



## Exploring Graduate Students Collaborative Problem-Solving in Engineering Design Tasks

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**Exploring Graduate Students Collaborative Problem-Solving in Engineering Design Tasks**

For Peer Review Only

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3 Abstract: This study evaluated seven engineering graduate students' collaborative problem-  
4 solving (CPS) skills using a rubric designed to assess CPS while working in teams to solve  
5 problems. Students worked in two different interdisciplinary teams, in face-to-face and online  
6 environments, to solve complex manufacturing design challenges posed by their instructor. The  
7 students were assessed using the rubric's four dimensions: *peer interactions*, *positive*  
8 *communication*, *tools and methods*, and *iteration and adaption*, and scored via each dimension's  
9 associated attributes, and subsequently interviewed. Six students scored emergent or proficient in  
10 CPS and had slightly higher CPS scores during the second observation. One student  
11 demonstrated a limited ability for CPS and the observable CPS skills decreased during the  
12 project. Interviews revealed the importance of (1) relying on instructor and student chosen  
13 technologies for collaborative tasks, (2) recognizing and drawing on peer expertise early in the  
14 project, (3) building trust during and outside of team meetings, and (4) valuing off-site and  
15 online collaborative work. Findings advance the understanding of how instructors can create  
16 engineering design challenges developed for effective CPS skill-building and future teamwork.  
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21 *Keywords:* collaborative problem solving, engineering design challenges, peer  
22 interactions, communication, teamwork  
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25 The ability to collaborate while solving problems is considered a core competency in the  
26 21<sup>st</sup> century and as such, has received significant attention from researcher and industry leaders  
27 with the rise of technology-enabled environments and increased emphasis on teamwork (Griffin,  
28 et al., 2011). Research demonstrates that the quality of solutions often improves when differing  
29 perspectives, innovative ideas, knowledge and experiences from a variety of group members  
30 working together are considered (Graesser et al. 2018). Much of the complex work in today's  
31 world is conducted in teams, but 'systemic training education and training on CPS is lacking for  
32 those entering and participating in the global workforce' (Graesser et al. 2018, 59). Teams are  
33 often defined as two or more members working interdependently toward a common goal (e.g.,  
34 Salas et al. 1992). Industry and academia, particularly in STEM fields, identify collaborative  
35 problem solving (CPS) among team members as important yet acknowledge that many graduates  
36 entering the workforce lack collaboration skills (National Science and Technology Council,  
37 2018). Interest in assessing skills associated with CPS, a critical component of preparing a  
38 STEM workforce, has led to numerous research efforts across fields including environmental  
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3 science, STEM, math, the military, marketing and medicine (Care, Scoular and Griffin 2016).  
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5 One important aim of this prior research includes defining the constructs of CPS in order to help  
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7 instructors provide effective CPS opportunities and assist students in gaining CPS expertise to  
8  
9 improve their future professional practice. With an increased desire to improve CPS proficiency  
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11 in order to develop deeper knowledge and practical solutions for novel and difficult problems  
12  
13 (Graesser et al. 2018), there is a need to support both students and instructors to create an  
14  
15 environment where productive CPS occurs.  
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19  
20 As part of a 5-year NSF funded engineering graduate traineeship program our research  
21  
22 team facilitated industry-sponsored collaborative projects embedded in coursework for students  
23  
24 to solve complex, multi-level human and systems manufacturing design challenges. Industry  
25  
26 partners worked with the instructors and students on identifying specific projects that would be  
27  
28 relevant to both the industry partner and the students. During their project work, we assessed the  
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30 students' CPS ability while solving manufacturing design challenges and then garnered their  
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32 perspectives on the collaborative work. The goal of our research is to offer a valid and practical  
33  
34 way to identify and assess CPS behaviours in engineering students. We also gathered students'  
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36 perspectives in order to assist researchers in understanding collaborative processes, and to inform  
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38 instructors in ways that create opportunities for collaboration. Furthermore, the feedback from  
39  
40 the assessment offers students a way to reflect on their individual CPS skills. Thus, our research  
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42 questions are: 1. How proficient are graduate students in collaborative problem-solving when  
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44 working in teams to solve engineering design challenges? and 2. What are the students'  
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46 perspectives towards collaborative problem solving?  
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## 51 **Literature Review**

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3 Much of the work done in science, technology, engineering, and mathematics (STEM)  
4 professions is performed by teams (Chang et al. 2017; Marra et al. 2016). At the same time,  
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6 technological advances in the modern workforce has increased the ability to connect across time  
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8 and discipline. This modern approach to teamwork has led to the need to understand  
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10 collaborative problem solving (CPS), which includes social and cognitive skills where collective  
11  
12 knowledge and skills can solve complex problems (Graesser et al. 2018; OEDC 2017).  
13  
14 Moreover, educational institutions value CPS believing it to be a necessary skill that should be  
15  
16 assessed (Care et al. 2016; Greiff, Holt and Funke 2013; Hao et al. 2015; Oliveri, Lawless and  
17  
18 Malloy 2017; Rosen & Foltz 2014). In the field of engineering, the international Accreditation  
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20 Board for Engineering and Technology (ABET) requires accredited engineering programs to  
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22 have CPS as a student outcome. In fact, when considering the seven identified student outcomes  
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24 to prepare engineering graduates to enter the practice of engineering, four of them are connected  
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26 to CPS and include attributes such as: solving complex problems, communicating effectively  
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28 and, functioning on a team (ABET 2020).  
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### 35 **Literature on CPS in Engineering in Higher Education**

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38 Researchers aptly point out that, ‘there are few studies that investigate whether students  
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40 can be successfully trained to collaborate’ (Lai 2011, 24). Training instructors to provide  
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42 students with explicit instruction in how to communicate, interact, help others, and negotiate  
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44 when solving a problem is necessary as today’s engineering challenges are complex, ill-defined  
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46 and ill-structured (Jonassen, Strobel and Lee 2006). At the same time, it is difficult because  
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48 engineering preparation is rarely interdisciplinary, (Zou & Mickelborough 2015), practical or  
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50 relevant to how an engineer behaves (Jonassen, Strobel and Lee [2006](#)). Zou and Mickleborough  
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3 (2015) argue that many courses simply assign students in a group, which does not inherently lead  
4 to the development of collaborative skills (Kavanagh and Crosthwaite [2007](#)).  
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8 With the call to increase CPS skills in education from the Organisation for Economic Co-  
9 operation and Development (OCED) and ABET, engineering education has incorporated CPS  
10 into their curriculum, research, and assessment (Passow and Passow 2017). For example,  
11 Todorovich, Marone and Vazquez (2012) used collaborative problem solving as a methodology  
12 to teach programmable logic to engineering students in an introductory design course. The  
13 course was structured to allow work across teams to find solution to complex projects. Results  
14 indicated students valued the hands-on experience and found it potentially useful for future  
15 engineering work (Todorovich, Marone and Vazquez 2012). Marra et al. (2016) argued for better  
16 support of collaborative skill development in engineering students using embedded collaborative  
17 technologies (i.e. Google Drive) and found ‘quantitative evidence that the use of the environment  
18 was significantly correlated to improved student learning outcomes’ (p. 14). Furthermore,  
19 qualitative results indicated students believed the collaborative technologies improved their  
20 work.  
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38 Students CPS abilities may also depend on their social or personal relationships with team  
39 members. One study on CPS in higher education examined the within-team and extended  
40 networks of 80 computer science engineering students (de Montjoye et al. 2014). The research  
41 demonstrated the students’ problem-solving ability was a function of the strength of both  
42 networks. The authors suggest that the structure of social interactions, which includes advice,  
43 expertise, contextualised knowledge and experience, matters when solving complex problems as  
44 it assists in accessing the right pieces of information. The study found a positive correlation  
45 between strong expressive ties (i.e. friendship, affective connections) and instrumental ties (i.e.  
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3 professional in nature, to exchange information) towards team performance in that the strongest  
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5 ties between both mattered.  
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8 Researchers have also extended CPS studies evaluate the impact on students' performance  
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10 after analyzing their collaborative practices. Meneske, Purzer and Heo (2019) examined types of  
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12 verbal episodes students used in collaborative groups looking at how the interactions occurred at  
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14 the individual and team level. Results indicated that effective CPS teams need balanced  
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16 participation from group members and should include active listening skills, which may need to  
17  
18 be developed (Meneske, Purzer and Heo 2019). More recently, Mabley and colleagues (2020)  
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20 argue that scaffolding and structure is needed in the early stages of a CPS pedagogy, especially if  
21  
22 prior instruction and learning was primarily offered through traditional lectures.  
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26 An extensive systematic review of engineering competencies summed up ways that  
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28 collaborative problem solving is used in engineering education. Passow and Passow (2017),  
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30 looked at engineering materials and research from 1990 to 2013 to determine what  
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32 competency(s) engineering education should give focus. Their results indicated that technical  
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34 competence was inseparable from effective collaboration. The diverse field of engineering is 'too  
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36 complex and interdisciplinary for one person to fully know' (Passow and Passow 2017, 491).  
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38 Therefore, collaborative social interactions are needed to solve real world ill-structured problems  
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40 faced by both professionals and students.  
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#### 44 **Theoretical Framework**

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47 We draw on socio-constructivist theory (Vygotsky 1980) to position our research as our  
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49 focus is on understanding how language, human interactions and available technologies during  
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51 collaborative relationships might assist in solving relevant problems (Squire 2004). Socio-  
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53 constructivist theorists recognise cognition as social and often support the theory using situated  
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3 cognition, in which knowledge is ‘situated’ within the activity, context, and culture in which it is  
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5 developed, where knowing and doing are considered entwined activities (Brown, Collins and  
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7 Duguid 1989). The pedagogical implications for socio-constructivist learning and situated  
8  
9 cognition suggest that situating problems in relevant or real world practices may engage people  
10  
11 in creating solutions. This ostensibly can be extended to students collaboratively solving  
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13 problems in engineering design environments, hence it is well aligned with our research.  
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### 16 17 **Method**

