

Towards the Development of Collaborative Problem Solving Training for Data Science Students

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1 Abstract

Collaborative Problem Solving (CPS) skills are necessary for success in today's workforce, especially in STEM fields like data science and engineering. Professionals in these fields often work across different business units and cultures, which requires strong CPS skills to solve critical problems. Despite this importance, more effective and personalized teaching methods for CPS skills are needed. In this paper, we present a pilot study that provides an approach for teaching CPS tailored to data scientists. Inspired by the Program for International Student Assessment (PISA) CPS framework, we've designed a specialized module to teach students about critical CPS skills and best practices in applying these competencies at the early stages of a collaboration. Our study examines the module's effectiveness in cultivating CPS competencies among students. [Students exposed to CPS best practices demonstrated an ability to understand the competency of their team and the limits of the team as well as general appropriate goals when scoping a project. These findings contribute to the growing knowledge of how to effectively teach and apply CPS skills, providing a promising pathway for improving science students' ability to work well in groups.

Introduction

Collaborative Problem Solving (CPS) is a multifaceted process in which individuals work together to address complex challenges by integrating varied perspectives, skills, and knowledge. It combines social skills, such as effective communication and conflict resolution, with cognitive abilities, including problem representation and strategic thinking¹. In an increasingly interconnected world, the ability to collaborate effectively to achieve common goals is not just a skill but a necessity. It allows teams to leverage the collective knowledge and abilities of team members most effectively. CPS is particularly important for data scientists, who frequently work across disciplines, integrating expertise from fields such as computer science, statistics, and domain-specific knowledge² to solve a range of problems. This demand for teamwork has revealed a gap in students' preparedness. While many students possess strong technical skills, they often lack the collaborative and interpersonal competencies needed for team-based problem solving^{3,4,5}. However, teaching these collaborative skills, particularly in ways tailored to the unique demands of data science education, remains an open challenge⁶. There have been efforts such as the Data Science Corps: Wrangle-Analyze-Visualize (DSC-WAV) and the Attitude, Skills, Communication, Collaboration, and Reflection (ASCCR) that have tried to teach students

how to collaborate but often do not focus exclusively on teaching the social skills necessary for success in collaboration. Thus, this work seeks to contribute an approach for teaching CPS to data science students. We've developed a module for teaching CPS that allow students to learn and apply their skills in a mock data science project. This work is grounded in well-established frameworks for CPS and follows a simulation-based approach to teaching these skills.

Although several existing frameworks provide a foundation for understanding and assessing CPS, including the Program for International Student Assessment (PISA)², and the ATC21⁷, frameworks, we decided to base our lessons on the PISA framework as it has been widely leveraged by others to assess CPS and provides a comprehensive list of skills. PISA emphasizes skills such as understanding roles in solving problems, negotiation, and coordination as vital to success^{8,9}. Using the PISA framework, we have built and tested a module in a Data Science class on how to understand the capacity of one's team and a module on scoping projects. Our study examines whether introducing students to best practices in team formation, team assessment, and project scoping can enhance their CPS skills^{10,11}. The results suggest that the students exposed to these practices demonstrate better collaborative skills and a better understanding of team dynamics and project management

The paper is organized as follows: The Background section provides an overview of efforts to teach data scientist to collaborate and introduces CPS, elaborating on its key components and its application to data science. The Teaching CPS to Data Scientists section outlines our instructional approach and the design of our module. The Evaluating the Impact of Collaborative Problem Solving Module section details our experiment and the results of trying to teach CPS to data science students. evaluation of this approach. Finally, the Conclusion and Future Work section summarizes the findings and suggests directions for future research.

Background

Data science education has historically prioritized technical proficiency over collaboration. Traditional group assignments often emphasize the final product rather than the collaborative process necessary to reach that final product. This limits collaboration skill development^{12,9}. to fill this gap, initiatives like DSC-WAV or frameworks like ASCCR can be leverage to fill this gap. However, they often fall short of teaching and measuring the full scope of collaboration skills.

1.1 Teaching Data Scientists How to Collaborate

Data Science Corps: Wrangle-Analyze-Visualize (DSC-WAV): DSC-WAV provides students with hands-on experience working in teams on real-world data problems, fostering both technical and teamwork skills¹³. Students engage in the full data science lifecycle, from data wrangling and analysis to visualization and communication of results. Although DSC-WAV promotes collaboration, it lacks a formalized instructional framework to teach collaboration skills explicitly. It relies more on the general experiential learning process to simulate a collaboration with the hope that students will learn how to collaborate by working with each other. However, this work may not address specific collaborative challenges systematically. For example, while students work in teams, they may not receive direct instruction on how to apply and understand the

strengths and weaknesses of a team, effective communication techniques, or methods for building a shared understanding of a project’s goals. This can lead to uneven team dynamics and potentially hinder the development of core CPS skills.

