Research Report

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RESEARCH REPORT

Collaborative Problem Solving Assessment in an Online Mathematics Task

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Collaborative problem solving (CPS) is an important 21st-century skill for academic and career success, and as a result, there is increased interest among businesses and educational institutions in the assessment and development of CPS skills. CPS skills are difficult to measure using traditional forms of assessment, and that difficulty has led to the use of computer environments that allow individuals to interact in complex situations and capture all actions throughout the process. In the current paper, we describe the design of a collaborative online mathematics task and explore student perceptions of the task and the extent to which the task elicits CPS skills. Results revealed areas of difficulty for students and showed that the task mostly elicited skills associated with the social dimension of CPS. We describe modifications to the task to provide better opportunities for students to display a broader range of CPS skills. An upcoming larger scale pilot study will explore whether the redesigned task can elicit the less observed CPS skills.

Keywords collaborative problem solving; collaboration; assessment; digitally based assessment; 21st century skills

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Collaborative problem solving (CPS) is becoming increasingly important for academic and career success in the 21st century (Burrus, Jackson, Xi, & Steinberg, 2013; Griffin, McGaw, & Care, 2012). Furthermore, technological transformations in these contexts have reshaped the way we live and work. Many tasks require collaboration and interaction among people who may not even be in the same physical location. These changes have motivated the need for curricular reform and national and international assessments to take greater interest in the teaching and assessment of CPS skills (Fiore et al., 2017; Graesser et al., 2018; National Research Council, 2011; OECD, 2013).

CPS involves a diverse set of skills across social and cognitive dimensions (OECD, 2013) and is a process-oriented construct making traditional forms of assessments (e.g., multiple-choice questions) difficult to utilize (Davey et al., 2015). Computer environments offer promise in measuring CPS, as they allow individuals to demonstrate performance in complex, interactive situations that are akin to everyday contexts and have the capability to capture all actions and discourse in the environment as additional sources of evidence. In the current paper, we describe work in designing an online collaborative mathematics task to elicit CPS behaviors outlined in a comprehensive CPS ontology (Andrews-Todd & Forsyth, 2018). In a play-testing study, we explored student perceptions of the task and the extent to which the task elicited CPS skills. We used results from the study to redesign the task to increase its measurement properties.

Online Mathematics Task

Components of a single-player conversation-based assessment (Cayton-Hodges, 2016) were used to create a collaborative online mathematics task called the T-Shirt Math Task in which students engaged in discussion and solved a problem together. The T-Shirt Math Task deals with concepts associated with linear equations and was intentionally designed to elicit communication and collaboration between two individuals working together on the task. In the task, students are presented with a problem statement in which a school student council is planning to sell T-shirts to the eighth-grade class and is considering three different companies for purchasing the T-shirts. Students are tasked with determining which of the three companies would be the best choice for purchasing the T-shirts given a maximum number of students who would be making purchases. Initially, the problem provides information about the charges per T-shirt and setup fee for each company. In solving the problem, students are first asked to work with their partner to make a recommendation for the company they would choose and then move through a series of pages in the task to complete activities (e.g., developing

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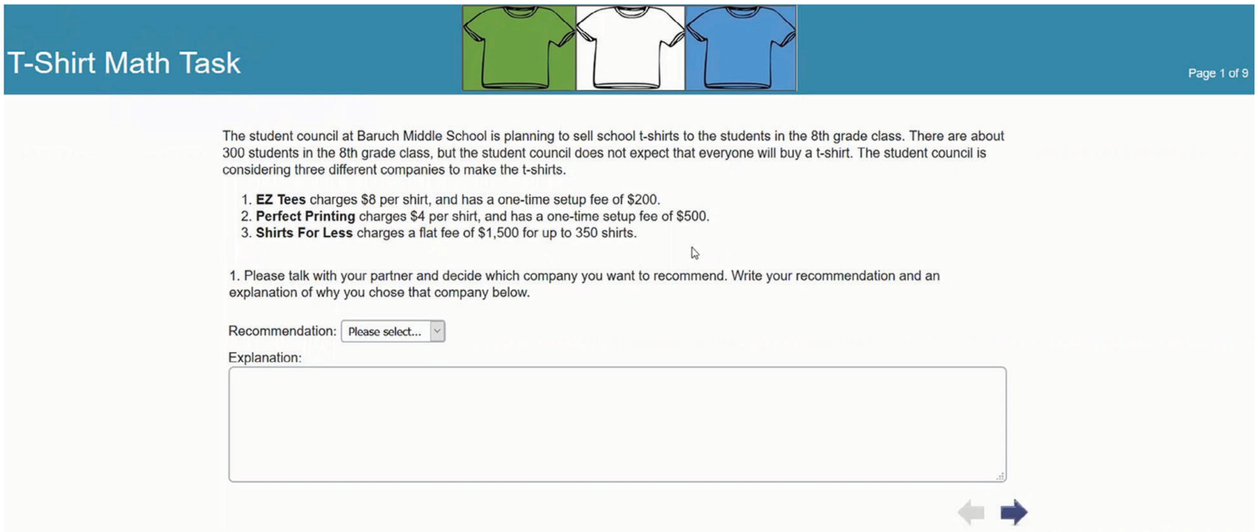