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



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

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

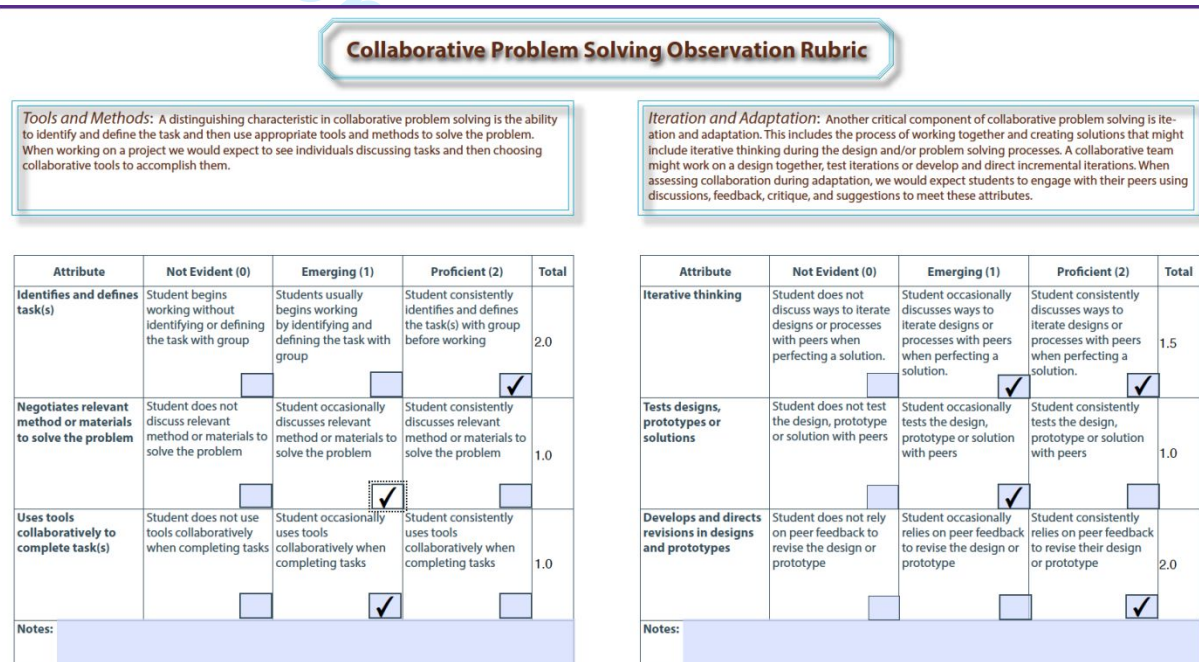


Figure 3: Screenshot from two dimensions of Traineeship Evaluation CPS rubric.

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                        |

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|            |   |
|------------|---|
|            | 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 |

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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 individual 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,

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3 searches email to find copper plates, directs others how to use sticky hands and talks  
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5 about the design.  
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8 Student G: Student expressed concern regarding the use of pipettes and looked up the  
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10 cost/ship date while consulting the group. Physically picked up materials and held them  
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12 via camera to show team examples; was prepared for the meeting and led testing sharing  
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14 the desktop. Conducted tests with alligator clips, reported the reading, then clarified and  
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16 made changes.  
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21 Next, we transcribed and analyzed student interviews to provide a more holistic  
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23 understanding of how students were collaborating and activities that either did or did not  
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25 promote collaboration. These were analyzed using a priori codes aligned to the dimensions on  
26  
27 Traineeship Evaluation CPS of positive communication, peer interactions, tools and methods and  
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29 iterations and adaption and used to answer the research question regarding student perspectives  
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31 of collaborating in teams to solve the challenges. We also noted emergent codes categorised the  
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33 codes into themes (Creswell 2007). The analysis was verified using inter-rater reliability in  
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35 which two researchers independently coded the student responses and categorised them into  
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37 themes, and then compared the results with one another to reach consensus (Creswell 2007). A  
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39 third member of the research team then checked the codes, themes and examples for accuracy.  
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## 47 Findings

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49 ***RQ 1: How proficient are graduate students in collaborative problem-solving when working***  
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51 ***teams to solve manufacturing challenges?***  
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3 During the first observation, six of the seven students consistently scored in the emerging  
4 or proficient range in the social dimensions of *peer interaction* and *positive communication*, and  
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6 five of the seven students also scored in the emerging or proficient range in the cognitive  
7  
8 dimensions of *tools and methods* and *iteration and adaption* (see Table 2 below). Three students  
9  
10 were proficient in all four dimensions, and one student (Student A) demonstrated an emerging  
11  
12 ability to interact with peers when solving problems, but no notable evidence of positive  
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14 communication or collaborating with tools or making changes to the prototype was observed.  
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16 Observation notes described this student as polite, but rarely engaging with the team other than  
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18 to occasionally respond to questions. Based on the conversation, it was evident that the student  
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20 had contributed to some of the prior work related to building a dashboard. While the student  
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22 didn't reject or monopolise the conversation, s/he simply did not contribute much.  
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28 For students who consistently scored in the emerging or proficient range, we noted them  
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30 repeatedly checking in with one another, asking clarifying questions (e.g. 'I think we can do  
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32 three, do you agree with that?' or 'How long would you want that tail, a quarter inch?'). They  
33  
34 would typically offer new ideas about changing a design idea or prototype, often sketching on  
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36 the whiteboard, making changes to a computer-aided design (CAD) drawing or physically  
37  
38 manipulating objects while discussing the math, tolerances or area of a design. At times students  
39  
40 were observed identifying the problem and then working through it together, oftentimes visually,  
41  
42 with one member drawing out the group's ideas for discussion (e.g. Student C made a  
43  
44 suggestion, while Student D drew on the board and Student F suggested how the group should  
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46 approach the issue, saying, 'I'm just going to sketch my ideas on paper, you can start drawing for  
47  
48 all of us.')

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3 During the second observation, which was conducted one month later, while students  
4 were collaborating in a Zoom break-out rooms, due to Covid 19, six of the seven students  
5 consistently demonstrated they were adept at social and cognitive CPS skills scoring *emerging* or  
6 *proficient* in each dimension, with four of the seven scoring proficient in every dimension. The  
7 same student who struggled earlier, Student A, scored lower in each dimension. This student was  
8 nearly absent from the conversation and even asked to turn off his camera. Although it was clear  
9 s/he was still connected via audio, s/he did not respond other than to comment twice to his group  
10 providing positive feedback and then to make a suggestion regarding a materials purchase.  
11 Similar to the first observation, nothing negative was noted however the overall lack of  
12 responsiveness demonstrated his inability to collaborate.  
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26 In the majority of instances where students scored emerging or proficient range, students  
27 were noted responding to design modifications in a manner that is was clear they were seeking  
28 feedback on steps they were taking, or some students noticeably took the lead by reminding the  
29 team where they were in project and answering questions. Some students were observed holding  
30 up or showing digital objects and then asking their team members questions about how the  
31 objects or materials could best be used to devise a strategy to solve the problem.  
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40 Across both observations, the students generally scored slightly lower on the cognitive  
41 dimension of *iteration/adaption* when collaborating, than on *tools/methods*. However, with the  
42 exception of Student A, the members of both teams were both adept at choosing appropriate  
43 tools and methods to solve the problem by the second observation (via Zoom). The students'  
44 ability to demonstrate iterative thinking or design processes and test ideas was generally less  
45 apparent in the first observation with 2 of the students scoring *not evident*, and 2 scoring  
46 *emerging*. Overall, the students scored higher in both *tools/methods* and *iteration/adaption* when  
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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           |

|    |           |                |              |              |                |
|----|-----------|----------------|--------------|--------------|----------------|
| 1  |           |                |              |              |                |
| 2  |           |                |              |              |                |
| 3  | Student E | 6/Emerging     | 6/Proficient | 5/Proficient | 3/Emerging     |
| 4  |           |                |              |              |                |
| 5  | Student F | 5.5/Proficient | 6/Proficient | 6/Proficient | 4.5/Proficient |
| 6  |           |                |              |              |                |
| 7  | Student G | 5/Proficient   | 6/Proficient | 6/Proficient | 5/Proficient   |
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***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 it, s/he suggested they use it in their project and find help

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2  
3 online. This led the student to LinkedIn Learning as a resource for his entire team, otherwise s/he  
4  
5 said they would 'have been aimlessly wandering around YouTube to find help.'

