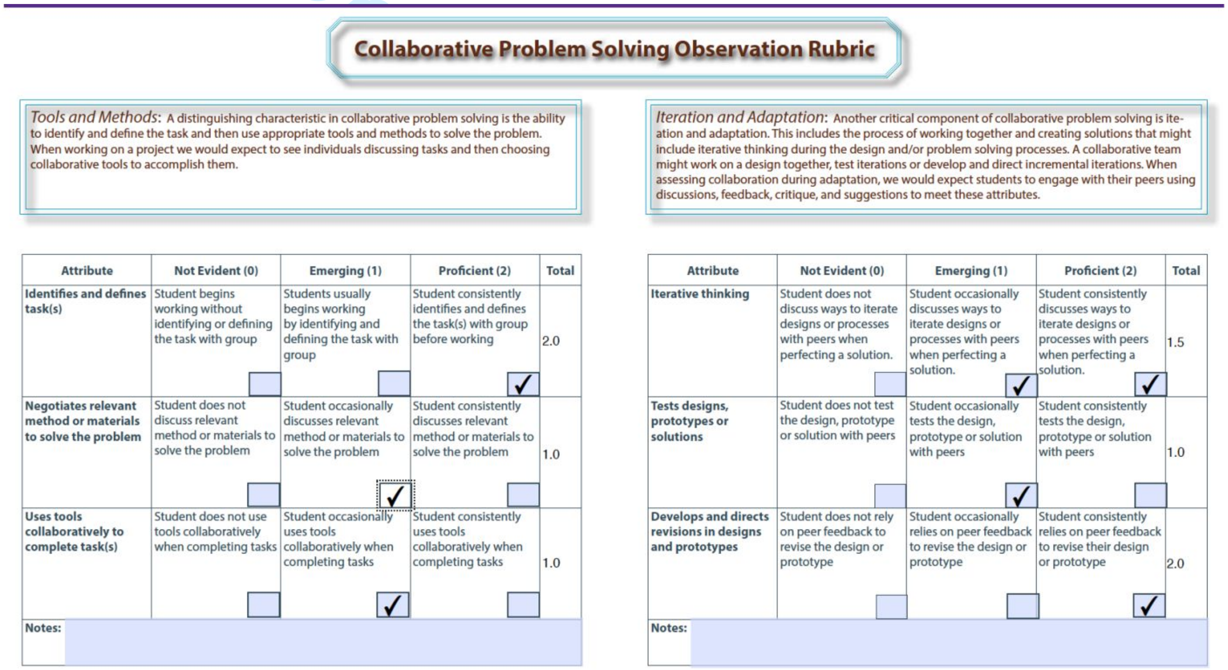
Figure 2: Samples of students' prototype and dashboard from one group.

Data sources

Our primary data sources were observations using the Traineeship Evaluation CPS rubric and semi-structured interviews all of the students. We video recorded the students working together to verify data collected via the rubrics, and audio recorded individual interviews. We describe each primary source in greater detail.

Traineeship Evaluation CPS

Traineeship Evaluation CPS is a rubric which defines four dimensions of CPS (two social dimensions: *Peer Interactions, Positive Communication,* and two cognitive dimensions *Tools and Methods and Iterations and Adaptions*) desirable when individuals are working in teams. Each dimension includes three attributes (e.g., 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) aligned with that dimension and scored as *'not evident,' 'emergent,'* or *'proficient'* .



Collaborative Problem Solving Observation Rubric

Tools and Methods: A distinguishing characteristic in collaborative problem solving is the ability to identify and define the task and then use appropriate tools and methods to solve the problem. When working on a project we would expect to see individuals discussing tasks and then choosing collaborative tools to accomplish them.

Attribute	Not Evident (0)	Emerging (1)	Proficient (2)	Total
Identifies and defines task(s)	Student begins working without identifying or defining the task with group	Students usually begins working by identifying and defining the task with group	Student consistently identifies and defines the task(s) with group before working ✓	2.0
Negotiates relevant method or materials to solve the problem	Student does not discuss relevant method or materials to solve the problem	Student occasionally discusses relevant method or materials to solve the problem ✓	Student consistently discusses relevant method or materials to solve the problem	1.0
Uses tools collaboratively to complete task(s)	Student does not use tools collaboratively when completing tasks	Student occasionally uses tools collaboratively when completing tasks ✓	Student consistently uses tools collaboratively when completing tasks	1.0
Notes:				

Iteration and Adaptation: Another critical component of collaborative problem solving is ite-ation and adaptation. This includes the process of working together and creating solutions that might include iterative thinking during the design and/or problem solving processes. A collaborative team might work on a design together, test iterations or develop and direct incremental iterations. When assessing collaboration during adaptation, we would expect students to engage with their peers using discussions, feedback, critique, and suggestions to meet these attributes.

Attribute	Not Evident (0)	Emerging (1)	Proficient (2)	Total
Iterative thinking	Student does not discuss ways to iterate designs or processes with peers when perfecting a solution.	Student occasionally discusses ways to iterate designs or processes with peers when perfecting a solution. ✓	Student consistently discusses ways to iterate designs or processes with peers when perfecting a solution. ✓	1.5
Tests designs, prototypes or solutions	Student does not test the design, prototype or solution with peers	Student occasionally tests the design, prototype or solution with peers ✓	Student consistently tests the design, prototype or solution with peers	1.0
Develops and directs revisions in designs and prototypes	Student does not rely on peer feedback to revise the design or prototype	Student occasionally relies on peer feedback to revise the design or prototype	Student consistently relies on peer feedback to revise their design or prototype ✓	2.0
Notes:				

Figure 3: Screenshot from two dimensions of Traineeship Evaluation CPS rubric.

Table 1

Table 1: Abridged Traineeship Evaluation CPS 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

There is also a space for observation notes which provides further information and justification for the rater's score in each dimension. Traineeship Evaluation CPS was modified from a similar rubric used to evaluate CPS in STEM work that was validated for construct validity and inter-rater reliability (Author 1 2017).

Four researchers were trained on how to use the rubric and it was piloted for usability by two of the four researchers in the semester preceding the study. During data collection the research team conducted the observations simultaneously, with two researchers each observing four participants as they worked in different teams for a minimum of 40 minutes, using a separate rubric for each individual. Since students were observed at the same time the team scrolled between the rubrics or dimensions as necessary. In the observation notes on Traineeship Evaluation CPS context specific information was recorded to support the selected levels or proficiency.

After the first observation, the university closed and in-person participation was not allowed due to Covid 19, however the teams continued working by having materials shipped to one another's homes and meeting online, so the final observation was conducted and recorded via Zoom. All seven students were observed at least twice by two researchers and sessions were video recorded to review during analysis.

Semi-structured interviews

Directly following the project work, students were interviewed individually. We posed a series of questions aligned with attributes on the rubric to gauge students' perspective regarding working with peers and collaborating. Example questions included: How satisfied were you with how your peers treated you while working in the group? How would you describe your interaction with your peers? How did you decide to divide up the work? How did your group decide how to choose tools and resources to complete the task? Thinking about your group project, did you make any iterations or changes to your presentation, design, or prototype?

Data analysis

We analyzed Traineeship Evaluation CPS data by assigning each student a summed score for each dimension of the rubric (*Peer Interactions, Positive Communication, Tools and Methods*, *Iterations and Adaption)* using a scale of 0 = not evident, 1= emerging, and 2 = proficient. Students could also receive a score of .5 or 1.5 if two indicators were checked for the same attribute. We created a summed score for each dimension, with ranges (0-2, 2.5-4 and 4.5-6) for proficiency levels. For example, a student scoring a 0, 1, 1 across all 3 attributes of the dimension of peer interaction would receive a summed score of 2 and be within the 'not evident' range of 0-2 for that dimension. A student scoring 0, 2, 1 in the same dimension would receive a summed score of 3 and fall in the 'emerging' range. The observation notes assisted in making evidence-based decisions to accurately assign scores. We provide two typical, representative examples of observation notes for indivdual students:

Student A: Student asks questions and responds affirmatively or with new questions, appearing to be listening intently as camera zooms in while speaking. Suggests the team can get one proof-of-concept prototype by the deadline. Shares a mold via screenshare, searches email to find copper plates, directs others how to use sticky hands and talks about the design.

Student G: Student expressed concern regarding the use of pipettes and looked up the cost/ship date while consulting the group. Physically picked up materials and held them via camera to show team examples; was prepared for the meeting and led testing sharing the desktop. Conducted tests with alligator clips, reported the reading, then clarified and made changes.

Next, we transcribed and analyzed student interviews to provide a more holistic understanding of how students were collaborating and activities that either did or did not promote collaboration. These were analyzed using a priori codes aligned to the dimensions on Traineeship Evaluation CPS of positive communication, peer interactions, tools and methods and iterations and adaption and used to answer the research question regarding student perspectives of collaborating in teams to solve the challenges. We also noted emergent codes categorised the codes into themes (Creswell 2007). The analysis was verified using inter-rater reliability in which two researchers independently coded the student responses and categorised them into themes, and then compared the results with one another to reach consensus (Creswell 2007). A third member of the research team then checked the codes, themes and examples for accuracy.