Attitude, Skills, Communication, Collaboration, and Reflection (ASCCR): The ASCCR framework offers a structured approach to teaching teamwork skills, emphasizing essential components like attitude, communication, and reflective practices⁴. It focuses on developing student attitudes towards teamwork, communication skills, collaborative abilities, and reflective practices to evaluate team processes. While the ASCCR framework provides a structured approach to teaching and assessing teamwork, it doesn’t necessarily address the specific collaborative needs of data science projects. Data science projects typically involve steps such as team formation, identifying skill sets, and defining objectives^{14,15,16}.

1.2 Collaborative Problem Solving

	(1) Establishing and maintaining shared understanding	(2) Taking appropriate action to solve the problem	(3) Establishing and maintaining team organisation
(A) Exploring and understanding	(A1) Discovering perspectives and abilities of team members	(A2) Discovering the type of collaborative interaction to solve the problem, along with goals	(A3) Understanding roles to solve the problem
(B) Representing and formulating	(B1) Building a shared representation and negotiating the meaning of the problem (common ground)	(B2) Identifying and describing tasks to be completed	(B3) Describing roles and team organisation (communication protocol/rules of engagement)
(C) Planning and executing	(C1) Communicating with team members about the actions to be/being performed	(C2) Enacting plans	(C3) Following rules of engagement, (e.g. prompting other team members to perform their tasks)
(D) Monitoring and reflecting	(D1) Monitoring and repairing the shared understanding	(D2) Monitoring results of actions and evaluating success in solving the problem	(D3) Monitoring, providing feedback and adapting the team organisation and roles

Figure 1: PISA 2015 CPS Framework

CPS is defined by PISA as “the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills, and efforts to reach that solution”^{17,2,18}. Unlike a generic definition of collaboration, where one may work together but have no interdependent needs, CPS differs in that participants who collaboratively solve problems often rely on each other to supply the necessary knowledge and resources to solve a problem. These align closely with the competencies emphasized in data science teams, suggesting that adapting such frameworks could enhance collaboration instruction for data science students.

Two of the most popular and widely used are the PISA 2015 CPS assessment model(PISA 2015)⁸ and the Assessment and Teaching of 21st Century Skills CPS Assessment(ATC21S)⁷. The PISA

2015 model of CPS views it as a cross between collaboration and individual problem-solving. The cross between the three collaboration components (Establishing and maintaining shared understanding, taking appropriate action to solve the problem, and establishing and maintaining team organization) and the individual four problem-solving components (Exploring and Understanding, Representing and Formulating, Planning and Executing, and Monitoring and Reflecting) produces a set of 12 core competencies that encompass CPS. Figure 1 provides a matrix of those competencies. The ATC21S framework viewed CPS as a composite skill arising from the links between critical thinking, problem-solving, decision-making, and collaboration and thus requires both inductive and deductive reasoning to apply these skills collectively. The ATC21S framework identifies social skills as important requirements for collaboration and problem-solving.

2 Teaching Collaborative Problem Solving to Data Scientists

In order to teach CPS to Data Science students, we developed a module based on CPS best practices that could be incorporated into any data science course. This module consists of two lessons (understanding the capabilities of a team and project scoping) focused on the early stages of a data science project and are also aligned with skills highlighted in the PISA CPS framework.

2.1 Collaborative Problem Solving Module

In this module, students are presented with a problem from a client and must work together to address the needs of the client. This means understanding who can serve in which role and then planning and assigning task according to each team member's strength. The module was broken into two lessons focused on two key principles of collaboration in a group project, "understanding the capacity of team members"¹⁹ and "project scoping"^{20,21}. Within each lesson, participants were first provided an overview of these activities and then introduced to a set of best practices and practical ways they could integrate those best practices into their data science project groups. This was done through a powerpoint presentation. After reviewing best practices, students were able to put their new knowledge to work and practice these skills in a mock data science exercise.