Figure 1 Screenshot of collaboration problem solving T-Shirt Math Task.

cost equations for each company) that will help them make a more informed decision about which company may be the appropriate choice. See Figure 1 for a screenshot of one page in the task interface.

Play-Testing Study

Participants

A total of 10 middle school participants worked in groups of two (five teams) who completed the study. The participants ranged in age from 11 to 14, with an average age of 12. Four participants reported being White, three reported being Asian, one reported being Indian, one reported being American Indian or Alaskan Native, and one reported being more than one race. There were six males and four females. With respect to gender distribution, there were two male/male teams, two male/female teams, and one female/female team.

Study Procedure

Two students formed a team for each study session. In the session, each student sat at a desk in front of his or her own computer. Each student first individually completed an online background information questionnaire on his or her respective computers. A video conference was then set up such that students could see each other using the webcam on their computers and communicate via a microphone attached to headphones. One student was chosen to virtually share his or her computer screen so that both students could view the same task screen on their computers. The video conferencing software allowed both students the capability to control the cursor on the screen and type answer choices using their own mouse. Once the video was set up, students were asked to work together to complete the T-Shirt Math Task. During task engagement, video, audio, and students' actions on the screen were recorded. After completing the task, a posttask interview was conducted in which students were individually asked about their experiences with the task. In the current paper, we describe results from qualitative coding of the videos of students' interaction with the T-Shirt Math Task and their reported experiences with the task.

Collaborative Problem Solving Ontology

An extensive literature review of CPS frameworks and relevant prior research on concepts associated with CPS (e.g., Hesse, Care, Buder, Sassenberg, & Griffin, 2015; Liu, von Davier, Hao, Kyllonen, & Zapata-Rivera, 2015; Meier, Spada, & Rummel, 2007; O'Neil, Chung, & Brown, 1995; OECD, 2013) was carried out to create a CPS ontology that would guide qualitative coding. An ontology provides a theory-driven representation of a construct or domain of interest, laying out the concepts and relationships between concepts in a construct. The CPS ontology comprised nine high-level CPS skills split into social and cognitive dimensions. The social dimension referred to collaboration and teamwork behaviors and included maintaining communication, sharing information, establishing shared understanding, and negotiating. The cognitive dimension referred to problem solving and task work behaviors and included exploring and understanding, representing and formulating, planning, executing, and monitoring.

Maintaining communication corresponds to content irrelevant social communication and includes general off-topic communication, rapport-building communication, and inappropriate communication. Sharing information corresponds to content relevant information communicated during collaboration and includes sharing one's own information, sharing task or resource information, and sharing understanding. Establishing shared understanding corresponds to communication in the service of attempting to learn the perspective of others and trying to establish that what has been said is understood. Negotiating refers to communication used to express agreement or disagreement and to attempt to resolve conflicts when they arise.

Exploring and understanding corresponds to actions in the task environment to explore and understand the problem space. Representing and formulating refers to actions and communication used to build a coherent mental representation of the problem and formulate hypotheses. Planning corresponds to communication used to develop a strategy or plan to solve the problem. Executing refers to actions and communication used in the service of carrying out a plan (e.g., enacting a strategy or communicating to teammates actions one is taking to carry out the plan). Monitoring refers to actions and communication used to monitor progress toward the goal and monitor the team's organization. For more in depth discussion of the CPS ontology, see Andrews-Todd and Forsyth (2018) or Andrews-Todd, Forsyth, Steinberg, and Rupp (2018).

Results

Collaborative Problem Solving Skills Displayed

In the T-Shirt Math Task, we found that students showed higher frequencies of social, as compared to cognitive, behaviors associated with CPS, with some skill frequencies too sparse to count as evidence. Specifically, for the social dimension, students demonstrated high frequencies of sharing information, establishing shared understanding, and negotiating. For the cognitive dimension, only executing had high frequencies. See Table 1 for the frequencies for each CPS skill and an example that corresponds to each skill.