6  
7 All seven of the students mentioned that that group members got along and were  
8  
9 respectful, and this appeared to emanate from early conversations about their research interests  
10  
11 and abilities. Student B explained:

12  
13 We did these (digital) presentations at the beginning of the semester that were all kind of  
14  
15 corny, like, get-to-know-you things. But we also talked about our research interests and  
16  
17 relative strengths and weaknesses. Because of that, I think everyone has a good amount  
18  
19 of mutual respect so we respect our [sic] project-related discussions. When I mention  
20  
21 something about air flow and how it might affect sensors, I've taken heat transfer and  
22  
23 fluid mechanics, so it's like, oh s/he knows that. And when Student C talks about data, I  
24  
25 respect her/his expertise.  
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33 A few of the students mentioned that the open-ended nature of the project assisted them  
34  
35 in interacting and communicating because, 'we don't know what works and what doesn't, so we  
36  
37 have to get as many ideas as we can and test them.' All of the students responded that they were  
38  
39 'satisfied' or 'pretty satisfied' with the team's ability to communicate and conveyed that they  
40  
41 respected their team members abilities and believed the tasks, while not always discussed in  
42  
43 detail, were clearly divided based on expertise. Student G mentioned, 'I think we all kind of  
44  
45 know who we can leverage', and Student B, explained how they divided tasks in greater detail:

46  
47 We work separately, we kind of have to decompose the question (referring to their  
48  
49 problem-solving task) a little bit. I think everyone's expectations are entirely clear. I  
50  
51 don't think anyone at any point has to wonder what the other person wants. It's an issue  
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3 I've seen in other groups, but we're just very clear on what everyone is doing and  
4 expected to get done. We'll put out a doc and it's like, 'hey everyone, mark your sections'  
5 and within two days it's all done.  
6  
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11  
12 One student described how tasks were divided based on talents the group recognised,  
13 saying:  
14

15  
16 It's all very positive like, we have individual conversations about everybody about  
17 certain tasks, like talking to Student F about material property stuff, and then taking to Student H  
18 (absent from second observation) about getting different prototypes and then taking to Student A  
19 about all of the dashboard stuff. It's easy to know who's background it suited for different things.  
20  
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24  
25 Another student talked about the ease in which he/his group communicated, indicating  
26 that team members were could easily provide assistance or redirect one another. S/he said:  
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29  
30 We don't have communication blocks. I mean, usually, if someone is confused about  
31 something, they just bring it up right there and it makes life a lot easier. Everyone asks,  
32 Student C a lot of questions about hardware because s/he knows all the stuff. S/He's, you  
33 know getting a PhD in it so after four-ish years, s/he knows the hardware in and out.  
34  
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38 S/He's under a fair bit of stress with his dissertation and I can still ask him pretty much  
39 anything at any time. Student G is doing his thesis, but my interactions with have not  
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3 students said they did not believe that the workload needed to be equitable, instead they  
4  
5 suggested it should be dependent on the team members strengths, and a relative to where the  
6  
7 team was in the project. Student D explained:

8  
9  
10 I would say it (referring to the workload) is equal, especially since here some people have  
11  
12 different strengths as a consequence of where we are in the project, so until we got to the  
13  
14 prototyping stuff Student A and F were really only talking to use about the pricing. S/He  
15  
16 then added, 'I think we've done a good job staying together in terms of contributions.'

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20  
21 This perspective regarding other team members contributions extended to Student A that we  
22  
23 observed interacting and contributing very little. During interviews it was apparent that the team  
24  
25 felt the student's contributions before and after team meetings (these were purposefully designed  
26  
27 as working meetings) were valuable, even if it was less than their own or not apparent during the  
28  
29 sessions we observed.  
30  
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### 32 33 *Students' perspective on tools, methods and iterations*

34  
35 When asked about how their team chose particular tools and resources or handled design  
36  
37 iterations, a majority of the students pointed to how they relied on one another's expertise and  
38  
39 past experience to divide tasks, choose tools and make changes. They also believed this division  
40  
41 of tasks and way of choosing tools or approaches was natural. For example, Student B said:

42  
43  
44 I hate to say it naturally coalesced, but it kind of did. I think me and Student E worked at  
45  
46 the same manufacturing site, I know that s/he is experienced. When we talk about what  
47  
48 we want the dashboard to look like, well we've both used dashboard in manufacturing  
49  
50 and created them in the past.  
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3 Students D explained,  
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5 I think we self-divided based on expertise into the two many area that we perceived as  
6 part of our project. We formed subgroups that are kind of natural – the programming and  
7 coding side and then the dashboarding and informatics side.  
8  
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11  
12 Student G told us:  
13

14 For me and Student E, we have fairly common background experience, we have general  
15 conversations about tech and outside conversations that aren't even related (directly to  
16 the project). There are other things I know he knows about, and if s/he knows those  
17 things that is probably what s/he wants to do.  
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26 A few of the students talked about the comfort they felt bringing ideas forward to for their team  
27 to discuss, try out or test, and revise if necessary. For instance, Student B explained:  
28  
29

30 I feel pretty thankful that we're pretty comfortable with this kind of thing. That if  
31 something isn't going to work, it's okay. When it comes down to the design, the right  
32 one, we're still going to try and test it. We all kind of acknowledged it might not give us  
33 the results we are looking for, but there is no harm in trying it. For a while Nikola Tesla  
34 was like, yeah, I don't think that's gonna [sic] work either, but from that you get other  
35 ideas. It's part of our brainstorming process.  
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47 A few other suggestions made during the student interviews that emerged are worth  
48 noting. One student indicated that while there was nobody on the team that s/he would prefer to  
49 *not* work with, the addition of an electrical engineer would have been helpful. Another student  
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3 from the other team responded similarly, even mentioning that the group enlisted the help of an  
4 electrical engineering graduate student not directly associated with the course or project.  
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6

7  
8 Four students also suggested that the entire team be exposed to the project and be  
9 allowed to form teams earlier, believing that spending time as a team prior to working on the  
10 project would help them better understanding one another's expertise and to build trust. To that  
11 end, another student remarked several times throughout the interview that there was an element  
12 of trust that made the teamwork effective. S/He talked about trust within and beyond the team,  
13 extending it to the fellowship (training program and instructor) believing that since the students  
14 were all vetted, they felt comfortable asking questions of other group members because they  
15 were 'credentialed to a degree' and likely had the answers. S/He then described the instructor as  
16 trusting them and treating the teams as if they were all 'extremely massively qualified.'  
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### 28 **Discussion**

29  
30 In this study, graduate student teams were tasked with solving two different  
31 manufacturing engineering challenge problems (developing a novel handheld sensor and creating  
32 a smart manufacturing system). Our research team followed each team throughout the process of  
33 completing teamwork, noting how each team member scored on a variety of CPS variables and  
34 also providing qualitative data about student teamwork perceptions and the manner in which  
35 students chose to enact collaboration.  
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44 The majority of the graduate students in this study demonstrated their ability to interact  
45 and communicate positively and proficiently, choose appropriate tools and methods to jointly  
46 solve problems, and work with team members to test and iterate designs and prototypes. Almost  
47 all of the students were observed developing CPS skills (emerging or proficient) during the  
48 course of the project work. We noted them asking new questions or responding to team members  
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3 questions based on their individual area of expertise, demonstrating ideas with tools, drawing or  
4 designs, dividing work and checking in, taking turns leading the team in their area of expertise,  
5 and appearing respectful of other team member's expertise.  
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10 Our observation notes and qualitative interviews highlight several instances of students  
11 bringing forth alternative ideas based on their own background and levels of proficiency. The  
12 presence of interdisciplinary individual backgrounds composing the overall team allowed for  
13 reinforced productive CPS skills to both be developed and applied. This implies, in part, that  
14 interdisciplinary students can be trained to successfully collaborate, and answers calls to build  
15 this body of research (Lai 2011). In addition there is the implication that training programs,  
16 similar to this NRT program, that focus on interdisciplinary problem solving with engineering  
17 challenges mirroring industry are a potential way forward to successfully hone collective  
18 knowledge and skills to solve complex problems (Graesse et al. 2018; OCED 2017). The  
19 matching of real world problem sets to students skills provides students with knowledge  
20 regarding these types of problems, but more importantly allows students a testbed to identify and  
21 practice relevant CPS skills in a testbed environment before they are implemented in a real world  
22 environment.  
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40 Both observations and student interviews illuminated the unique methods that  
41 engineering instructors worked in concert with industry partners to develop feasible classroom  
42 projects mirroring real world challenges. The challenges were ill-defined and ill-structured,  
43 much like today's complex engineering challenges in the workforce (Jonassen, Strobel and Lee  
44 2006; Zou and Mikelborough, 2015) and likely assisted the students in having to rely on team  
45 members to advance in solving each problem.  
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3 Although one student (Student A) was not observed participating fully or collaboratively,  
4 his team members still identified, acknowledged and viewed his ‘between working meetings’  
5 and offline contributions as valuable. This finding highlights an important facet of this type of  
6 work, and teamwork in the class in general, in that contributions are not always occurring within  
7 the classroom or during team meetings. As educators, it is important that we understand student  
8 enact teamwork in a myriad of ways, many of which are not apparent to us while in the  
9 classroom. The type of project enlisted in this program required a great deal of outside the  
10 classroom work, and it appears that this is when Student A completed his work while still being  
11 accountable to s/he’s team. It is easy to bias our viewpoints on this student’s work by simply not  
12 being able to directly observe that work or their CPS skills, but it is important to understand that  
13 teamwork is dynamic and occurs in many ways.  
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28 In general, our research team concluded that CPS may occur productively outside of  
29 team meetings and further research is necessary to understand the overall impact of CPS for  
30 work occurring outside of team meetings is warranted, especially in light of the increased value  
31 of remote work during and after Covid 19. To that end, having students aware of the dimensions  
32 and attributes of CPS skills, using a checklist derived from Traineeship Evaluation CPS, and then  
33 asking them to self-monitor and compare their observed and self-assessments is the next step in  
34 our research.  
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44 Four main themes emerged from the interview data: (1) the use of instructor and student  
45 chosen technologies enhanced each team’s ability to collaborate, (2) team member’s expertise  
46 played a crucial role in task division and ways work was distributed, (3) building trust and  
47 feeling trusted, early on, was perceived as important to the success of the team’s CPS, (4)  
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3 members valued contributions that occurred outside of working meetings. We discuss each  
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5 below and note when observations also supported the themes.  
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### 7 ***Blending instructor and student technology choices to enhance CPS***