Findings

RQ 1: How proficient are graduate students in collaborative problem-solving when working teams to solve manufacturing challenges?

During the first observation, six of the seven students consistently scored in the emerging or proficient range in the social dimensions of *peer interaction* and *positive communication*, and five of the seven students also scored in the emerging or proficient range in the cognitive dimensions of *tools and methods* and *iteration and adaption* (see Table 2 below). Three students were proficient in all four dimensions, and one student (Student A) demonstrated an emerging ability to interact with peers when solving problems, but no notable evidence of positive communication or collaborating with tools or making changes to the prototype was observed. Observation notes described this student as polite, but rarely engaging with the team other than to occasionally respond to questions. Based on the conversation, it was evident that the student had contributed to some of the prior work related to building a dashboard. While the student didn't reject or monopolise the conversation, s/he simply did not contribute much.

For students who consistently scored in the emerging or proficient range, we noted them repeatedly checking in with one another, asking clarifying questions (e.g. 'I think we can do three, do you agree with that?' or 'How long would you want that tail, a quarter inch?'). They would typically offer new ideas about changing a design idea or prototype, often sketching on the whiteboard, making changes to a computer-aided design (CAD) drawing or physically manipulating objects while discussing the math, tolerances or area of a design. At times students were observed identifying the problem and then working through it together, oftentimes visually, with one member drawing out the group's ideas for discussion (e.g. Student C made a suggestion, while Student D drew on the board and Student F suggested how the group should approach the issue, saying, 'I'm just going to sketch my ideas on paper, you can start drawing for all of us.')

During the second observation, which was conducted one month later, while students were collaborating in a Zoom break-out rooms, due to Covid 19, six of the seven students consistently demonstrated they were adept at social and cognitive CPS skills scoring *emerging* or *proficient* in each dimension, with four of the seven scoring proficient in every dimension. The same student who struggled earlier, Student A, scored lower in each dimension. This student was nearly absent from the conversation and even asked to turn off his camera. Although it was clear s/he was still connected via audio, s/he did not respond other than to comment twice to his group providing positive feedback and then to make a suggestion regarding a materials purchase. Similar to the first observation, nothing negative was noted however the overall lack of responsiveness demonstrated his inability to collaborate.

In the majority of instances where students scored emerging or proficient range, students were noted responding to design modifications in a manner that is was clear they were seeking feedback on steps they were taking, or some students noticeably took the lead by reminding the team where they were in project and answering questions. Some students were observed holding up or showing digital objects and then asking their team members questions about how the objects or materials could best be used to devise a strategy to solve the problem.

Across both observations, the students generally scored slightly lower on the cognitive dimension of *iteration/adaption* when collaborating, than on *tools/methods*. However, with the exception of Student A, the members of both teams were both adept at choosing appropriate tools and methods to solve the problem by the second observation (via Zoom). The students' ability to demonstrate iterative thinking or design processes and test ideas was generally less apparent in the first observation with 2 of the students scoring *not evident*, and 2 scoring *emerging*. Overall, the students scored higher in both *tools/methods* and *iteration/adaption* when working online. Students scoring *proficient* were noted using the screenshare function frequently, demonstrating how tools and materials might work while teammates asked to see the object or digital drawing manipulated, or actively making changes to physical objects (e.g. using calipers to demonstrate a current and changed measurement, showing a box with and without clamped ends, showing how sticky hands might work with the prototype, reviewing a CAD draft and making a change).

Table 2

Trainee Evaluate CPS Rubric Data: First and Second Observation Results

Student	Peer Interaction	Positive Communication	Tools and Methods	Iteration and Adaption
		Observation 1		
Student A	3/Emerging	1/Not Evident	1/Not Evident	1/Not Evident
Student B	6/Proficient	5.5/Proficient	4.5/Proficient	4.5/Proficient
Student C	5/Proficient	5.5/Proficient	5/Proficient	4.5/Proficient
Student D	4/Emerging	4/Emerging	3/Emerging	1/Not Evident
Student E	4/Emerging	6/Proficient	3/Emerging	3/Emerging
Student F	6/Proficient	6/Proficient	5.5/Proficient	4.5/Proficient
Student G	4/Emerging	6/Proficient	6/Proficient	4/Emerging
		Observation 2		
Student A	0/Emerging	.5/Not Evident	0/Not Evident	0/Not Evident
Student B	4/Emerging	6/Proficient	5/Proficient	3/Emerging
Student C	5.5/Proficient	6/Proficient	5.5/Proficient	4.5/Proficient
Student D	6/Proficient	6/Proficient	6/Proficient	6/Proficient

Student E	6/Emerging	6/Proficient	5/Proficient	3/Emerging
Student F	5.5/Proficient	6/Proficient	6/Proficient	4.5/Proficient
Student G	5/Proficient	6/Proficient	6/Proficient	5/Proficient

RQ 2: What are the student perspectives towards collaborative problem solving?

The students' interviews provided their perspectives of CPS during the team projects. Although the Traineeship Evaluation CPS attributes guided the development of the interview questions, the goal of the interviews was not to verify ratings, but instead to better understand how the students viewed collaborating with peers while solving engineering challenges. We discuss their perspectives of the social and cognitive dimensions of their teamwork and acknowledge the overlap between the dimensions. To that end, we noted how often students would describe an interaction or communication with their peers in conjunction with dividing work, an approach they took, a method or tool that they chose or a change they decided to make.

Students' perspective on interacting and communicating with their team

Overall, the students described their peer interactions and communication as constructive and positive noting how the effective use of Slack, Google Hangouts, and a Gantt Chart or what they deemed, 'high level mapping on a flowchart' kept them on task and allowed them to monitor tasks throughout the project. A couple of the students talked about how chat function on OneDrive made it easier to collaborate. One student even pointed out that their team had 'really good communication through email, which is not the norm.' Another student mentioned that using Power BI for the visualizations was confusing at first and s/he would have likely not taken the time to really utilise it without both technology and another team member. S/He explained that they had limited experience with data streams, but after talking with a team member who was slightly more experienced with hit, s/he suggested they use in their project and find help online. This led the student to LinkedIn Learning as a resource for his entire team, otherwise s/he said they would 'have been aimlessly wandering around YouTube to find help.'

All seven of the students mentioned that that group members got along and were respectful, and this appeared to emanate from early conversations about their research interests and abilities. Student B explained:

> We did these (digital) presentations at the beginning of the semester that were all kind of corny, like, get-to-know-you things. But we also talked about our research interests and relative strengths and weaknesses. Because of that, I think everyone has a good amount of mutual respect so we respect our [sic] project-related discussions. When I mention something about air flow and how it might affect sensors, I've taken heat transfer and fluid mechanics, so it's like, oh s/he knows that. And when Student C talks about data, I respect her/his expertise.

A few of the students mentioned that the open-ended nature of the project assisted them in interacting and communicating because, 'we don't know what works and what doesn't, so we have to get as many ideas as we can and test them.' All of the students responded that they were 'satisfied' or 'pretty satisfied' with the team's ability to communicate and conveyed that they respected their team members abilities and believed the tasks, while not always discussed in detail, were clearly divided based on expertise. Student G mentioned, 'I think we all kind of know who we can leverage', and Student B, explained how they divided tasks in greater detail:

> We work separately, we kind of have to decompose the question (referring to their problem-solving task) a little bit. I think everyone's expectations are entirely clear. I don't think anyone at any point has to wonder what the other person wants. It's an issue

I've seen in other groups, but we're just very clear on what everyone is doing and expected to get done. We'll put out a doc and it's like, 'hey everyone, mark your sections' and within two days it's all done.

One student described how tasks were divided based on talents the group recognised, saying:

It's all very positive like, we have individual conversations about everybody about certain tasks, like talking to Student F about material property stuff, and then taking to Student H (absent from second observation) about getting different prototypes and then taking to Student A about all of the dashboard stuff. It's easy to know who's background it suited for different things.

Another student talked about the ease in which he/his group communicated, indicating that team members were could easily provide assistance or redirect one another. S/he said:

We don't have communication blocks. I mean, usually, if someone is confused about something, they just bring it up right there and it makes life a lot easier. Everyone asks, Student C a lot of questions about hardware because s/he knows all the stuff. S/He's, you know getting a PhD in it so after four-ish years, s/he knows the hardware in and out. S/He's under a fair bit of stress with his dissertation and I can still ask him pretty much anything at any time. Student G is doing his thesis, but my interactions with have not been standoffish at all. We have our (morning) meeting times and they go just fine.