Lesson One: Understanding the capacity of team members The first lesson focused on understanding the capacity of team members. This is an important aspect of CPS. Different team members come from different backgrounds and have been through different experiences. Getting to know each other, allows a team to understand different strengths and weaknesses of individual team members which lead to better understanding the different skills possessed by each member. This in turn puts team members in a better position to plan their tasks and assign duties to different team members based on their skills and interests.²² These align with key CPS skills specified in the PISA framework. Understanding the abilities of team members supports exploring and understanding as it helps the team understand different perspectives and abilities. It also contributes to establishing and maintaining team organization by ensuring that roles are properly organized and aids in representing and formulating by establishing a shared understanding between teammates.¹⁸ In order to understand the capacity of team members, the following best practices were taught.

1. **Identify and assess your own skills relevant to the project** Participants are taught that to understand the capacity of the team, they must first know what they bring to the team. To do this well, it is suggested that they list all the skills they have that are relevant to the project. This makes individual team members aware of how their skills and background align with the project.
2. **Identify the strengths and weaknesses of team members** Participants are taught to assess the skills of members of the team by asking good questions and keeping a list of the skills their team members have that are relevant to the project. This allows them to have a clear picture of their teammates' abilities and is also useful for identifying any missing skills.
3. **Use ice breakers to improve team comfort and communication** Participants are taught to use ice breakers with example ice breakers provided. Newer teams may initially struggle to communicate with each other due to a lack of familiarity and initial apprehension. Ice breakers allow teammates to get comfortable with each other and thus improve the overall communication among different team members.
4. **Communicating skills and gaps effectively for better collaboration** Participants are taught to openly communicate any skills/gaps relevant to the project they see as it can save a lot of time and aid the project scoping process. It becomes easier to allot roles and responsibilities to different team members. Teammates would also be better suited to communicate with each other, collaborate and resolve any conflicts.
5. **Good note taking practices to track team skills and discussions** Participants are taught the importance of note taking and best way to take notes about team members. It is important to take notes during team meetings as it can be difficult to keep track of all the skills and ideas that may be discussed. Keeping note of all these factors also allows the team to have a working knowledge base that they can refer to.

Lesson Two: Project Scoping For the second lesson in this module, participants were taught about the importance of project scoping and how to scope a project, which refers to the process of planning a project based on the requirements of a client and the skills and background of the team members. Project scoping is an essential part of the software development cycle because it allows teams to determine the feasibility of the project, figure out any problems associated with the project and improves the overall control the team has over the project. It gives a team the information necessary to plan different aspects of a project properly.²⁰ This lesson also aligns with the CPS skills highlighted in the PISA framework. The process of assessing project feasibility supports exploring and understanding. Establishing and maintaining team organization is supported by defining project scope based on team skills and client requirements. Planning and executing is another crucial factor as project scoping provides the necessary foundation for executing tasks effectively and overall project control.

1. **Summarize client requirements for better team understanding:** Participants study the client's requirements carefully and then summarize these requirements properly. This ensures that every teammate has a proper understanding of the project. A clearer understanding of the requirements facilitates better group discussions and decision making.
2. **Summarize project tasks prior to the meeting for focused discussions:** Participants are

taught to each make a list of tasks before a project meeting. This ensures that participants are aware of their responsibilities and are in a better position to discuss their perspectives. This also helps to ensure that none of the crucial steps are overlooked.

3. **Generating clarifying questions to explore different perspectives:** Participants are taught to generate a list of questions based on the client's requirements. This ensures that different angles and potential issues are considered.
4. **Asking questions openly for clarity:** After listing questions, it is also important to ensure that they are raised and properly addressed. This also encourages an environment with open communication, promotes inclusivity and acknowledges each member's contribution.
5. **Keep track of new questions for continuous understanding:** Discussions can lead to new questions and insights that may not be immediately apparent. It is important that these new questions are properly documented and addressed. Doing this in an iterative manner ensures that the team has a proper understanding of the project at every stage.

3 Evaluating the Impact of Collaborative Problem Solving Module

To examine the effectiveness of the proposed CPS module, we conducted a training session as part of a data science class over a 3-hour class period.

Participants: A total of 69 students participated in this study. These students were divided into ten groups of seven, with one group having six students. Informed consent was obtained from all participants, and appropriate measures were taken to protect their privacy and well-being throughout the study.

Task: Each group was given a mock data science project. This project was designed to simulate a real world scenarios. Groups were told that a company named WebWiz Solutions is looking to develop a system to analyze user interactions and provide users with personalized recommendations. Participants were provided with a list of requirements for the project and mock data which includes user interaction data, clickstreams, page views, time spent on pages, engagement metrics. They were also given data related to the content of the website (articles, products, and services).