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10 The observations and interviews helped demonstrate the value of using a host of  
11  
12 technologies to effectively communicate and collaboratively solve problems. This is not a novel  
13  
14 or surprising finding, as numerous studies point to technological advancements increasing the  
15  
16 capacity for CPS (Chang et al. 2017). However, in this study, the engineering students provided  
17  
18 insight towards the value of blending instructor facilitated and student chosen technologies.  
19  
20 Students discussed using digital tools provided by the instructors such as Slack, OneDrive and  
21  
22 numerous Google Apps, and choosing communication tools that students were comfortable with  
23  
24 or had knowledge of such as LinkedIn Learning, Google Hangouts and FaceTime. Introducing  
25  
26 students to productive collaborative tools and allowing them to choose their own appeared to  
27  
28 effectively foster collaboration and extended expertise to other members of the team. The  
29  
30 instructor's willingness to not restrict technology choices, and the students' willingness to  
31  
32 introduce digital tools to each other assisted in the team's ability to successfully complete tasks.  
33  
34 We suspect, that much liked the ill-defined nature of the entire project, the ill-defined nature of  
35  
36 articulating what tools should be used actually helped the student team members develop  
37  
38 investment and autonomy in their teamwork and their final products. Allowing students to have a  
39  
40 choice in multiple aspects of the projects (not just in relation to tools) engenders a level of  
41  
42 investment from the students, as the student made that choice and the outcome (positive or  
43  
44 negative), at some level, depends on the choice that the student made, not the instructor. Simply  
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46 stated, this level of choice has the potential to increase both individual and team level  
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48 accountability.  
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3 After Covid 19 forced the teams to move to Zoom and utilise the breakout room  
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5 affordance (each team is in their own room), they continued to collaborate and managed their  
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7 individual workload and schedules to remain productive during the online meeting. In  
8  
9 observations this was evidenced as students discussed purchases of equipment ordered far in  
10  
11 advance of their working meetings, or progress they shared regarding designs and molds  
12  
13 developed for electrical boxes or creating their team's dashboard. Similar to Marra et al. (2016)  
14  
15 the students believed the collaborative technologies improved the quality of their work, and they  
16  
17 also believed it enhanced their ability to share and benefit from team members' expertise.  
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### 20 21 ***The importance of recognizing expertise in forming teams and discussing roles*** 22

23  
24 The observations and interviews illustrated the ease in which students positively  
25  
26 communicated with team members. The innovative and open-ended nature of the problems  
27  
28 meant they had to rely on each other to plan, innovate and rethink ideas when efforts failed. We  
29  
30 seldom saw, nor did the students indicate, any difficulty in getting along or being respectful to  
31  
32 teammates. Several of the students talked about how respect emanated from recognizing each  
33  
34 other's expertise, whether they were in an MA or PhD program, and knowing a particular area  
35  
36 (hardware, technology, design, visual display, environmental sensing) 'inside and out' – and  
37  
38 being open to helping one another. The collective nature of being a student in the NRT program  
39  
40 may have also helped to develop respect among team members. Students pointed to efforts early  
41  
42 in the project to share their own expertise and talk with their team as beneficial. Although, these  
43  
44 students said the efforts should have begun even earlier as a productive way to form teams and  
45  
46 think about how their skills aligned with roles they might play in completing tasks and solving  
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48 the problems. This finding supports de Montjoye et al. (2015) who posit that CPS is supported by  
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3 the function of social interactions and suggest that advice, expertise and contextualised  
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5 knowledge and experience matters when solving complex problems.  
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### 7 ***Building trust to strengthen CPS***

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10 A theme that emerged from the student interviews was the need for trust and  
11  
12 teambuilding exercises early on in the program or coursework in order to share expertise,  
13  
14 identify and acknowledge what might be lacking in the team (in this case, electrical engineering  
15  
16 proficiency), and to provide time to thoroughly understand the problem. Four of the students  
17  
18 talked at length about the need to trust group members in order to feel comfortable bringing any  
19  
20 question forward, and not feel embarrassed when their individual or collective idea failed.  
21  
22 Similar to the prior theme of recognizing expertise, almost every student interviewed discussed  
23  
24 the open-ended and hands-on nature of the project as requiring a level of flexibility and  
25  
26 ‘respecting the discussion’, which meant trusting each other’s knowledge related to their  
27  
28 expertise. This could be addressed by class discussions early in the training program, short  
29  
30 student presentations detailing own interests and strengths, and attention to additional team and  
31  
32 trust-building exercises. To further building trust around expertise in open-ended CPS,  
33  
34 instructors could include opportunities to work with industry mentors to simulate how trust,  
35  
36 expertise and CPS is approached in the real world.  
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### 42 ***Valuing off-site work and online collaboration***

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45 An unexpected theme noted in the analysis of the interviews was the general belief that  
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47 work done outside of the teams working meetings played a significant role in solving the  
48  
49 engineering challenges, and thus work done during team meetings or during particular points in  
50  
51 the project did not have equitable to be valuable. This was further evidenced and supported in  
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53 observations conducted while the teams meet in Zoom Breakout rooms. These meetings were  
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3 mainly viewed as touchpoint meetings, to plan and provide a path forward for each individual  
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5 member team roles in relation to the overall team goals. After Covid 19, the value of off-site  
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7 work and online collaboration was realised more than ever, by students completely working off-  
8  
9 site and utilizing online to facilitate collaboration. Our research team did not set forth with this  
10  
11 research to solely focus on the impacts of digital collaborative technologies, but the advent of  
12  
13 Covid 19 certainly allowed us the opportunity to examine this in greater detail. In general, based  
14  
15 on observations, interviews, and informal meetings among the research team, we found these  
16  
17 students to be very resilient in completing their teamwork, and also not having issues relating to  
18  
19 using online collaboration. This is significant for two reasons: 1) students can and will use online  
20  
21 collaborative technologies in a meaningful way to complete teamwork, and 2) as educators, we  
22  
23 should be purposefully developing projects that require the use of these types of technologies as  
24  
25 they are likely to become permanent fixtures within our world.  
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### 30 **Limitations, next steps and conclusion**

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32 We acknowledge some limitations with this research. First, the small sample size may  
33  
34 limit the generalizability of this research, however this qualitative research provides an in-depth  
35  
36 and more contextualised perspective of collaboration between individual students and their  
37  
38 teams. Conducting observations over a longer period of time might provide richer, comparative  
39  
40 data, and help us better understand the progression of CPS for individuals. That said, Traineeship  
41  
42 Evaluation CPS is designed to provide a relatively quick observation of students' ability to  
43  
44 collaborate in short periods of time to offer instructors and educational researchers feasibility in  
45  
46 using it. As the next cohort of NRT trainees are included we will extend data collection to the  
47  
48 larger group to mitigate both limitations. Next steps in our research also includes the creation of  
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50 a self-assessment CPS checklist for students to self-monitor and reflect on their collaborative  
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3 activities. The checklists will be used to make students aware of the constructs of CPS and  
4  
5 discuss their perceptions, expectations and abilities when collaborating and teams.  
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7  
8 Opportunities to hone CPS in existing engineering curricula are lacking or inadequate (Zou  
9  
10 and Mickleborough, 2015). While modest in scope, this study offers an initial first step and valid  
11  
12 way to identify and assess CPS behaviours in engineering students. We assist researchers in  
13  
14 further understanding collaborative processes, instructors in developing teaching practices aimed  
15  
16 at fostering effective projects that promote CPS and provide a way for students to understand and  
17  
18 self-monitor their own CPS ability.  
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25  
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28 The authors declare that they have no competing interests.  
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For Peer Review Only

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**Exploring Graduate Students Collaborative Problem-Solving in Engineering Design Tasks**

For Peer Review Only

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3 Abstract: This study evaluated seven engineering graduate students' collaborative problem-  
4 solving (CPS) skills using a rubric designed to assess CPS while working in teams to solve  
5 problems. Students worked in two different interdisciplinary teams, in face-to-face and online  
6 environments, to solve complex manufacturing design challenges posed by their instructor. The  
7 students were assessed using the rubric's four dimensions: *peer interactions*, *positive*  
8 *communication*, *tools and methods*, and *iteration and adaptation*, and scored via each dimension's  
9 associated attributes, and subsequently interviewed. Six students scored emergent or proficient in  
10 CPS and had slightly higher CPS scores during the second observation. One student  
11 demonstrated a limited ability for CPS and the observable CPS skills decreased during the  
12 project. Interviews revealed the importance of (1) relying on instructor and student chosen  
13 technologies for collaborative tasks, (2) recognizing and drawing on peer expertise early in the  
14 project, (3) building trust during and outside of team meetings, and (4) valuing off-site and  
15 online collaborative work. Findings advance the understanding of how instructors can create  
16 engineering design challenges designed for effective CPS skill-building and future teamwork.  
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20  
21 *Keywords:* collaborative problem solving, engineering design challenges, peer  
22 interactions, communication, teamwork  
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25 The ability to collaborate while solving problems is considered a core competency in the  
26 21<sup>st</sup> century and as such, has received significant attention from researcher and industry leaders  
27 with the rise of technology-enabled environments and increased emphasis on teamwork (Griffin,  
28 et al. 2011). Research demonstrates that the quality of solutions often improves when differing  
29 perspectives, innovative ideas, knowledge and experiences from a variety of group members  
30 working together are considered (Graesser et al. 2018). Much of the complex work in today's  
31 world is conducted in teams, but 'systemic training education and training on CPS is lacking for  
32 those entering and participating in the global workforce' (Graesser et al. 2018, 59). Teams are  
33 often defined as two or more members working interdependently toward a common goal (e.g.,  
34 Salas et al. 1992). Industry and academia, particularly in STEM fields, identify collaborative  
35 problem solving (CPS) among team members as important yet acknowledge that many graduates  
36 entering the workforce lack collaboration skills (National Science and Technology Council,  
37 2018). Interest in assessing skills associated with CPS, a critical component of preparing a  
38 STEM workforce, has led to numerous research efforts across fields including environmental  
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3 science, STEM, math, the military, marketing and medicine (Care, Scoular and Griffin 2016).