The students also believed they freely shared knowledge, materials, and the workload with one other - although not necessary equally or even equitably at different points in the project. This included the student we observed contributing very little during our observations. That said, most students said they did not believe that the workload needed to be equitable, instead they suggested it should be dependent on the team members strengths, and a relative to where the team was in the project. Student D explained:

> I would say it (referring to the workload) is equal, especially since here some people have different strengths as a consequence of where we are in the project, so until we got to the prototyping stuff Student A and F were really only talking to use about the pricing. S/He then added, 'I think we've done a good job staying together in terms of contributions.'

This perspective regarding other team members contributions extended to Student A that we observed interacting and contributing very little. During interviews it was apparent that the team felt the student's contributions before and after team meetings (these were purposefully designed as working meetings) were valuable, even if it was less than their own or not apparent during the sessions we observed.

Students' perspective on tools, methods and iterations

When asked about how their team chose particular tools and resources or handled design iterations, a majority of the students pointed to how they relied on one another's expertise and past experience to divide tasks, choose tools and make changes. They also believed this division of tasks and way of choosing tools or approaches was natural. For example, Student B said:

> I hate to say it naturally coalesced, but it kind of did. I think me and Student E worked at the same manufacturing site, I know that s/he is experienced. When we talk about what we want the dashboard to look like, well we've both used dashboard in manufacturing and created them in the past.

Students D explained,

> I think we self-divided based on expertise into the two many area that we perceived as part of our project. We formed subgroups that are kind of natural – the programming and coding side and then the dashboarding and informatics side.

Student G told us:

> For me and Student E, we have fairly common background experience, we have general conversations about tech and outside conversations that aren't even related (directly to the project). There are other things I know he knows about, and if s/he knows those things that is probably what s/he wants to do.

A few of the students talked about the comfort they felt bringing ideas forward to for their team to discuss, try out or test, and revise if necessary. For instance, Student B explained:

> I feel pretty thankful that we're pretty comfortable with this kind of thing. That if something isn't going to work, it's okay. When it comes down to the design, the right one, we're still going to try and test it. We all kind of acknowledged it might not give us the results we are looking for, but there is no harm in trying it. For a while Nikola Tesla was like, yeah, I don't think that's gonna [sic] work either, but from that you get other ideas. It's part of our brainstorming process.

A few other suggestions made during the student interviews that emerged are worth noting. One student indicated that while there was nobody on the team that s/he would prefer to *not* work with, the addition of an electrical engineer would have been helpful. Another student from the other team responded similarly, even mentioning that the group enlisted the help of an electrical engineering graduate student not directly associated with the course or project.

Four students also suggested that the entire team be exposed to the project and be allowed to form teams earlier, believing that spending time as a team prior to working on the project would help them better understanding one another's expertise and to build trust. To that end, another student remarked several times throughout the interview that there was an element of trust that made the teamwork effective. S/He talked about trust within and beyond the team, extending it to the fellowship (training program and instructor) believing that since the students were all vetted, they felt comfortable asking questions of other group members because they were 'credentialed to a degre' and likely had the answers. S/He then described the instructor as trusting them and treating the teams as if they were all 'extremely massively qualified.'

Discussion

In this study, graduate student teams were tasked with solving two different manufacturing engineering challenge problems (developing a novel handheld sensor and creating a smart manufacturing system). Our research team followed each team throughout the process of completing teamwork, noting how each team member scored on a variety of CPS variables and also providing qualitative data about student teamwork perceptions and the manner in which students chose to enact collaboration.

The majority of the graduate students in this study demonstrated their ability to interact and communicate positively and proficiently, choose appropriate tools and methods to jointly solve problems, and work with team members to test and iterate designs and prototypes. Almost all of the students were observed developing CPS skills (emerging or proficient) during the course of the project work. We noted them asking new questions or responding to team members questions based on their individual area of expertise, demonstrating ideas with tools, drawing or designs, dividing work and checking in, taking turns leading the team in their area of expertise, and appearing respectful of other team member's expertise.

Our observation notes and qualitative interviews highlight several instances of students bringing forth alternative ideas based on their own background and levels of proficiency. The presence of interdisciplinary individual backgrounds composing the overall team allowed for reinforced productive CPS skills to both be developed and applied. This implies, in part, that interdisciplinary students can be trained to successfully collaborate, and answers calls to build this body of research (Lai 2011). In addition there is the implication that training programs, similar to this NRT program, that focus on interdisciplinary problem solving with engineering challenges mirroring industry are a potential way forward to successfully hone collective knowledge and skills to solve complex problems (Graesse et al. 2018; OCED 2017). The matching of real world problem sets to students skills provides students with knowledge regarding these types of problems, but more importantly allows students a testbed to identify and practice relevant CPS skills in a testbed environment before they are implemented in a real world environment.

Both observations and student interviews illuminated the unique methods that engineering instructors worked in concer with industry partners to develop feasible classroom projects mirroring real world challenges. The challenges were ill-defined and ill-structured, much like today's complex engineering challenges in the workforce (Jonassen, Strobel and Lee 2006; Zou and Mikelborough, 2015) and likely assisted the students in having to rely on team members to advance in solving each problem.

Although one student (Student A) was not observed participating fully or collaboratively, his team members still identified, acknowledged and viewed his 'between working meetings' and offline contributions as valuable. This finding highlights an important facet of this type of work, and teamwork in the class in general, in that contributions are not always occurring within the classroom or during team meetings. As educators, it is important that we understand student enact teamwork in a myriad of ways, many of which are not apparent to us while in the classroom. The type of project enlisted in this program required a great deal of outside the classroom work, and it appears that this is when Student A completed his work while still being accountable to s/he's team. It is easy to bias our viewpoints on this student's work by simply not being able to directly observe that work or their CPS skills, but it is important to understand that teamwork is dynamic and occurs in many ways.

In general, our research team concluded that CPS may occur productively outside of team meetings and further research is necessary to understand the overall impact of CPS for work occurring outside of team meetings is warranted, especially in light of the increased value of remote work during and after Covid 19. To that end, having students aware of the dimensions and attributes of CPS skills, using a checklist derived from Traineeship Evaluation CPS, and then asking them to self-monitor and compare their observed and self-assessments is the next step in our research.

Four main themes emerged from the interview data: (1) the use of instructor and student chosen technologies enhanced each team's ability to collaborate, (2) team member's expertise played a crucial role in task division and ways work was distributed, (3) building trust and feeling trusted, early on, was perceived as important to the success of the team's CPS, (4) members valued contributions that occurred outside of working meetings. We discuss each below and note when observations also supported the themes.

Blending instructor and student technology choices to enhance CPS

The observations and interviews helped demonstrate the value of using a host of technologies to effectively communicate and collaboratively solve problems. This is not a novel or surprising finding, as numerous studies point to technological advancements increasing the capacity for CPS (Chang et al. 2017). However, in this study, the engineering students provided insight towards the value of blending instructor facilitated and student chosen technologies. Students discussed using digital tools provided by the instructors such as Slack, OneDrive and numerous Google Apps, and choosing communication tools that students were comfortable with or had knowledge of such as LinkedIn Learning, Google Hangouts and FaceTime. Introducing students to productive collaborative tools and allowing them to choose their own appeared to effectively foster collaboration and extended expertise to other members of the team. The instructor's willingness to not restrict technology choices, and the students' willingness to introduce digital tools to each other assisted in the team's ability to successfully complete tasks. We suspect, that much liked the ill-defined nature of the entire project, the ill-defined nature of articulating what tools should be used actually helped the student team members develop investment and autonomy in their teamwork and their final products. Allowing students to have a choice in multiple aspects of the projects (not just in relation to tools) engenders a level of investment from the students, as the student made that choice and the outcome (positive or negative), at some level, depends on the choice that the student made, not the instructor. Simply stated, this level of choice has the potential to increase both individual and team level accountability.

After Covid 19 forced the teams to move to Zoom and utilise the breakout room affordance (each team is in their own room), they continued to collaborate and managed their individual workload and schedules to remain productive during the online meeting. In observations this was evidenced as students discussed purchases of equipment ordered far in advance of their working meetings, or progress they shared regarding designs and molds developed for electrical boxes or creating their team's dashboard. Similar to Marra et al. (2016) the students believed the collaborative technologies improved the quality of their work, and they also believed it enhanced their ability to share and benefit from team members' expertise.

The importance of recognizing expertise in forming teams and discussing roles

The observations and interviews illustrated the ease in which students positively communicated with team members. The innovative and open-ended nature of the problems meant they had to rely on each other to plan, innovate and rethink ideas when efforts failed. We seldom saw, nor did the students indicate, any difficulty in getting along or being respectful to teammates. Several of the students talked about how respect emanated from recognizing each other's expertise, whether they were in an MA or PhD program, and knowing a particular area (hardware, technology, design, visual display, environmental sensing) 'inside and out' – and being open to helping one another. The collective nature of being a student in the NRT program may have also helped to develop respect among team members. Students pointed to efforts early in the project to share their own expertise and talk with their team as beneficial. Although, these students said the efforts should have begun even earlier as a productive way to form teams and think about how their skills aligned with roles they might play in completing tasks and solving the problems. This finding supports de Montjoye et al. (2015) who posit that CPS is supported by the function of social interactions and suggest that advice, expertise and contextualised knowledge and experience matters when solving complex problems.