Experiment Procedure: In the first lesson, participants were asked to spend ten minutes getting to know each others. After those ten minutes, these participants were asked a series of questions (highlighted in Table1) to understand how well they understood both their capacity and the capacity of their teammates. After this initial exercise, participants are then taught best practices for understanding their teammates' backgrounds and experiences. After the lesson, participant then repeated the same exercises and completed the post-lesson survey that was the same as the pre-survey. Lesson two followed a similar approach, except it focused on project scoping. Participants were given the survey highlighted in Table 2 that assessed how they would perform and collaborate over different aspects of the project scoping process. After this, they were taught best practices for project scoping. They were then given a post-lesson survey.

	Questions
1.1	List all of your skills that you considered relevant for this project
1.2	List each teammate's username and what you learned about them that is personal or social
1.3	List all of your skills that you communicated to others during the practice
1.4	List each teammate's username and all of the skills that you learned they have
1.5	List all the skills that you think are missing in the team
1.6	List all the skills that you believe others are aware are missing in the team

Table 1: Questions asked in Lesson One survey

	Questions
2.1	List the tasks that are to be completed for this project
2.2	List the skills needed to complete the tasks listed earlier and one member of the team who will complete it
2.3	List two examples of SMART GOALS for this project
2.4	List all of the dependencies you see in the schedule for your task
2.5	List all the skills that you believe others are aware are missing in the team

Table 2: Questions asked in Lesson Two survey

Measures

In order to measure how effective the training was, the results from the participant's pre and post survey for each lesson were compared to determine if there was a change in their responses to those surveys. This provided an indication of the effectiveness of the lesson. Participants filled out the survey in diverse formats. Due to this, we received a wide range of responses. In order to make the data more consistent and better suited for analysis, the data was cleaned and standardized. This process involved getting rid of empty entries and aligning all entries to a fixed format determined for data analysis. We then obtained the counts relevant to each question. For instance, for the factor "skills relevant to the project", participants listed all the skills that they had in their own words. We then calculated the number of skills they listed in the pre-lesson survey and the post-lesson survey. This process was repeated for each factor. This gave us pre-lesson and post-lesson counts for each question. For analysis, we ran paired sample T tests on the pre-survey and post-survey counts to measure the extent to which their responses had improved.

Lesson One Measures: From the first lesson survey, we looked at four factors to determine how well participants knew their teammates - skills they had relevant to the project, skills that they communicated to their teammates, skills that they thought were missing from the team and missing skills that were reported by other teammates.

For measuring skills relevant to the project, participants listed all the skills that they had in their own words. We then counted the number of skills they listed in the pre-lesson survey and the post-lesson survey separately. The difference between their pre and post counts was used to measure the impact of teaching participants to take account of their own skills. Similarly, we obtained counts for the skills participants communicated to their teammates, skills they felt were

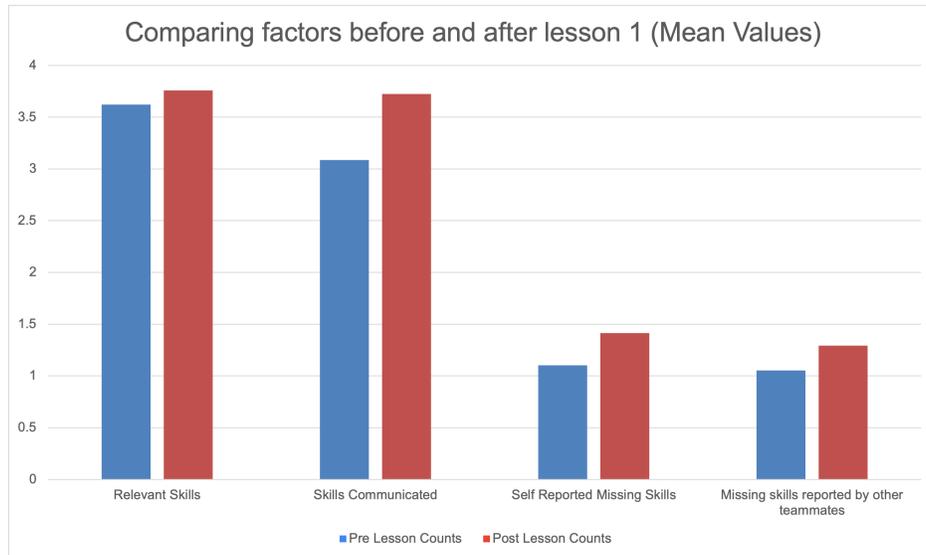


Figure 2: Lesson One Survey Results

missing from the team and the missing skills that were reported by their other teammates.