4  
5 One important aim of this prior research includes defining the constructs of CPS in order to help  
6  
7 instructors provide effective CPS opportunities and assist students in gaining CPS expertise to  
8  
9 improve their future professional practice. With an increased desire to improve CPS proficiency  
10  
11 in order to develop deeper knowledge and practical solutions for novel and difficult problems  
12  
13 (Graesser et al. 2018), there is a need to support both students and instructors to create an  
14  
15 environment where productive CPS occurs.  
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19  
20 As part of a 5-year NSF funded engineering graduate traineeship program our research  
21  
22 team facilitated industry-sponsored collaborative projects embedded in coursework for students  
23  
24 to solve complex, multi-level human and systems manufacturing design challenges. Industry  
25  
26 partners worked with the instructors and students on identifying specific projects that would be  
27  
28 relevant to both the industry partner and the students. During their project work, we assessed the  
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30 students' CPS ability while solving manufacturing design challenges and then garnered their  
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32 perspectives on the collaborative work. The goal of our research is to offer a valid and practical  
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34 way to identify and assess CPS behaviours in engineering students. We also gathered students'  
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36 perspectives in order to assist researchers in understanding collaborative processes, and to inform  
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38 instructors in ways that create opportunities for collaboration. Furthermore, the feedback from  
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40 the assessment offers students a way to reflect on their individual CPS skills. Thus, our research  
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42 questions are: 1. How proficient are graduate students in collaborative problem-solving when  
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44 working in teams to solve engineering design challenges? and 2. What are the students'  
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46 perspectives towards collaborative problem solving?  
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## 51 **Literature Review**

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3 Much of the work done in science, technology, engineering, and mathematics (STEM)  
4 professions is performed by teams (Chang et al. 2017; Marra et al. 2016). At the same time,  
5  
6 technological advances in the modern workforce has increased the ability to connect across time  
7  
8 and discipline. This modern approach to teamwork has led to the need to understand  
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10 collaborative problem solving (CPS), which includes social and cognitive skills where collective  
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12 knowledge and skills can solve complex problems (Graesser et al. 2018; OEDC, 2017).  
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14 Moreover, educational institutions value CPS believing it to be a necessary skill that should be  
15  
16 assessed (Care et al. 2016; Greiff, Holt and Funke 2013; Hao et al. 2015; Oliveri, Lawless and  
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18 Malloy 2017; Rosen and Foltz 2014). In the field of engineering, the international Accreditation  
19  
20 Board for Engineering and Technology (ABET) requires accredited engineering programs to  
21  
22 have CPS as a student outcome. In fact, when considering the seven identified student outcomes  
23  
24 to prepare engineering graduates to enter the practice of engineering, four of them are connected  
25  
26 to CPS and include attributes such as: solving complex problems, communicating effectively  
27  
28 and, functioning on a team (ABET, 2020).  
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### 35 **Literature on CPS in Engineering in Higher Education**

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38 Researchers aptly point out that, ‘there are few studies that investigate whether students  
39  
40 can be successfully trained to collaborate’ (Lai 2011, 24). Training instructors to provide  
41  
42 students with explicit instruction in how to communicate, interact, help others, and negotiate  
43  
44 when solving a problem is necessary as today’s engineering challenges are complex, ill-defined  
45  
46 and ill-structured (Jonassen, Strobel and Lee 2006). At the same time, it is difficult because  
47  
48 engineering preparation is rarely interdisciplinary, (Zou and Mickelborough,2015), practical or  
49  
50 relevant to how an engineer behaves (Jonassen, Strobel and Lee [2006](#)). Zou and Mickleborough  
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3 (2015) argue that many courses simply assign students in a group, which does not inherently lead  
4 to the development of collaborative skills (Kavanagh and Crosthwaite [2007](#)).

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8 With the call to increase CPS skills in education from the Organisation for Economic Co-  
9 operation and Development (OCED) and ABET, engineering education has incorporated CPS  
10 into their curriculum, research, and assessment (Passow and Passow, 2017). For example,  
11 Todorovich, Marone and Vazquez (2012) used collaborative problem solving as a methodology  
12 to teach programmable logic to engineering students in an introductory design course. The  
13 course was structured to allow work across teams to find solution to complex projects. Results  
14 indicated students valued the hands-on experience and found it potentially useful for future  
15 engineering work (Todorovich, Marone and Vazquez 2012). Marra et al. (2016) argued for better  
16 support of collaborative skill development in engineering students using embedded collaborative  
17 technologies (i.e. Google Drive) and found ‘quantitative evidence that the use of the environment  
18 was significantly correlated to improved student learning outcomes’ (p. 14). Furthermore,  
19 qualitative results indicated students believed the collaborative technologies improved their  
20 work.  
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37 Students CPS abilities may also depend on their social or personal relationships with team  
38 members. One study on CPS in higher education examined the within-team and extended  
39 networks of 80 computer science engineering students (de Montjoye et al. 2014). The research  
40 demonstrated the students’ problem-solving ability was a function of the strength of both  
41 networks. The authors suggest that the structure of social interactions, which includes advice,  
42 expertise, contextualised knowledge and experience, matters when solving complex problems as  
43 it assists in accessing the right pieces of information. The study found a positive correlation  
44 between strong expressive ties (i.e. friendship, affective connections) and instrumental ties (i.e.  
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3 professional in nature, to exchange information) towards team performance in that the strongest  
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5 ties between both mattered.  
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8 Researchers have also extended CPS studies evaluate the impact on students' performance  
9  
10 after analyzing their collaborative practices. Meneske, Purzer and Heo (2019) examined types of  
11  
12 verbal episodes students used in collaborative groups looking at how the interactions occurred at  
13  
14 the individual and team level. Results indicated that effective CPS teams need balanced  
15  
16 participation from group members and should include active listening skills, which may need to  
17  
18 be developed (Meneske, Purzer and Heo 2019). More recently, Mabley and colleagues (2020)  
19  
20 argue that scaffolding and structure is needed in the early stages of a CPS pedagogy, especially if  
21  
22 prior instruction and learning was primarily offered through traditional lectures.  
23  
24

25  
26 An extensive systematic review of engineering competencies summed up ways that  
27  
28 collaborative problem solving is used in engineering education. Passow and Passow (2017),  
29  
30 looked at engineering materials and research from 1990 to 2013 to determine what  
31  
32 competency(s) engineering education should give focus. Their results indicated that technical  
33  
34 competence was inseparable from effective collaboration. The diverse field of engineering is 'too  
35  
36 complex and interdisciplinary for one person to fully know' (Passow and Passow 2017, 491).  
37  
38 Therefore, collaborative social interactions are needed to solve real world ill-structured problems  
39  
40 faced by both professionals and students.  
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#### 44 **Theoretical Framework**

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46 We draw on socio-constructivist theory (Vygotsky 1980) to position our research as our  
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48 focus is on understanding how language, human interactions and available technologies during  
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50 collaborative relationships might assist in solving relevant problems (Squire 2004). Socio-  
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52 constructivist theorists recognise cognition as social and often support the theory using situated  
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3 cognition, in which knowledge is ‘situated’ within the activity, context, and culture in which it is  
4  
5 developed, where knowing and doing are considered entwined activities (Brown, Collins and  
6  
7 Duguid 1989). The pedagogical implications for socio-constructivist learning and situated  
8  
9 cognition suggest that situating problems in relevant or real world practices may engage people  
10  
11 in creating solutions. This ostensibly can be extended to students collaboratively solving  
12  
13 problems in engineering design environments, hence it is well aligned with our research.  
14  
15

### 16 17 **Method**

18  
19 We used qualitative case study (Merriam 2009), to understand graduate students’ CPS  
20  
21 while working in collaborative teams to solve manufacturing design challenges. Case study is  
22  
23 appropriate as it relies on multiple sources of evidence and theoretical propositions when  
24  
25 searching for meaning or developing deeper understandings. In this study, case study assists us in  
26  
27 studying the phenomena of collaboration in its natural setting to make sense of and then describe,  
28  
29 via our analysis of observations and interviews, how collaboration occurred in engineering  
30  
31 students’ project work. Our case was bound by students enrolled an advanced manufacturing  
32  
33 course during the spring semester of 2020. Our participants were seven graduate students who  
34  
35 attended the same university in the southeast United States and moved through each course  
36  
37 within the manufacturing trainee program together. Eight students were enrolled in the program  
38  
39 and all of them were selected to participate, however one student was not present for all of the  
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41 observations and data collection, and thus was not included in the final analysis. During our  
42  
43 research, we paid particular attention to students’ actions aligned with dimensions and attributes  
44  
45 using the Traineeship Evaluation CPS rubric (pseudonym used; further described below).  
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### 51 ***The context***

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3 The seven participating students applied to participate in the trainee program after it was  
4 broadly advertised via academic media outlets; applications were reviewed by participating  
5 researchers and students were selected based on the achievements and the fit of their  
6 interdisciplinary background within the trainee program. All students identified as White or  
7 Caucasian, five were male and two were female (students are referred to as Student A-G and  
8 genders as s/he in this paper to protect their anonymity). Three students were earning their PhD  
9 in Computing, one was earning his PhD in Automotive Engineering, and three students (both of  
10 the females) were enrolled in the Mechanical Engineering MS program. The goal of the program  
11 was to recreate experiences in which researchers, engineers and technicians collaborated on  
12 projects in actual factories. Graduate students took advanced coursework together in three key  
13 areas – manufacturing, data management, and human technologies, and then developed projects  
14 and solutions while working collaboratively. For this study, students were in the first year of the  
15 program and taking a capstone course focused on interdisciplinary collaboration on applied  
16 manufacturing projects relating to advanced manufacturing capabilities. Within the projects, they  
17 conducted research, imagined solutions, planned and created prototypes, tested their prototypes  
18 and iterated their designs before presenting them to peers, instructors and industry partners.  
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40 In one project team, four students worked on problem-solving an applied manufacturing  
41 project, attempting to measure shear and normal forces with a novel sensor designed for  
42 handheld use cases, while also integrating IoT (Internet of Things) data collection capabilities. A  
43 second project group of four students focused on developing a smart manufacturing system  
44 capable of integrating environmental and machine data to create a more complete picture of the  
45 manufacturing environment that could be used to predict future maintenance and workforce  
46 concerns. [Insert figure 1 and figure 2 about here]  
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### ***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