Building trust to strengthen CPS

A theme that emerged from the student interviews was the need for trust and teambuilding exercises early on in the program or coursework in order to share expertise, identify and acknowledge what might be lacking in the team (in this case, electrical engineering proficiency), and to provide time to thoroughly understand the problem. Four of the students talked at length about the need to trust group members in order to feel comfortable bringing any question forward, and not feel embarrassed when their individual or collective idea failed. Similar to the prior theme of recognizing expertise, almost every student interviewed discussed the open-ended and hands-on nature of the project as requiring a level of flexibility and 'respecting the discussion', which meant trusting each other's knowledge related to their expertise. This could be addressed by class discussions early in the training program, short student presentations detailing own interests and strengths, and attention to additional team and trust-building exercises. To further building trust around expertise in open-ended CPS, instructors could include opportunities to work with industry mentors to simulate how trust, expertise and CPS is approached in the real world.

Valuing off-site work and online collaboration

An unexpected theme noted in the analysis of the interviews was the general belief that work done outside of the teams working meetings played a significant role in solving the engineering challenges, and thus work done during team meetings or during particular points in the project did not have equitable to be valuable. This was further evidenced and supported in observations conducted while the teams meet in Zoom Breakout rooms. These meetings were mainly viewed as touchpoint meetings, to plan and provide a path forward for each individual member team roles in relation to the overall team goals. After Covid 19, the value of off-site work and online collaboration was realised more than ever, by students completely working off-site and utilizing online to facilitate collaboration. Our research team did not set forth with this research to solely focus on the impacts of digital collaborative technologies, but the advent of Covid 19 certainly allowed us the opportunity to examine this in greater detail. In general, based on observations, interviews, and informal meetings among the research team, we found these students to be very resilient in completing their teamwork, and also not having issues relating to using online collaboration. This is significant for two reasons: 1) students can and will use online collaborative technologies in a meaningful way to complete teamwork, and 2) as educators, we should be purposefully developing projects that require the use of these types of technologies as they are likely to become permanent fixtures within our world.

Limitations, next steps and conclusion

We acknowledge some limitations with this research. First, the small sample size may limit the generalizability of this research, however this qualitative research provides an in-depth and more contextualised perspective of collaboration between individual students and their teams. Conducting observations over a longer period of time might provide richer, comparative data, and help us better understand the progression of CPS for individuals. That said, Traineeship Evaluation CPS is designed to provide a relatively quick observation of students' ability to collaborate in short periods of time to offer instructors and educational researchers feasibility in using it. As the next cohort of NRT trainees are included we will extend data collection to the larger group to mitigate both limitations. Next steps in our research also includes the creation of a self-assessment CPS checklist for students to self-monitor and reflect on their collaborative activities. The checklists will be used to make students aware of the constructs of CPS and discuss their perceptions, expectations and abilities when collaborating and teams.

Opportunities to hone CPS in existing engineering curricula are lacking or inadequate (Zou and Mickleborough, 2015). While modest in scope, this study offers an initial first step and valid way to identify and assess CPS behaviours in engineering students. We assist researchers in further understanding collaborative processes, instructors in developing teaching practices aimed at fostering effective projects that promote CPS and provide a way for students to understand and self-monitor their own CPS ability.

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Exploring Graduate Students Collaborative Problem-Solving in Engineering Design Tasks

Abstract: This study evaluated seven engineering graduate students' collaborative problem-solving (CPS) skills using a rubric designed to assess CPS while working in teams to solve problems. Students worked in two different interdisciplinary teams, in face-to-face and online environments, to solve complex manufacturing design challenges posed by their instructor. The students were assessed using the rubric's four dimensions: *peer interactions, positive communication, tools and methods*, and *iteration and adaption*, and scored via each dimension's associated attributes, and subsequently interviewed. Six students scored emergent or proficient in CPS and had slightly higher CPS scores during the second observation. One student demonstrated a limited ability for CPS and the observable CPS skills decreased during the project. Interviews revealed the importance of (1) relying on instructor and student chosen technologies for collaborative tasks, (2) recognizing and drawing on peer expertise early in the project, (3) building trust during and outside of team meetings, and (4) valuing off-site and online collaborative work. Findings advance the understanding of how instructors can create engineering design challenges designed for effective CPS skill-building and future teamwork.

Keywords: collaborative problem solving, engineering design challenges, peer interactions, communication, teamwork

The ability to collaborate while solving problems is considered a core competency in the 21st century and as such, has received significant attention from researcher and industry leaders with the rise of technology-enabled environments and increased emphasis on teamwork (Griffin, et al. 2011). Research demonstrates that the quality of solutions often improves when differing perspectives, innovative ideas, knowledge and experiences from a variety of group members working together are considered (Graesser et al. 2018). Much of the complex work in today's world is conducted in teams, but 'systemic training education and training on CPS is lacking for those entering and participating in the global workforce' (Graesser et al. 2018, 59). Teams are often defined as two or more members working interdependently toward a common goal (e.g., Salas et al. 1992). Industry and academia, particularly in STEM fields, identify collaborative problem solving (CPS) among team members as important yet acknowledge that many graduates entering the workforce lack collaboration skills (National Science and Technology Council, 2018). Interest in assessing skills associated with CPS, a critical component of preparing a STEM workforce, has led to numerous research efforts across fields including environmental science, STEM, math, the military, marketing and medicine (Care, Scoular and Griffin 2016). One important aim of this prior research includes defining the constructs of CPS in order to help instructors provide effective CPS opportunities and assist students in gaining CPS expertise to improve their future professional practice. With an increased desire to improve CPS proficiency in order to develop deeper knowledge and practical solutions for novel and difficult problems (Graesser et al. 2018), there is a need to support both students and instructors to create an environment where productive CPS occurs.

As part of a 5-year NSF funded engineering graduate traineeship program our research team facilitated industry-sponsored collaborative projects embedded in coursework for students to solve complex, multi-level human and systems manufacturing design challenges. Industry partners worked with the instructors and students on identifying specific projects that would be relevant to both the industry partner and the students. During their project work, we assessed the students' CPS ability while solving manufacturing design challenges and then garnered their perspectives on the collaborative work. The goal of our research is to offer a valid and practical way to identify and assess CPS behaviours in engineering students. We also gathered students' perspectives in order to assist researchers in understanding collaborative processes, and to inform instructors in ways that create opportunities for collaboration. Furthermore, the feedback from the assessment offers students a way to reflect on their individual CPS skills. Thus, our research questions are: 1. How proficient are graduate students in collaborative problem-solving when working in teams to solve engineering design challenges? and 2. What are the students' perspectives towards collaborative problem solving?

Literature Review

Much of the work done in science, technology, engineering, and mathematics (STEM) professions is performed by teams (Chang et al. 2017; Marra et al. 2016). At the same time, technological advances in the modern workforce has increased the ability to connect across time and discipline. This modern approach to teamwork has led to the need to understand collaborative problem solving (CPS), which includes social and cognitive skills where collective knowledge and skills can solve complex problems (Graesser et al. 2018; OEDC, 2017). Moreover, educational institutions value CPS believing it to be a necessary skill that should be assessed (Care et al. 2016; Greiff, Holt and Funke 2013; Hao et al. 2015; Oliveri, Lawless and Malloy 2017; Rosen and Foltz 2014). In the field of engineering, the international Accreditation Board for Engineering and Technology (ABET) requires accredited engineering programs to have CPS as a student outcome. In fact, when considering the seven identified student outcomes to prepare engineering graduates to enter the practice of engineering, four of them are connected to CPS and include attributes such as: solving complex problems, communicating effectively and, functioning on a team (ABET, 2020).

Literature on CPS in Engineering in Higher Education

Researchers aptly point out that, ‘there are few studies that investigate whether students can be successfully trained to collaborate’ (Lai 2011, 24). Training instructors to provide students with explicit instruction in how to communicate, interact, help others, and negotiate when solving a problem is necessary as today’s engineering challenges are complex, ill-defined and ill-structured (Jonassen, Strobel and Lee 2006). At the same time, it is difficult because engineering preparation is rarely interdisciplinary, (Zou and Mickelborough,2015), practical or relevant to how an engineer behaves (Jonassen, Strobel and Lee 2006). Zou and Mickleborough

(2015) argue that many courses simply assign students in a group, which does not inherently lead to the development of collaborative skills (Kavanagh and Crosthwaite 2007).

With the call to increase CPS skills in education from the Organisation for Economic Co-operation and Development (OCED) and ABET, engineering education has incorporated CPS into their curriculum, research, and assessment (Passow and Passow, 2017). For example, Todorovich, Marone and Vazquez (2012) used collaborative problem solving as a methodology to teach programmable logic to engineering students in an introductory design course. The course was structured to allow work across teams to find solution to complex projects. Results indicated students valued the hands-on experience and found it potentially useful for future engineering work (Todorovich, Marone and Vazquez 2012). Marra et al. (2016) argued for better support of collaborative skill development in engineering students using embedded collaborative technologies (i.e. Google Drive) and found 'quantitative evidence that the use of the environment was significantly correlated to improved student learning outcomes' (p. 14). Furthermore, qualitative results indicated students believed the collaborative technologies improved their work.