Lesson Two Measures: From the second survey, we looked at four factors to determine how participants approached the project survey process and collaborated with their teammates - tasks that they thought needed to be completed for the project, skills that were required to complete these tasks, dependencies associated with their tasks and any missing skills that were required to finish these tasks. Similar to Lesson One, we obtained the counts associated with each of these factors using the difference between the pre-lesson survey and post-lesson survey counts. Additionally, we also asked participants to list two examples of SMART (Specific, Measurable, Achievable, Realistic, and Timely) goals corresponding to the project. In order to analyze whether there was any improvement in the SMART goals listed by the participants, we calculated a smart goal score. This assigns scores to the participants based on the goals that they submitted. If they successfully listed two SMART goals, we gave them a score of 1. If they listed a single SMART goal, they received a score of 0.5. If they listed two goals, but these goals weren't SMART goals, they received a score of 0.25. If they listed a single goal, but this goal wasn't a SMART goal, they were given a score of 0.1. And if they didn't list anything, they received a score of 0. This was done for the pre-survey and the post-survey goals that they listed.

3.1 Results

We conducted paired-sample t-tests to compare pre-and post-lesson scores to understand the impact of our modules on adopting best practices.

Lesson One: Understanding Team Capacity We found no significant difference in the number of skills participants found relevant to the project before and after Lesson One: $t(57)=-0.404$, $p=0.69$). The participants did not identify any additional skills needed to complete the project after the lesson. Regarding the number of skills participants communicated to their teammates, we see significant results ($t(57)=-1.845$, $p=0.03$). This indicates that although participants did not

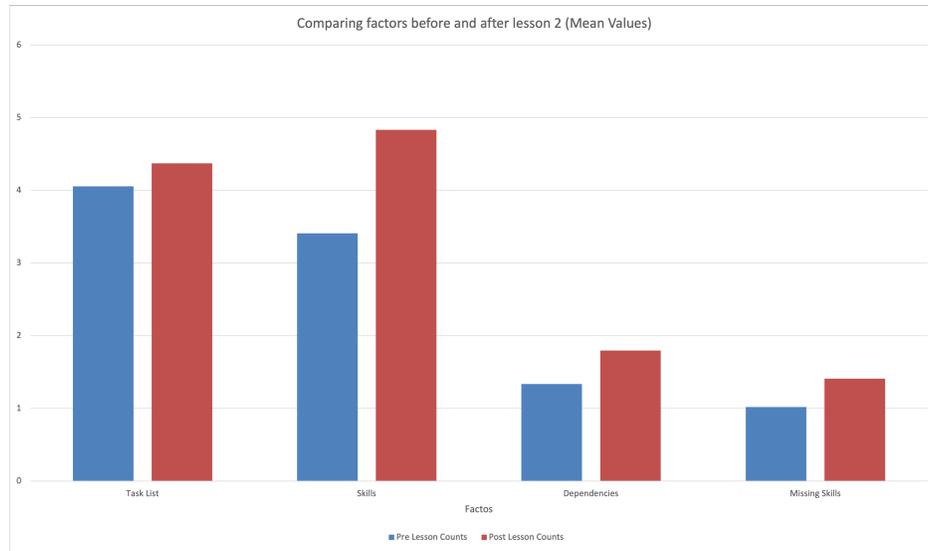


Figure 3: Lesson Two Survey Results

identify additional skills, they did improve in communicating those skills they already had. However, we found significant differences in the number of skills participants found missing from the team as a whole, ($t(57)=-1.966$, $p=0.05$), and the number of skills missing from the team reported by other teammates before and after the lesson, ($t(57)=-1.990$, $p=0.05$). This implies that participants got better at identifying gaps in the team capacity and while they may not have identified any additional skills of their own after the lesson, they had a better understanding of the limitations of the team as a whole.