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2  
3 four participants as they worked in different teams for a minimum of 40 minutes, using a  
4  
5 separate rubric for each individual. Since students were observed at the same time the team  
6  
7 scrolled between the rubrics or dimensions as necessary. In the observation notes on Traineeship  
8  
9 Evaluation CPS context specific information was recorded to support the selected levels or  
10  
11 proficiency.  
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14  
15 After the first observation, the university closed and in-person participation was not  
16  
17 allowed due to Covid 19, however the teams continued working by having materials shipped to  
18  
19 one another's homes and meeting online, so the final observation was conducted and recorded  
20  
21 via Zoom. All seven students were observed at least twice by two researchers and sessions were  
22  
23 video recorded to review during analysis.  
24  
25

#### 26 *Semi-structured interviews*

27  
28 Directly following the project work, students were interviewed individually. We posed a  
29  
30 series of questions aligned with attributes on the rubric to gauge students' perspective regarding  
31  
32 working with peers and collaborating. Example questions included: How satisfied were you with  
33  
34 how your peers treated you while working in the group? How would you describe your  
35  
36 interaction with your peers? How did you decide to divide up the work? How did your group  
37  
38 decide how to choose tools and resources to complete the task? Thinking about your group  
39  
40 project, did you make any iterations or changes to your presentation, design, or prototype?  
41  
42  
43

#### 44 *Data analysis*

45  
46 We analyzed Traineeship Evaluation CPS data by assigning each student a summed score  
47  
48 for each dimension of the rubric (*Peer Interactions, Positive Communication, Tools and*  
49  
50 *Methods, Iterations and Adaption*) using a scale of 0 = not evident, 1= emerging, and 2 =  
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52 proficient. Students could also receive a score of .5 or 1.5 if two indicators were checked for the  
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3 same attribute. We created a summed score for each dimension, with ranges (0-2, 2.5-4 and 4.5-  
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5 6) for proficiency levels. For example, a student scoring a 0, 1, 1 across all 3 attributes of the  
6  
7 dimension of peer interaction would receive a summed score of 2 and be within the 'not evident'  
8  
9 range of 0-2 for that dimension. A student scoring 0, 2, 1 in the same dimension would receive a  
10  
11 summed score of 3 and fall in the 'emerging' range. The observation notes assisted in making  
12  
13 evidence-based decisions to accurately assign scores. We provide two typical, representative  
14  
15 examples of observation notes for individual students:  
16  
17

18  
19 Student A: Student asks questions and responds affirmatively or with new questions,  
20  
21 appearing to be listening intently as camera zooms in while speaking. Suggests the team  
22  
23 can get one proof-of-concept prototype by the deadline. Shares a mold via screenshare,  
24  
25 searches email to find copper plates, directs others how to use sticky hands and talks  
26  
27 about the design.  
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30  
31 Student G: Student expressed concern regarding the use of pipettes and looked up the  
32  
33 cost/ship date while consulting the group. Physically picked up materials and held them  
34  
35 via camera to show team examples; was prepared for the meeting and led testing sharing  
36  
37 the desktop. Conducted tests with alligator clips, reported the reading, then clarified and  
38  
39 made changes.  
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45 Next, we transcribed and analyzed student interviews to provide a more holistic  
46  
47 understanding of how students were collaborating and activities that either did or did not  
48  
49 promote collaboration. These were analyzed using a priori codes aligned to the dimensions on  
50  
51 Traineeship Evaluation CPS of positive communication, peer interactions, tools and methods and  
52  
53 iterations and adaption and used to answer the research question regarding student perspectives  
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3 of collaborating in teams to solve the challenges. We also noted emergent codes categorised the  
4 codes into themes (Creswell 2007). The analysis was verified using inter-rater reliability in  
5  
6 which two researchers independently coded the student responses and categorised them into  
7  
8 themes, and then compared the results with one another to reach consensus (Creswell 2007). A  
9  
10 third member of the research team then checked the codes, themes and examples for accuracy.  
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## 17 Findings

### 18 19 ***RQ 1: How proficient are graduate students in collaborative problem-solving when working*** 20 21 ***teams to solve manufacturing challenges?*** 22 23

24 During the first observation, six of the seven students consistently scored in the emerging  
25 or proficient range in the social dimensions of *peer interaction* and *positive communication*, and  
26 five of the seven students also scored in the emerging or proficient range in the cognitive  
27 dimensions of *tools and methods* and *iteration and adaption* (see Table 2 below). Three students  
28 were proficient in all four dimensions, and one student (Student A) demonstrated an emerging  
29 ability to interact with peers when solving problems, but no notable evidence of positive  
30 communication or collaborating with tools or making changes to the prototype was observed.  
31 Observation notes described this student as polite, but rarely engaging with the team other than  
32 to occasionally respond to questions. Based on the conversation, it was evident that the student  
33 had contributed to some of the prior work related to building a dashboard. While the student  
34 didn't reject or monopolise the conversation, s/he simply did not contribute much.  
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49 For students who consistently scored in the emerging or proficient range, we noted them  
50 repeatedly checking in with one another, asking clarifying questions (e.g. 'I think we can do  
51 three, do you agree with that?' or 'How long would you want that tail, a quarter inch?'). They  
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3 would typically offer new ideas about changing a design idea or prototype, often sketching on  
4 the whiteboard, making changes to a computer-aided design (CAD) drawing or physically  
5  
6 manipulating objects while discussing the math, tolerances or area of a design. At times students  
7  
8 were observed identifying the problem and then working through it together, oftentimes visually,  
9  
10 with one member drawing out the group's ideas for discussion (e.g. Student C made a  
11  
12 suggestion, while Student D drew on the board and Student F suggested how the group should  
13  
14 approach the issue, saying, 'I'm just going to sketch my ideas on paper, you can start drawing for  
15  
16 all of us.')

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21 During the second observation, which was conducted one month later, while students  
22  
23 were collaborating in a Zoom break-out rooms, due to Covid 19, six of the seven students  
24  
25 consistently demonstrated they were adept at social and cognitive CPS skills scoring *emerging* or  
26  
27 *proficient* in each dimension, with four of the seven scoring proficient in every dimension. The  
28  
29 same student who struggled earlier, Student A, scored lower in each dimension. This student was  
30  
31 nearly absent from the conversation and even asked to turn off his camera. Although it was clear  
32  
33 s/he was still connected via audio, s/he did not respond other than to comment twice to his group  
34  
35 providing positive feedback and then to make a suggestion regarding a materials purchase.  
36  
37 Similar to the first observation, nothing negative was noted however the overall lack of  
38  
39 responsiveness demonstrated his inability to collaborate.  
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44  
45 In the majority of instances where students scored emerging or proficient range, students  
46  
47 were noted responding to design modifications in a manner that is was clear they were seeking  
48  
49 feedback on steps they were taking, or some students noticeably took the lead by reminding the  
50  
51 team where they were in project and answering questions. Some students were observed holding  
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3 up or showing digital objects and then asking their team members questions about how the  
4  
5 objects or materials could best be used to devise a strategy to solve the problem.  
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8 Across both observations, the students generally scored slightly lower on the cognitive  
9  
10 dimension of *iteration/adaption* when collaborating, than on *tools/methods*. However, with the  
11  
12 exception of Student A, the members of both teams were both adept at choosing appropriate  
13  
14 tools and methods to solve the problem by the second observation (via Zoom). The students'  
15  
16 ability to demonstrate iterative thinking or design processes and test ideas was generally less  
17  
18 apparent in the first observation with 2 of the students scoring *not evident*, and 2 scoring  
19  
20 *emerging*. Overall, the students scored higher in both *tools/methods* and *iteration/adaption* when  
21  
22 working online. Students scoring *proficient* were noted using the screenshare function  
23  
24 frequently, demonstrating how tools and materials might work while teammates asked to see the  
25  
26 object or digital drawing manipulated, or actively making changes to physical objects (e.g. using  
27  
28 calipers to demonstrate a current and changed measurement, showing a box with and without  
29  
30 clamped ends, showing how sticky hands might work with the prototype, reviewing a CAD draft  
31  
32 and making a change).

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37 [insert table 2 about here]

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

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41 The students' interviews provided their perspectives of CPS during the team projects.  
42  
43 Although the Traineeship Evaluation CPS attributes guided the development of the interview  
44  
45 questions, the goal of the interviews was not to verify ratings, but instead to better understand  
46  
47 how the students viewed collaborating with peers while solving engineering challenges. We  
48  
49 discuss their perspectives of the social and cognitive dimensions of their teamwork and  
50  
51 acknowledge the overlap between the dimensions. To that end, we noted how often students  
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3 would describe an interaction or communication with their peers in conjunction with dividing  
4 work, an approach they took, a method or tool that they chose or a change they decided to make.  
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7  
8 *Students' perspective on interacting and communicating with their team*  
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10 Overall, the students described their peer interactions and communication as constructive  
11 and positive noting how the effective use of Slack, Google Hangouts, and a Gantt Chart or what  
12 they deemed, 'high level mapping on a flowchart' kept them on task and allowed them to  
13 monitor tasks throughout the project. A couple of the students talked about how chat function on  
14 OneDrive made it easier to collaborate. One student even pointed out that their team had 'really  
15 good communication through email, which is not the norm.' Another student mentioned that  
16 using Power BI for the visualizations was confusing at first and s/he would have likely not taken  
17 the time to really utilise it without both technology and another team member. S/He explained  
18 that they had limited experience with data streams, but after talking with a team member who  
19 was slightly more experienced with it, s/he suggested they use it in their project and find help  
20 online. This led the student to LinkedIn Learning as a resource for his entire team, otherwise s/he  
21 said they would 'have been aimlessly wandering around YouTube to find help.'  
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37 All seven of the students mentioned that that group members got along and were  
38 respectful, and this appeared to emanate from early conversations about their research interests  
39 and abilities. Student B explained:  
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44 We did these (digital) presentations at the beginning of the semester that were all kind of  
45 corny, like, get-to-know-you things. But we also talked about our research interests and  
46 relative strengths and weaknesses. Because of that, I think everyone has a good amount  
47 of mutual respect so we respect our [sic] project-related discussions. When I mention  
48 something about air flow and how it might affect sensors, I've taken heat transfer and  
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3 fluid mechanics, so it's like, oh s/he knows that. And when Student C talks about data, I  
4 respect her/his expertise.  
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10 A few of the students mentioned that the open-ended nature of the project assisted them  
11 in interacting and communicating because, 'we don't know what works and what doesn't, so we  
12 have to get as many ideas as we can and test them.' All of the students responded that they were  
13 'satisfied' or 'pretty satisfied' with the team's ability to communicate and conveyed that they  
14 respected their team members abilities and believed the tasks, while not always discussed in  
15 detail, were clearly divided based on expertise. Student G mentioned, 'I think we all kind of  
16 know who we can leverage', and Student B, explained how they divided tasks in greater detail:  
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26 We work separately, we kind of have to decompose the question (referring to their  
27 problem-solving task) a little bit. I think everyone's expectations are entirely clear. I  
28 don't think anyone at any point has to wonder what the other person wants. It's an issue  
29 I've seen in other groups, but we're just very clear on what everyone is doing and  
30 expected to get done. We'll put out a doc and it's like, 'hey everyone, mark your sections'  
31 and within two days it's all done.  
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42 One student described how tasks were divided based on talents the group recognised,  
43 saying:  
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47 It's all very positive like, we have individual conversations about everybody about  
48 certain tasks, like talking to Student F about material property stuff, and then taking to Student H  
49 (absent from second observation) about getting different prototypes and then taking to Student A  
50 about all of the dashboard stuff. It's easy to know who's background it suited for different things.  
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3 Another student talked about the ease in which he/his group communicated, indicating  
4 that team members were could easily provide assistance or redirect one another. S/he said:

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7 We don't have communication blocks. I mean, usually, if someone is confused about  
8 something, they just bring it up right there and it makes life a lot easier. Everyone asks,  
9  
10 Student C a lot of questions about hardware because s/he knows all the stuff. S/He's, you  
11 know getting a PhD in it so after four-ish years, s/he knows the hardware in and out.  
12  
13 S/He's under a fair bit of stress with his dissertation and I can still ask him pretty much  
14 anything at any time. Student G is doing his thesis, but my interactions with have not  
15 been standoffish at all. We have our (morning) meeting times and they go just fine.  
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26 The students also believed they freely shared knowledge, materials, and the workload with one  
27 other - although not necessary equally or even equitably at different points in the project. This  
28 included the student we observed contributing very little during our observations. That said, most  
29 students said they did not believe that the workload needed to be equitable, instead they  
30 suggested it should be dependent on the team members strengths, and a relative to where the  
31 team was in the project. Student D explained:  
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40 I would say it (referring to the workload) is equal, especially since here some people have  
41 different strengths as a consequence of where we are in the project, so until we got to the  
42 prototyping stuff Student A and F were really only talking to use about the pricing. S/He  
43 then added, 'I think we've done a good job staying together in terms of contributions.'  
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51 This perspective regarding other team members contributions extended to Student A that we  
52 observed interacting and contributing very little. During interviews it was apparent that the team  
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3 felt the student's contributions before and after team meetings (these were purposefully designed  
4 as working meetings) were valuable, even if it was less than their own or not apparent during the  
5 sessions we observed.  
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### 10 *Students' perspective on tools, methods and iterations*

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12 When asked about how their team chose particular tools and resources or handled design  
13 iterations, a majority of the students pointed to how they relied on one another's expertise and  
14 past experience to divide tasks, choose tools and make changes. They also believed this division  
15 of tasks and way of choosing tools or approaches was natural. For example, Student B said:  
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21 I hate to say it naturally coalesced, but it kind of did. I think me and Student E worked at  
22 the same manufacturing site, I know that s/he is experienced. When we talk about what  
23 we want the dashboard to look like, well we've both used dashboard in manufacturing  
24 and created them in the past.  
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33 Students D explained,

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35 I think we self-divided based on expertise into the two many area that we perceived as  
36 part of our project. We formed subgroups that are kind of natural – the programming and  
37 coding side and then the dashboarding and informatics side.  
38  
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42 Student G told us:

43  
44 For me and Student E, we have fairly common background experience, we have general  
45 conversations about tech and outside conversations that aren't even related (directly to  
46 the project). There are other things I know he knows about, and if s/he knows those  
47 things that is probably what s/he wants to do.  
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3 A few of the students talked about the comfort they felt bringing ideas forward to for their team  
4  
5 to discuss, try out or test, and revise if necessary. For instance, Student B explained:

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7 I feel pretty thankful that we're pretty comfortable with this kind of thing. That if  
8  
9 something isn't going to work, it's okay. When it comes down to the design, the right  
10  
11 one, we're still going to try and test it. We all kind of acknowledged it might not give us  
12  
13 the results we are looking for, but there is no harm in trying it. For a while Nikola Tesla  
14  
15 was like, yeah, I don't think that's gonna [sic] work either, but from that you get other  
16  
17 ideas. It's part of our brainstorming process.  
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24 A few other suggestions made during the student interviews that emerged are worth  
25  
26 noting. One student indicated that while there was nobody on the team that s/he would prefer to  
27  
28 *not* work with, the addition of an electrical engineer would have been helpful. Another student  
29  
30 from the other team responded similarly, even mentioning that the group enlisted the help of an  
31  
32 electrical engineering graduate student not directly associated with the course or project.  
33  
34

35 Four students also suggested that the entire team be exposed to the project and be  
36  
37 allowed to form teams earlier, believing that spending time as a team prior to working on the  
38  
39 project would help them better understanding one another's expertise and to build trust. To that  
40  
41 end, another student remarked several times throughout the interview that there was an element  
42  
43 of trust that made the teamwork effective. S/He talked about trust within and beyond the team,  
44  
45 extending it to the fellowship (training program and instructor) believing that since the students  
46  
47 were all vetted, they felt comfortable asking questions of other group members because they  
48  
49 were 'credentialed to a degree' and likely had the answers. S/He then described the instructor as  
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51 trusting them and treating the teams as if they were all 'extremely massively qualified.'  
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## 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

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2  
3 knowledge and skills to solve complex problems (Graesse et al. 2018; OCED 2017). The  
4  
5 matching of real world problem sets to students skills provides students with knowledge  
6  
7 regarding these types of problems, but more importantly allows students a testbed to identify and  
8  
9 practice relevant CPS skills in a testbed environment before they are implemented in a real world  
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11 environment.  
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14 Both observations and student interviews illuminated the unique methods that  
15  
16 engineering instructors worked in concert with industry partners to develop feasible classroom  
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18 projects mirroring real world challenges. The challenges were ill-defined and ill-structured,  
19  
20 much like today's complex engineering challenges in the workforce (Jonassen, Strobel and Lee  
21  
22 2006; Zou and Mikelborough 2015) and likely assisted the students in having to rely on team  
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24 members to advance in solving each problem.  
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28 Although one student (Student A) was not observed participating fully or collaboratively,  
29  
30 his team members still identified, acknowledged and viewed his 'between working meetings'  
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32 and offline contributions as valuable. This finding highlights an important facet of this type of  
33  
34 work, and teamwork in the class in general, in that contributions are not always occurring within  
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36 the classroom or during team meetings. As educators, it is important that we understand student  
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38 enact teamwork in a myriad of ways, many of which are not apparent to us while in the  
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40 classroom. The type of project enlisted in this program required a great deal of outside the  
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42 classroom work, and it appears that this is when Student A completed his work while still being  
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44 accountable to s/he's team. It is easy to bias our viewpoints on this student's work by simply not  
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46 being able to directly observe that work or their CPS skills, but it is important to understand that  
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48 teamwork is dynamic and occurs in many ways.  
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3 In general, our research team concluded that CPS may occur productively outside of  
4 team meetings and further research is necessary to understand the overall impact of CPS for  
5 work occurring outside of team meetings is warranted, especially in light of the increased value  
6 of remote work during and after Covid 19. To that end, having students aware of the dimensions  
7 and attributes of CPS skills, using a checklist derived from Traineeship Evaluation CPS, and then  
8 asking them to self-monitor and compare their observed and self-assessments is the next step in  
9 our research.  
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19 Four main themes emerged from the interview data: (1) the use of instructor and student  
20 chosen technologies enhanced each team's ability to collaborate, (2) team member's expertise  
21 played a crucial role in task division and ways work was distributed, (3) building trust and  
22 feeling trusted, early on, was perceived as important to the success of the team's CPS, (4)  
23 members valued contributions that occurred outside of working meetings. We discuss each  
24 below and note when observations also supported the themes.  
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### 33 ***Blending instructor and student technology choices to enhance CPS***

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35 The observations and interviews helped demonstrate the value of using a host of  
36 technologies to effectively communicate and collaboratively solve problems. This is not a novel  
37 or surprising finding, as numerous studies point to technological advancements increasing the  
38 capacity for CPS (Chang et al. 2017). However, in this study, the engineering students provided  
39 insight towards the value of blending instructor facilitated and student chosen technologies.  
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45 Students discussed using digital tools provided by the instructors such as Slack, OneDrive and  
46 numerous Google Apps, and choosing communication tools that students were comfortable with  
47 or had knowledge of such as LinkedIn Learning, Google Hangouts and FaceTime. Introducing  
48 students to productive collaborative tools and allowing them to choose their own appeared to  
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3 effectively foster collaboration and extended expertise to other members of the team. The  
4 instructor's willingness to not restrict technology choices, and the students' willingness to  
5 introduce digital tools to each other assisted in the team's ability to successfully complete tasks.  
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7 We suspect, that much like the ill-defined nature of the entire project, the ill-defined nature of  
8 articulating what tools should be used actually helped the student team members develop  
9  
10 investment and autonomy in their teamwork and their final products. Allowing students to have a  
11 choice in multiple aspects of the projects (not just in relation to tools) engenders a level of  
12 investment from the students, as the student made that choice and the outcome (positive or  
13 negative), at some level, depends on the choice that the student made, not the instructor. Simply  
14 stated, this level of choice has the potential to increase both individual and team level  
15 accountability.