Students CPS abilities may also depend on their social or personal relationships with team members. One study on CPS in higher education examined the within-team and extended networks of 80 computer science engineering students (de Montjoye et al. 2014). The research demonstrated the students' problem-solving ability was a function of the strength of both networks. The authors suggest that the structure of social interactions, which includes advice, expertise, contextualised knowledge and experience, matters when solving complex problems as it assists in accessing the right pieces of information. The study found a positive correlation between strong expressive ties (i.e. friendship, affective connections) and instrumental ties (i.e.

professional in nature, to exchange information) towards team performance in that the strongest ties between both mattered.

Researchers have also extended CPS studies evaluate the impact on students' performance after analyzing their collaborative practices. Meneske, Purzer and Heo (2019) examined types of verbal episodes students used in collaborative groups looking at how the interactions occurred at the individual and team level. Results indicated that effective CPS teams need balanced participation from group members and should include active listening skills, which may need to be developed (Meneske, Purzer and Heo 2019). More recently, Mabley and colleagues (2020) argue that scaffolding and structure is needed in the early stages of a CPS pedagogy, especially if prior instruction and learning was primarily offered through traditional lectures.

An extensive systematic review of engineering competencies summed up ways that collaborative problem solving is used in engineering education. Passow and Passow (2017), looked at engineering materials and research from 1990 to 2013 to determine what competency(s) engineering education should give focus. Their results indicated that technical competence was inseparable from effective collaboration. The diverse field of engineering is 'too complex and interdisciplinary for one person to fully know' (Passow and Passow 2017, 491). Therefore, collaborative social interactions are needed to solve real world ill-structured problems faced by both professionals and students.

Theoretical Framework

We draw on socio-constructivist theory (Vygotsky 1980) to position our research as our focus is on understanding how language, human interactions and available technologies during collaborative relationships might assist in solving relevant problems (Squire 2004). Socio-constructivist theorists recognise cognition as social and often support the theory using situated cognition, in which knowledge is 'situated' within the activity, context, and culture in which it is developed, where knowing and doing are considered entwined activities (Brown, Collins and Duguid 1989). The pedagogical implications for socio-constructivist learning and situated cognition suggest that situating problems in relevant or real world practices may engage people in creating solutions. This ostensibly can be extended to students collaboratively solving problems in engineering design environments, hence it is well aligned with our research.

Method

We used qualitative case study (Merriam 2009), to understand graduate students' CPS while working in collaborative teams to solve manufacturing design challenges. Case study is appropriate as it relies on multiple sources of evidence and theoretical propositions when searching for meaning or developing deeper understandings. In this study, case study assists us in studying the phenomena of collaboration in its natural setting to make sense of and then describe, via our analysis of observations and interviews, how collaboration occurred in engineering students' project work. Our case was bound by students enrolled an advanced manufacturing course during the spring semester of 2020. Our participants were seven graduate students who attended the same university in the southeast United States and moved through each course within the manufacturing trainee program together. Eight students were enrolled in the program and all of them were selected to participate, however one student was not present for all of the observations and data collection, and thus was not included in the final analysis. During our research, we paid particular attention to students' actions aligned with dimensions and attributes using the Traineeship Evaluation CPS rubric (pseudonym used; further described below).

The context

The seven participating students applied to participate in the trainee program after it was broadly advertised via academic media outlets; applications were reviewed by participating researchers and students were selected based on the achievements and the fit of their interdisciplinary background within the trainee program. All students identified as White or Caucasian, five were male and two were female (students are referred to as Student A-G and genders as s/he in this paper to protect their anonymity). Three students were earning their PhD in Computing, one was earning his PhD in Automotive Engineering, and three students (both of the females) were enrolled in the Mechanical Engineering MS program. The goal of the program was to recreate experiences in which researchers, engineers and technicians collaborated on projects in actual factories. Graduate students took advanced coursework together in three key areas – manufacturing, data management, and human technologies, and then developed projects and solutions while working collaboratively. For this study, students were in the first year of the program and taking a capstone course focused on interdisciplinary collaboration on applied manufacturing projects relating to advanced manufacturing capabilities. Within the projects, they conducted research, imagined solutions, planned and created prototypes, tested their prototypes and iterated their designs before presenting them to peers, instructors and industry partners.

In one project team, four students worked on problem-solving an applied manufacturing project, attempting to measure shear and normal forces with a novel sensor designed for handheld use cases, while also integrating IoT (Internet of Things) data collection capabilities. A second project group of four students focused on developing a smart manufacturing system capable of integrating environmental and machine data to create a more complete picture of the manufacturing environment that could be used to predict future maintenance and workforce concerns. [Insert figure 1 and figure 2 about here]

Data sources

Our primary data sources were observations using the Traineeship Evaluation CPS rubric and semi-structured interviews all of the students. We video recorded the students working together to verify data collected via the rubrics, and audio recorded individual interviews. We describe each primary source in greater detail.

Traineeship Evaluation CPS

Traineeship Evaluation CPS is a rubric which defines four dimensions of CPS (two social dimensions: *Peer Interactions, Positive Communication,* and two cognitive dimensions *Tools and Methods and Iterations and Adaptions*) desirable when individuals are working in teams. Each dimension includes three attributes (e.g., 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) aligned with that dimension and scored as *'not evident,' 'emergent,'* or *'proficient'* .

[insert figure 3 about here]

[insert table 1 about here]

There is also a space for observation notes which provides further information and justification for the rater's score in each dimension. Traineeship Evaluation CPS was modified from a similar rubric used to evaluate CPS in STEM work that was validated for construct validity and inter-rater reliability (Author 1 2017).

Four researchers were trained on how to use the rubric and it was piloted for usability by two of the four researchers in the semester preceding the study. During data collection the research team conducted the observations simultaneously, with two researchers each observing four participants as they worked in different teams for a minimum of 40 minutes, using a separate rubric for each individual. Since students were observed at the same time the team scrolled between the rubrics or dimensions as necessary. In the observation notes on Traineeship Evaluation CPS context specific information was recorded to support the selected levels or proficiency.

After the first observation, the university closed and in-person participation was not allowed due to Covid 19, however the teams continued working by having materials shipped to one another's homes and meeting online, so the final observation was conducted and recorded via Zoom. All seven students were observed at least twice by two researchers and sessions were video recorded to review during analysis.

Semi-structured interviews

Directly following the project work, students were interviewed individually. We posed a series of questions aligned with attributes on the rubric to gauge students' perspective regarding working with peers and collaborating. Example questions included: How satisfied were you with how your peers treated you while working in the group? How would you describe your interaction with your peers? How did you decide to divide up the work? How did your group decide how to choose tools and resources to complete the task? Thinking about your group project, did you make any iterations or changes to your presentation, design, or prototype?

Data analysis

We analyzed Traineeship Evaluation CPS data by assigning each student a summed score for each dimension of the rubric (*Peer Interactions, Positive Communication, Tools and Methods*, *Iterations and Adaption)* using a scale of 0 = not evident, 1= emerging, and 2 = proficient. Students could also receive a score of .5 or 1.5 if two indicators were checked for the same attribute. We created a summed score for each dimension, with ranges (0-2, 2.5-4 and 4.5-6) for proficiency levels. For example, a student scoring a 0, 1, 1 across all 3 attributes of the dimension of peer interaction would receive a summed score of 2 and be within the 'not evident' range of 0-2 for that dimension. A student scoring 0, 2, 1 in the same dimension would receive a summed score of 3 and fall in the 'emerging' range. The observation notes assisted in making evidence-based decisions to accurately assign scores. We provide two typical, representative examples of observation notes for indivdual students:

> Student A: Student asks questions and responds affirmatively or with new questions, appearing to be listening intently as camera zooms in while speaking. Suggests the team can get one proof-of-concept prototype by the deadline. Shares a mold via screenshare, searches email to find copper plates, directs others how to use sticky hands and talks about the design.

> Student G: Student expressed concern regarding the use of pipettes and looked up the cost/ship date while consulting the group. Physically picked up materials and held them via camera to show team examples; was prepared for the meeting and led testing sharing the desktop. Conducted tests with alligator clips, reported the reading, then clarified and made changes.

Next, we transcribed and analyzed student interviews to provide a more holistic understanding of how students were collaborating and activities that either did or did not promote collaboration. These were analyzed using a priori codes aligned to the dimensions on Traineeship Evaluation CPS of positive communication, peer interactions, tools and methods and iterations and adaption and used to answer the research question regarding student perspectives of collaborating in teams to solve the challenges. We also noted emergent codes categorised the codes into themes (Creswell 2007). The analysis was verified using inter-rater reliability in which two researchers independently coded the student responses and categorised them into themes, and then compared the results with one another to reach consensus (Creswell 2007). A third member of the research team then checked the codes, themes and examples for accuracy.