Lesson Two: Project Scoping Examining the results of the second lesson, we found no significant difference in the number of tasks reported by the users before and after the lessons, ($t(53)=-1.192$, $p=0.24$). This implies that the participants could not identify any additional tasks required to complete the project after they were shown the lesson. While the participants may not have identified additional tasks, we did find a significant difference in the number of skills required by the team to complete their tasks, reported by the users before and after the lesson, ($t(53)=-3.790$, $p=0.001$). The participants were able to identify more skills required to finish the project after they were given the lesson. This implies that participants showed a greater understanding of the abilities of their team members and how they fit into the project as a whole. We also found a significant difference in the numbers of dependencies reported by the participants before and after the lesson, ($t(53)=-2.535$, $p=0.01$). The participants were able to identify more dependencies after they were shown the lesson. We found a significant difference in the number of skills missing from the team reported by the participants before and after the lesson two, ($t(53)=-2.052$, $p=0.045$). We also found a significant increase in the SMART goals listed by participants ($t(53) = -2.782$, $p=0.003$). This implies that the participants had a greater overall understanding of SMART goals and how it tied into project scoping.

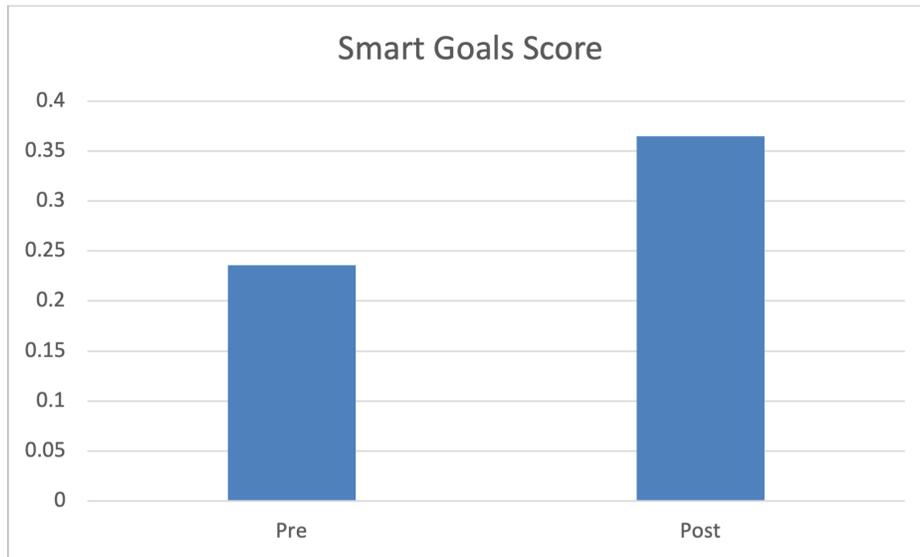


Figure 4: Smart Goal Score Results

4 Conclusion and Future Work

In this paper, we present a module used to teach CPS in the context of data science by highlighting best practices through a set power point slides. We looked at two important CPS factors, how well participants knew their teammates' skills, and how best to collaborate with their teammates to scope a project. We simulated a data science project and assessed differences in participants performance depending on whether or not they received training. Based on the difference in the pre and post survey results, it is evident that there was an overall increase in participants' ability to apply these different best practices in a mock activity. Looking at individual factors, we observed a significant difference in the responses reported by the participants after both lessons. After the first lesson, we observed improvements in the number of skills participants reported missing from the team and the number of skills missing reported by their other teammates. This implies that the participants had a better understanding of their teammates' backgrounds and abilities after the lesson, and thus they were able to provide a greater amount of details about them when they were given the survey. We observed similar trends for the responses to the second survey. There were significant improvements in the number of skills participants reported were required to complete the project, the number of dependencies that would be required to work on their tasks and the skills that were missing from the team. Participants showed a greater understanding of the project scoping process after they were shown the second lesson. There were a number of limitations we wanted to highlight. First, this study did not have a controlled condition which may undermine the effectiveness of this intervention compared to others. We hope to do this comparison in the future. Also, we recognize that the repeated-designed measures can introduce testing effects. However, while one might assume that the participants improved post-survey was because they were familiar with the process, this was not the case. In the first survey, the participants showed improvements in two out of the four factors, and in the second survey, participants showed improvements in four of the five factors. This lack of improvement in scores for some questions provides evidence that it wasn't just the

mere repeated nature of the measure that caused improvement. The significant improvement in the responses across specific questions supports the idea that the lessons did have an effect on those specific skills. This study serves as the preliminary study in building a personalized learning system for teaching CPS. Building on prior work and grounded in the PISA framework, this research piloted a module designed to foster collaborative problem-solving skills. Future work will explore incorporating virtual agents to personalize the training experience and enable self-directed learning, ultimately enhancing the effectiveness of these lessons by providing accessible and engaging training in a safe environment.

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