16  
17 After Covid 19 forced the teams to move to Zoom and utilise the breakout room  
18 affordance (each team is in their own room), they continued to collaborate and managed their  
19 individual workload and schedules to remain productive during the online meeting. In  
20 observations this was evidenced as students discussed purchases of equipment ordered far in  
21 advance of their working meetings, or progress they shared regarding designs and molds  
22 developed for electrical boxes or creating their team's dashboard. Similar to Marra et al. (2016)  
23 the students believed the collaborative technologies improved the quality of their work, and they  
24 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***

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26 The observations and interviews illustrated the ease in which students positively  
27 communicated with team members. The innovative and open-ended nature of the problems  
28 meant they had to rely on each other to plan, innovate and rethink ideas when efforts failed. We



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3 seldom saw, nor did the students indicate, any difficulty in getting along or being respectful to  
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5 teammates. Several of the students talked about how respect emanated from recognizing each  
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7 other's expertise, whether they were in an MA or PhD program, and knowing a particular area  
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9 (hardware, technology, design, visual display, environmental sensing) 'inside and out' – and  
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11 being open to helping one another. The collective nature of being a student in the NRT program  
12  
13 may have also helped to develop respect among team members. Students pointed to efforts early  
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15 in the project to share their own expertise and talk with their team as beneficial. Although, these  
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17 students said the efforts should have begun even earlier as a productive way to form teams and  
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19 think about how their skills aligned with roles they might play in completing tasks and solving  
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21 the problems. This finding supports de Montjoye et al. (2015) who posit that CPS is supported by  
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23 the function of social interactions and suggest that advice, expertise and contextualised  
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25 knowledge and experience matters when solving complex problems.  
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### 30 ***Building trust to strengthen CPS***

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

### 11 12 ***Valuing off-site work and online collaboration*** 13

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15 An unexpected theme noted in the analysis of the interviews was the general belief that  
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17 work done outside of the teams working meetings played a significant role in solving the  
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19 engineering challenges, and thus work done during team meetings or during particular points in  
20  
21 the project did not have equitable to be valuable. This was further evidenced and supported in  
22  
23 observations conducted while the teams meet in Zoom Breakout rooms. These meetings were  
24  
25 mainly viewed as touchpoint meetings, to plan and provide a path forward for each individual  
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27 member team roles in relation to the overall team goals. After Covid 19, the value of off-site  
28  
29 work and online collaboration was realised more than ever, by students completely working off-  
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31 site and utilizing online to facilitate collaboration. Our research team did not set forth with this  
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33 research to solely focus on the impacts of digital collaborative technologies, but the advent of  
34  
35 Covid 19 certainly allowed us the opportunity to examine this in greater detail. In general, based  
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37 on observations, interviews, and informal meetings among the research team, we found these  
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39 students to be very resilient in completing their teamwork, and also not having issues relating to  
40  
41 using online collaboration. This is significant for two reasons: 1) students can and will use online  
42  
43 collaborative technologies in a meaningful way to complete teamwork, and 2) as educators, we  
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45 should be purposefully developing projects that require the use of these types of technologies as  
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47 they are likely to become permanent fixtures within our world.  
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### 53 54 **Limitations, next steps and conclusion** 55 56 57 58 59 60

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3 We acknowledge some limitations with this research. First, the small sample size may  
4 limit the generalizability of this research, however this qualitative research provides an in-depth  
5 and more contextualised perspective of collaboration between individual students and their  
6 teams. Conducting observations over a longer period of time might provide richer, comparative  
7 data, and help us better understand the progression of CPS for individuals. That said, Traineeship  
8 Evaluation CPS is designed to provide a relatively quick observation of students' ability to  
9 collaborate in short periods of time to offer instructors and educational researchers feasibility in  
10 using it. As the next cohort of NRT trainees are included we will extend data collection to the  
11 larger group to mitigate both limitations. Next steps in our research also includes the creation of  
12 a self-assessment CPS checklist for students to self-monitor and reflect on their collaborative  
13 activities. The checklists will be used to make students aware of the constructs of CPS and  
14 discuss their perceptions, expectations and abilities when collaborating and teams.  
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31 Opportunities to hone CPS in existing engineering curricula are lacking or inadequate (Zou  
32 & Mickleborough, 2015). While modest in scope, this study offers an initial first step and valid  
33 way to identify and assess CPS behaviours in engineering students. We assist researchers in  
34 further understanding collaborative processes, instructors in developing teaching practices aimed  
35 at fostering effective projects that promote CPS and provide a way for students to understand and  
36 self-monitor their own CPS ability.  
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48

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50

51 The authors declare that they have no competing interests.  
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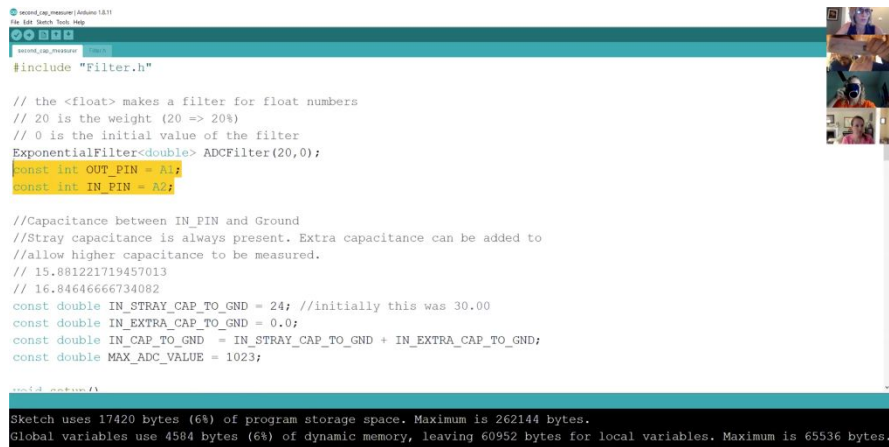
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#include "Filter.h"  
  
// the <float> makes a filter for float numbers  
// 20 is the weight (20 => 20%)  
// 0 is the initial value of the filter  
ExponentialFilter<double> ADCFilter(20,0);  
const int OUT_PIN = A2;  
const int IN_PIN = A2;  
  
//Capacitance between IN_PIN and Ground  
//Stray capacitance is always present. Extra capacitance can be added to  
//allow higher capacitance to be measured.  
// 15.881221719457013  
// 16.8464666734082  
const double IN_STRAY_CAP_TO_GND = 24; //initially this was 30.00  
const double IN_EXTRA_CAP_TO_GND = 0.0;  
const double IN_CAP_TO_GND = IN_STRAY_CAP_TO_GND + IN_EXTRA_CAP_TO_GND;  
const double MAX_ADC_VALUE = 1023;  
  
void setup()  
  
Sketch uses 17420 bytes (6%) of program storage space. Maximum is 262144 bytes.  
Global variables use 4584 bytes (6%) of dynamic memory, leaving 60952 bytes for local variables. Maximum is 65536 bytes.
```

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

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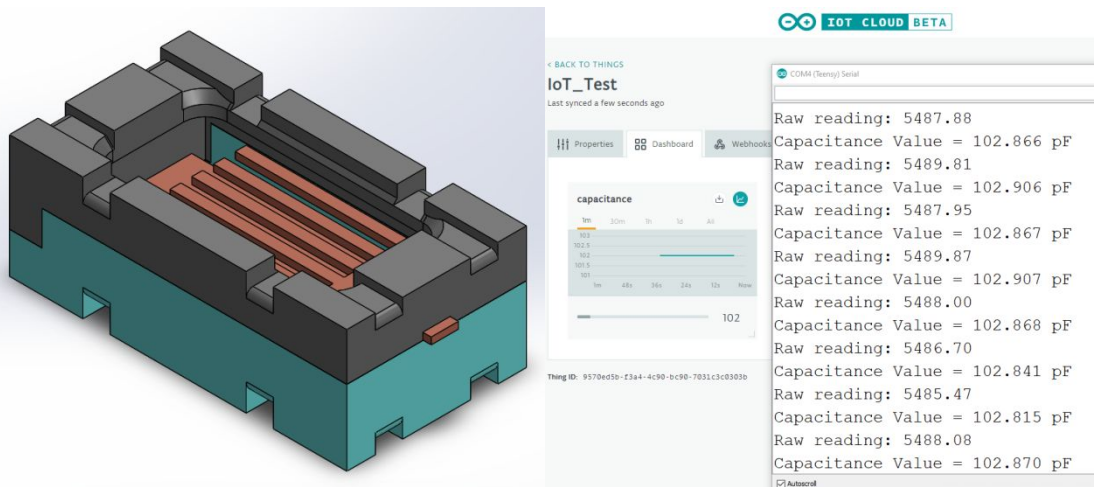


Figure 2: Samples of students' prototype and dashboard from one group.



**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.

**Iteration and Adaptation:** Another critical component of collaborative problem solving is iteration 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 |
|---|--|--|---|-------|
| <b>Identifies and defines task(s)</b>                               | 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   |
| <b>Negotiates relevant method or materials to solve the problem</b> | 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   |
| <b>Uses tools collaboratively to complete task(s)</b>               | 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:  |  |  |   |       |

| Attribute   | Not Evident (0)  | Emerging (1)   | Proficient (2)   | Total |
|---|--|--|--|-------|
| <b>Iterative thinking</b>                                       | 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   |
| <b>Tests designs, prototypes or solutions</b>                   | 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   |
| <b>Develops and directs revisions in designs and prototypes</b> | 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*


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|   |
|---|
| 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   |

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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           |