Findings

RQ 1: How proficient are graduate students in collaborative problem-solving when working teams to solve manufacturing challenges?

During the first observation, six of the seven students consistently scored in the emerging or proficient range in the social dimensions of *peer interaction* and *positive communication*, and five of the seven students also scored in the emerging or proficient range in the cognitive dimensions of *tools and methods* and *iteration and adaption* (see Table 2 below). Three students were proficient in all four dimensions, and one student (Student A) demonstrated an emerging ability to interact with peers when solving problems, but no notable evidence of positive communication or collaborating with tools or making changes to the prototype was observed. Observation notes described this student as polite, but rarely engaging with the team other than to occasionally respond to questions. Based on the conversation, it was evident that the student had contributed to some of the prior work related to building a dashboard. While the student didn't reject or monopolise the conversation, s/he simply did not contribute much.

For students who consistently scored in the emerging or proficient range, we noted them repeatedly checking in with one another, asking clarifying questions (e.g. 'I think we can do three, do you agree with that?' or 'How long would you want that tail, a quarter inch?'). They would typically offer new ideas about changing a design idea or prototype, often sketching on the whiteboard, making changes to a computer-aided design (CAD) drawing or physically manipulating objects while discussing the math, tolerances or area of a design. At times students were observed identifying the problem and then working through it together, oftentimes visually, with one member drawing out the group's ideas for discussion (e.g. Student C made a suggestion, while Student D drew on the board and Student F suggested how the group should approach the issue, saying, 'I'm just going to sketch my ideas on paper, you can start drawing for all of us.')

During the second observation, which was conducted one month later, while students were collaborating in a Zoom break-out rooms, due to Covid 19, six of the seven students consistently demonstrated they were adept at social and cognitive CPS skills scoring *emerging* or *proficient* in each dimension, with four of the seven scoring proficient in every dimension. The same student who struggled earlier, Student A, scored lower in each dimension. This student was nearly absent from the conversation and even asked to turn off his camera. Although it was clear s/he was still connected via audio, s/he did not respond other than to comment twice to his group providing positive feedback and then to make a suggestion regarding a materials purchase. Similar to the first observation, nothing negative was noted however the overall lack of responsiveness demonstrated his inability to collaborate.

In the majority of instances where students scored emerging or proficient range, students were noted responding to design modifications in a manner that is was clear they were seeking feedback on steps they were taking, or some students noticeably took the lead by reminding the team where they were in project and answering questions. Some students were observed holding up or showing digital objects and then asking their team members questions about how the objects or materials could best be used to devise a strategy to solve the problem.

Across both observations, the students generally scored slightly lower on the cognitive dimension of *iteration/adaption* when collaborating, than on *tools/methods.* However, with the exception of Student A, the members of both teams were both adept at choosing appropriate tools and methods to solve the problem by the second observation (via Zoom). The students' ability to demonstrate iterative thinking or design processes and test ideas was generally less apparent in the first observation with 2 of the students scoring *not evident*, and 2 scoring *emerging*. Overall, the students scored higher in both *tools/methods* and *iteration/adaption* when working online. Students scoring *proficient* were noted using the screenshare function frequently, demonstrating how tools and materials might work while teammates asked to see the object or digital drawing manipulated, or actively making changes to physical objects (e.g. using calipers to demonstrate a current and changed measurement, showing a box with and without clamped ends, showing how sticky hands might work with the prototype, reviewing a CAD draft and making a change).

[insert table 2 about here]

RQ 2: What are the student perspectives towards collaborative problem solving?

The students' interviews provided their perspectives of CPS during the team projects. Although the Traineeship Evaluation CPS attributes guided the development of the interview questions, the goal of the interviews was not to verify ratings, but instead to better understand how the students viewed collaborating with peers while solving engineering challenges. We discuss their perspectives of the social and cognitive dimensions of their teamwork and acknowledge the overlap between the dimensions. To that end, we noted how often students would describe an interaction or communication with their peers in conjunction with dividing work, an approach they took, a method or tool that they chose or a change they decided to make.

Students' perspective on interacting and communicating with their team

Overall, the students described their peer interactions and communication as constructive and positive noting how the effective use of Slack, Google Hangouts, and a Gantt Chart or what they deemed, 'high level mapping on a flowchart' kept them on task and allowed them to monitor tasks throughout the project. A couple of the students talked about how chat function on OneDrive made it easier to collaborate. One student even pointed out that their team had 'really good communication through email, which is not the norm.' Another student mentioned that using Power BI for the visualizations was confusing at first and s/he would have likely not taken the time to really utilise it without both technology and another team member. S/He explained that they had limited experience with data streams, but after talking with a team member who was slightly more experienced with hit, s/he suggested they use in their project and find help online. This led the student to LinkedIn Learning as a resource for his entire team, otherwise s/he said they would 'have been aimlessly wandering around YouTube to find help.'

All seven of the students mentioned that that group members got along and were respectful, and this appeared to emanate from early conversations about their research interests and abilities. Student B explained:

> We did these (digital) presentations at the beginning of the semester that were all kind of corny, like, get-to-know-you things. But we also talked about our research interests and relative strengths and weaknesses. Because of that, I think everyone has a good amount of mutual respect so we respect our [sic] project-related discussions. When I mention something about air flow and how it might affect sensors, I've taken heat transfer and

fluid mechanics, so it's like, oh s/he knows that. And when Student C talks about data, I respect her/his expertise.

A few of the students mentioned that the open-ended nature of the project assisted them in interacting and communicating because, 'we don't know what works and what doesn't, so we have to get as many ideas as we can and test them.' All of the students responded that they were 'satisfied' or 'pretty satisfied' with the team's ability to communicate and conveyed that they respected their team members abilities and believed the tasks, while not always discussed in detail, were clearly divided based on expertise. Student G mentioned, 'I think we all kind of know who we can leverage', and Student B, explained how they divided tasks in greater detail:

> We work separately, we kind of have to decompose the question (referring to their problem-solving task) a little bit. I think everyone's expectations are entirely clear. I don't think anyone at any point has to wonder what the other person wants. It's an issue I've seen in other groups, but we're just very clear on what everyone is doing and expected to get done. We'll put out a doc and it's like, 'hey everyone, mark your sections' and within two days it's all done.

One student described how tasks were divided based on talents the group recognised, saying:

It's all very positive like, we have individual conversations about everybody about certain tasks, like talking to Student F about material property stuff, and then taking to Student H (absent from second observation) about getting different prototypes and then taking to Student A about all of the dashboard stuff. It's easy to know who's background it suited for different things.

Another student talked about the ease in which he/his group communicated, indicating that team members were could easily provide assistance or redirect one another. S/he said:

> We don't have communication blocks. I mean, usually, if someone is confused about something, they just bring it up right there and it makes life a lot easier. Everyone asks, Student C a lot of questions about hardware because s/he knows all the stuff. S/He's, you know getting a PhD in it so after four-ish years, s/he knows the hardware in and out. S/He's under a fair bit of stress with his dissertation and I can still ask him pretty much anything at any time. Student G is doing his thesis, but my interactions with have not been standoffish at all. We have our (morning) meeting times and they go just fine.

The students also believed they freely shared knowledge, materials, and the workload with one other - although not necessary equally or even equitably at different points in the project. This included the student we observed contributing very little during our observations. That said, most students said they did not believe that the workload needed to be equitable, instead they suggested it should be dependent on the team members strengths, and a relative to where the team was in the project. Student D explained:

> I would say it (referring to the workload) is equal, especially since here some people have different strengths as a consequence of where we are in the project, so until we got to the prototyping stuff Student A and F were really only talking to use about the pricing. S/He then added, 'I think we've done a good job staying together in terms of contributions.'

This perspective regarding other team members contributions extended to Student A that we observed interacting and contributing very little. During interviews it was apparent that the team felt the student's contributions before and after team meetings (these were purposefully designed as working meetings) were valuable, even if it was less than their own or not apparent during the sessions we observed.

Students' perspective on tools, methods and iterations

When asked about how their team chose particular tools and resources or handled design iterations, a majority of the students pointed to how they relied on one another's expertise and past experience to divide tasks, choose tools and make changes. They also believed this division of tasks and way of choosing tools or approaches was natural. For example, Student B said:

> I hate to say it naturally coalesced, but it kind of did. I think me and Student E worked at the same manufacturing site, I know that s/he is experienced. When we talk about what we want the dashboard to look like, well we've both used dashboard in manufacturing and created them in the past.

Students D explained,

> I think we self-divided based on expertise into the two many area that we perceived as part of our project. We formed subgroups that are kind of natural – the programming and coding side and then the dashboarding and informatics side.

Student G told us:

> For me and Student E, we have fairly common background experience, we have general conversations about tech and outside conversations that aren't even related (directly to the project). There are other things I know he knows about, and if s/he knows those things that is probably what s/he wants to do.