Student Perceptions of the Task

In developing the T-Shirt Math Task, we wanted to create a task that students could find engaging and that would closely resemble what students might encounter in a classroom. In a posttask interview, students were individually asked a series of questions about their experiences with the task. They were asked (a) whether they enjoyed the task, (b) whether they would recommend it to friends, (c) to describe their favorite and least favorite parts of the task, (d) whether the task looked like an activity they would complete in their classroom, and (e) the extent to which the task was more like work or more like play.

Results showed mixed feelings with respect to whether students enjoyed the task and would recommend it to friends. Three students reported enjoying the task, four students said they did not enjoy the task, one student reported liking math,

Table 1 Collaborative Problem Solving (CPS) Skill Frequencies

Dimension	CPS skills	Frequency	Example
Social	Maintaining communication	1	"nice job"
	Sharing information	123	"*m* would be the price per shirt and *b* would be the set up fee"
	Establishing shared understanding	119	"So what are you confused on?"
	Negotiating	91	"wait, *m* is slope, yeah I think so"
Cognitive	Exploring and understanding	2	Scrolling through the task interface prior to beginning the problem
	Representing and formulating	4	"Shirts for Less is probably the cheapest one"
	Planning	14	"Let's just break this up, so let's figure out what *y* means … "
	Executing	90	Typing answer choice
	Monitoring	1	"Let's get a move on"

and the other said the task was okay. Further, four students said they would recommend the task to friends and one to teachers; one student said it would depend on the grade level; and three students said they would not recommend the task to friends. Most students also described the task as looking like activities they would complete in a classroom and that it was a lot like work as opposed to play. There was a great deal of variation with respect to students' favorite parts of the task. There were reports of the graphs being a favorite, writing out explanations, conversing with a teammate, solving the problem, and the math. Most students ($n = 7$) referred to doing math/equations as being their least favorite part of the task.

Task Redesign

Using data from students' behaviors in the task and feedback in the posttask interview, we modified the T-Shirt Math Task in an effort to increase the scope of CPS behaviors elicited while maintaining a task design that represents what students might do as normal classroom activities. Some students (particularly younger students) expressed difficulty in developing and understanding linear equations ($y = mx + b$), which contributed to not enjoying the task. To address this issue, the design was streamlined to scaffold students through the math equation building and allow more time to be devoted to the open-ended and deliberative aspects of trying to make a decision for a specific T-shirt company. As such, to augment the existing open-ended equation entry items a selected-response format was added where students select values for "m" and "b" from dropdown menus to complete equations for each T-shirt company. This change from open-ended to selected-response format narrows the space of potential options for the "m" and "b" variables in the cost equations for each T-shirt company. In an additional change, students were then provided with immediate feedback on whether their equations were correct or incorrect and shown the correct equation. Students then selected the graph that matched the cost equation developed for each T-shirt company.

In order to increase CPS behaviors such as negotiating, planning, and representing and formulating, additional task modifications were made. The problem statement initially provided a maximum number of T-shirts that would be purchased with the caveat that not all students were expected to purchase a shirt. In the task redesign, the problem statement was modified to incorporate a range for expected purchases to elicit more communication around possibilities for the appropriate T-shirt company and strategies for reaching the decision. To augment the task further, we reduced the text provided on many pages in order to reduce the reading load for students. Lastly, a new item involving hypothetical reasoning was added to the end of the task which asked students to incorporate new information from a previous school year in which only 30% of students ordered T-shirts. Given this new information and the original graph of all three companies' cost equations, students were instructed to provide a recommendation and explanation for which company would be the best option. This added item could increase behaviors from the set of cognitive CPS skills (e.g., representing and formulating, and planning), as it provides an additional open-ended item that could elicit discussion around what has changed in the problem and how to go about solving the new problem.

Conclusions and Future Work

The complexity of CPS and the process-oriented nature of the construct make online environments well suited as assessment instruments because they allow individuals to interact with others in performance situations and capture behaviors in process. In the current study, we developed a collaborative online mathematics task for CPS assessment. Results from a play-testing study showed that the task elicited CPS skills, particularly those associated with the social dimension of CPS. We redesigned the task in an effort to reduce some student frustrations and create better opportunities for students to provide both additional and broader evidence of their skills. Currently, we are conducting a larger scale pilot study to explore whether modifications to the task can elicit the less observed CPS skills. The field of CPS assessment is still in its infancy so additional foundational work like the study discussed in this paper is needed to better understand what kinds of situations are more likely to provide opportunities to display certain CPS skills.

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