A few of the students talked about the comfort they felt bringing ideas forward to for their team to discuss, try out or test, and revise if necessary. For instance, Student B explained:

> I feel pretty thankful that we're pretty comfortable with this kind of thing. That if something isn't going to work, it's okay. When it comes down to the design, the right one, we're still going to try and test it. We all kind of acknowledged it might not give us the results we are looking for, but there is no harm in trying it. For a while Nikola Tesla was like, yeah, I don't think that's gonna [sic] work either, but from that you get other ideas. It's part of our brainstorming process.

A few other suggestions made during the student interviews that emerged are worth noting. One student indicated that while there was nobody on the team that s/he would prefer to *not* work with, the addition of an electrical engineer would have been helpful. Another student from the other team responded similarly, even mentioning that the group enlisted the help of an electrical engineering graduate student not directly associated with the course or project.

Four students also suggested that the entire team be exposed to the project and be allowed to form teams earlier, believing that spending time as a team prior to working on the project would help them better understanding one another's expertise and to build trust. To that end, another student remarked several times throughout the interview that there was an element of trust that made the teamwork effective. S/He talked about trust within and beyond the team, extending it to the fellowship (training program and instructor) believing that since the students were all vetted, they felt comfortable asking questions of other group members because they were 'credentialed to a degre' and likely had the answers. S/He then described the instructor as trusting them and treating the teams as if they were all 'extremely massively qualified.'

Discussion

In this study, graduate student teams were tasked with solving two different manufacturing engineering challenge problems (developing a novel handheld sensor and creating a smart manufacturing system). Our research team followed each team throughout the process of completing teamwork, noting how each team member scored on a variety of CPS variables and also providing qualitative data about student teamwork perceptions and the manner in which students chose to enact collaboration.

The majority of the graduate students in this study demonstrated their ability to interact and communicate positively and proficiently, choose appropriate tools and methods to jointly solve problems, and work with team members to test and iterate designs and prototypes. Almost all of the students were observed developing CPS skills (emerging or proficient) during the course of the project work. We noted them asking new questions or responding to team members questions based on their individual area of expertise, demonstrating ideas with tools, drawing or designs, dividing work and checking in, taking turns leading the team in their area of expertise, and appearing respectful of other team member's expertise.

Our observation notes and qualitative interviews highlight several instances of students bringing forth alternative ideas based on their own background and levels of proficiency. The presence of interdisciplinary individual backgrounds composing the overall team allowed for reinforced productive CPS skills to both be developed and applied. This implies, in part, that interdisciplinary students can be trained to successfully collaborate, and answers calls to build this body of research (Lai 2011). In addition there is the implication that training programs, similar to this NRT program, that focus on interdisciplinary problem solving with engineering challenges mirroring industry are a potential way forward to successfully hone collective knowledge and skills to solve complex problems (Graesse et al. 2018; OCED 2017). The matching of real world problem sets to students skills provides students with knowledge regarding these types of problems, but more importantly allows students a testbed to identify and practice relevant CPS skills in a testbed environment before they are implemented in a real world environment.

Both observations and student interviews illuminated the unique methods that engineering instructors worked in concer with industry partners to develop feasible classroom projects mirroring real world challenges. The challenges were ill-defined and ill-structured, much like today's complex engineering challenges in the workforce (Jonassen, Strobel and Lee 2006; Zou and Mikelborough 2015) and likely assisted the students in having to rely on team members to advance in solving each problem.

Although one student (Student A) was not observed participating fully or collaboratively, his team members still identified, acknowledged and viewed his 'between working meetings' and offline contributions as valuable. This finding highlights an important facet of this type of work, and teamwork in the class in general, in that contributions are not always occurring within the classroom or during team meetings. As educators, it is important that we understand student enact teamwork in a myriad of ways, many of which are not apparent to us while in the classroom. The type of project enlisted in this program required a great deal of outside the classroom work, and it appears that this is when Student A completed his work while still being accountable to s/he's team. It is easy to bias our viewpoints on this student's work by simply not being able to directly observe that work or their CPS skills, but it is important to understand that teamwork is dynamic and occurs in many ways.

In general, our research team concluded that CPS may occur productively outside of team meetings and further research is necessary to understand the overall impact of CPS for work occurring outside of team meetings is warranted, especially in light of the increased value of remote work during and after Covid 19. To that end, having students aware of the dimensions and attributes of CPS skills, using a checklist derived from Traineeship Evaluation CPS, and then asking them to self-monitor and compare their observed and self-assessments is the next step in our research.

Four main themes emerged from the interview data: (1) the use of instructor and student chosen technologies enhanced each team's ability to collaborate, (2) team member's expertise played a crucial role in task division and ways work was distributed, (3) building trust and feeling trusted, early on, was perceived as important to the success of the team's CPS, (4) members valued contributions that occurred outside of working meetings. We discuss each below and note when observations also supported the themes.

Blending instructor and student technology choices to enhance CPS

The observations and interviews helped demonstrate the value of using a host of technologies to effectively communicate and collaboratively solve problems. This is not a novel or surprising finding, as numerous studies point to technological advancements increasing the capacity for CPS (Chang et al. 2017). However, in this study, the engineering students provided insight towards the value of blending instructor facilitated and student chosen technologies. Students discussed using digital tools provided by the instructors such as Slack, OneDrive and numerous Google Apps, and choosing communication tools that students were comfortable with or had knowledge of such as LinkedIn Learning, Google Hangouts and FaceTime. Introducing students to productive collaborative tools and allowing them to choose their own appeared to effectively foster collaboration and extended expertise to other members of the team. The instructor's willingness to not restrict technology choices, and the students' willingness to introduce digital tools to each other assisted in the team's ability to successfully complete tasks. We suspect, that much liked the ill-defined nature of the entire project, the ill-defined nature of articulating what tools should be used actually helped the student team members develop investment and autonomy in their teamwork and their final products. Allowing students to have a choice in multiple aspects of the projects (not just in relation to tools) engenders a level of investment from the students, as the student made that choice and the outcome (positive or negative), at some level, depends on the choice that the student made, not the instructor. Simply stated, this level of choice has the potential to increase both individual and team level accountability.

After Covid 19 forced the teams to move to Zoom and utilise the breakout room affordance (each team is in their own room), they continued to collaborate and managed their individual workload and schedules to remain productive during the online meeting. In observations this was evidenced as students discussed purchases of equipment ordered far in advance of their working meetings, or progress they shared regarding designs and molds developed for electrical boxes or creating their team's dashboard. Similar to Marra et al. (2016) the students believed the collaborative technologies improved the quality of their work, and they also believed it enhanced their ability to share and benefit from team members' expertise.

The importance of recognizing expertise in forming teams and discussing roles

The observations and interviews illustrated the ease in which students positively communicated with team members. The innovative and open-ended nature of the problems meant they had to rely on each other to plan, innovate and rethink ideas when efforts failed. We seldom saw, nor did the students indicate, any difficulty in getting along or being respectful to teammates. Several of the students talked about how respect emanated from recognizing each other's expertise, whether they were in an MA or PhD program, and knowing a particular area (hardware, technology, design, visual display, environmental sensing) 'inside and out' – and being open to helping one another. The collective nature of being a student in the NRT program may have also helped to develop respect among team members. Students pointed to efforts early in the project to share their own expertise and talk with their team as beneficial. Although, these students said the efforts should have begun even earlier as a productive way to form teams and think about how their skills aligned with roles they might play in completing tasks and solving the problems. This finding supports de Montjoye et al. (2015) who posit that CPS is supported by the function of social interactions and suggest that advice, expertise and contextualised knowledge and experience matters when solving complex problems.

Building trust to strengthen CPS

A theme that emerged from the student interviews was the need for trust and teambuilding exercises early on in the program or coursework in order to share expertise, identify and acknowledge what might be lacking in the team (in this case, electrical engineering proficiency), and to provide time to thoroughly understand the problem. Four of the students talked at length about the need to trust group members in order to feel comfortable bringing any question forward, and not feel embarrassed when their individual or collective idea failed. Similar to the prior theme of recognizing expertise, almost every student interviewed discussed the open-ended and hands-on nature of the project as requiring a level of flexibility and 'respecting the discussion', which meant trusting each other's knowledge related to their expertise. This could be addressed by class discussions early in the training program, short student presentations detailing own interests and strengths, and attention to additional team and trust-building exercises. To further building trust around expertise in open-ended CPS, instructors could include opportunities to work with industry mentors to simulate how trust, expertise and CPS is approached in the real world.

Valuing off-site work and online collaboration

An unexpected theme noted in the analysis of the interviews was the general belief that work done outside of the teams working meetings played a significant role in solving the engineering challenges, and thus work done during team meetings or during particular points in the project did not have equitable to be valuable. This was further evidenced and supported in observations conducted while the teams meet in Zoom Breakout rooms. These meetings were mainly viewed as touchpoint meetings, to plan and provide a path forward for each individual member team roles in relation to the overall team goals. After Covid 19, the value of off-site work and online collaboration was realised more than ever, by students completely working off-site and utilizing online to facilitate collaboration. Our research team did not set forth with this research to solely focus on the impacts of digital collaborative technologies, but the advent of Covid 19 certainly allowed us the opportunity to examine this in greater detail. In general, based on observations, interviews, and informal meetings among the research team, we found these students to be very resilient in completing their teamwork, and also not having issues relating to using online collaboration. This is significant for two reasons: 1) students can and will use online collaborative technologies in a meaningful way to complete teamwork, and 2) as educators, we should be purposefully developing projects that require the use of these types of technologies as they are likely to become permanent fixtures within our world.

Limitations, next steps and conclusion

We acknowledge some limitations with this research. First, the small sample size may limit the generalizability of this research, however this qualitative research provides an in-depth and more contextualised perspective of collaboration between individual students and their teams. Conducting observations over a longer period of time might provide richer, comparative data, and help us better understand the progression of CPS for individuals. That said, Traineeship Evaluation CPS is designed to provide a relatively quick observation of students' ability to collaborate in short periods of time to offer instructors and educational researchers feasibility in using it. As the next cohort of NRT trainees are included we will extend data collection to the larger group to mitigate both limitations. Next steps in our research also includes the creation of a self-assessment CPS checklist for students to self-monitor and reflect on their collaborative activities. The checklists will be used to make students aware of the constructs of CPS and discuss their perceptions, expectations and abilities when collaborating and teams.

Opportunities to hone CPS in existing engineering curricula are lacking or inadequate (Zou & Mickleborough, 2015). While modest in scope, this study offers an initial first step and valid way to identify and assess CPS behaviours in engineering students. We assist researchers in further understanding collaborative processes, instructors in developing teaching practices aimed at fostering effective projects that promote CPS and provide a way for students to understand and self-monitor their own CPS ability.

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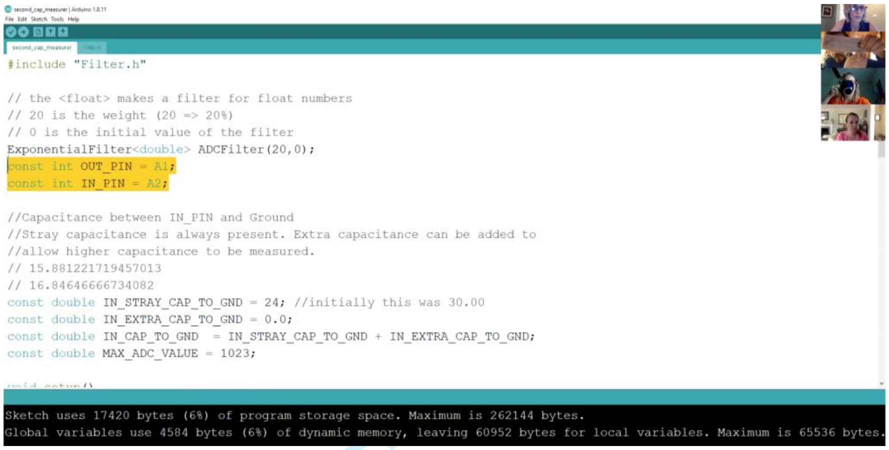

Figure 1: Students meeting online to share code before testing and iterating capacitor sensors.

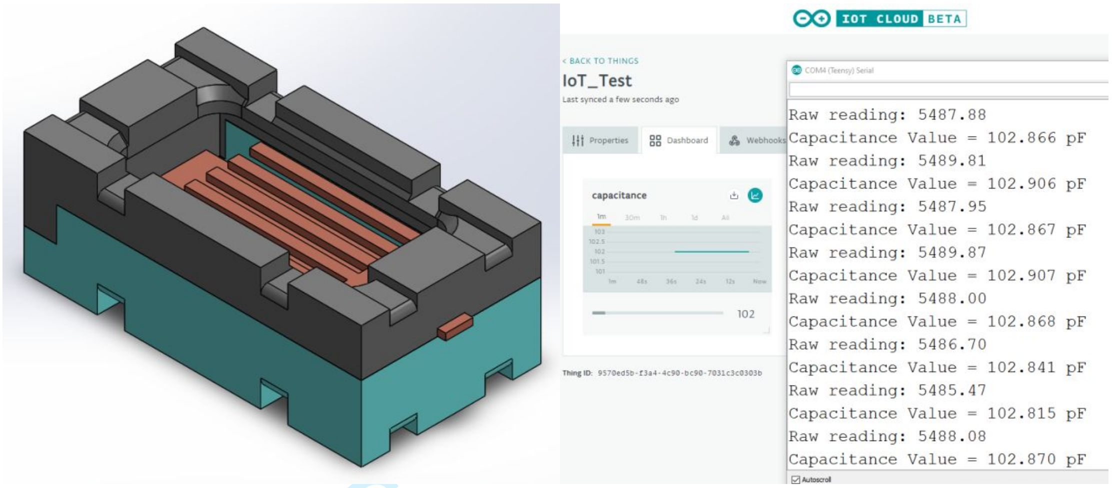

Figure 2: Samples of students' prototype and dashboard from one group.

Collaborative Problem Solving Observation Rubric

Tools and Methods: A distinguishing characteristic in collaborative problem solving is the ability to identify and define the task and then use appropriate tools and methods to solve the problem. When working on a project we would expect to see individuals discussing tasks and then choosing collaborative tools to accomplish them.

Attribute	Not Evident (0)	Emerging (1)	Proficient (2)	Total
Identifies and defines task(s)	Student begins working without identifying or defining the task with group	Students usually begins working by identifying and defining the task with group	Student consistently identifies and defines the task(s) with group before working ✓	2.0
Negotiates relevant method or materials to solve the problem	Student does not discuss relevant method or materials to solve the problem	Student occasionally discusses relevant method or materials to solve the problem ✓	Student consistently discusses relevant method or materials to solve the problem	1.0
Uses tools collaboratively to complete task(s)	Student does not use tools collaboratively when completing tasks	Student occasionally uses tools collaboratively when completing tasks ✓	Student consistently uses tools collaboratively when completing tasks	1.0
Notes:				

Iteration and Adaptation: Another critical component of collaborative problem solving is ite-ation and adaptation. This includes the process of working together and creating solutions that might include iterative thinking during the design and/or problem solving processes. A collaborative team might work on a design together, test iterations or develop and direct incremental iterations. When assessing collaboration during adaptation, we would expect students to engage with their peers using discussions, feedback, critique, and suggestions to meet these attributes.

Attribute	Not Evident (0)	Emerging (1)	Proficient (2)	Total
Iterative thinking	Student does not discuss ways to iterate designs or processes with peers when perfecting a solution.	Student occasionally discusses ways to iterate designs or processes with peers when perfecting a solution. ✓	Student consistently discusses ways to iterate designs or processes with peers when perfecting a solution. ✓	1.5
Tests designs, prototypes or solutions	Student does not test the design, prototype or solution with peers	Student occasionally tests the design, prototype or solution with peers ✓	Student consistently tests the design, prototype or solution with peers	1.0
Develops and directs revisions in designs and prototypes	Student does not rely on peer feedback to revise the design or prototype	Student occasionally relies on peer feedback to revise the design or prototype	Student consistently relies on peer feedback to revise their design or prototype ✓	2.0
Notes:				

Figure 3: Screenshot from two dimensions of Traineeship Evaluation CPS rubric.

Table 1

Table 1: Abridged Traineeship Evaluation CPS 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

Table 2

Traineeship Evaluation CPS Rubric Data: First and Second Observation Results

Student	Peer Interaction	Positive Communication	Tools and Methods	Iteration and Adaption
	Observation 1			
Student A	3/Emerging	1/Not Evident	1/Not Evident	1/Not Evident
Student B	6/Proficient	5.5/Proficient	4.5/Proficient	4.5/Proficient
Student C	5/Proficient	5.5/Proficient	5/Proficient	4.5/Proficient
Student D	4/Emerging	4/Emerging	3/Emerging	1/Not Evident
Student E	4/Emerging	6/Proficient	3/Emerging	3/Emerging
Student F	6/Proficient	6/Proficient	5.5/Proficient	4.5/Proficient
Student G	4/Emerging	6/Proficient	6/Proficient	4/Emerging
	Observation 2			
Student A	0/Emerging	.5/Not Evident	0/Not Evident	0/Not Evident
Student B	4/Emerging	6/Proficient	5/Proficient	3/Emerging
Student C	5.5/Proficient	6/Proficient	5.5/Proficient	4.5/Proficient
Student D	6/Proficient	6/Proficient	6/Proficient	6/Proficient
Student E	6/Emerging	6/Proficient	5/Proficient	3/Emerging
Student F	5.5/Proficient	6/Proficient	6/Proficient	4.5/Proficient
Student G	5/Proficient	6/Proficient	6/Proficient	5/Proficient