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Supporting Teachers to Implement Engineering Design Challenges using Sensor Technologies in a Remote Classroom Environment

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I am a Professor at the University of Colorado, with a joint appointment between the Institute of Cognitive Science and the Department of Computer Science. I am currently serving as the Director of the Institute of Cognitive Science. I lead an interdisciplinary research and development lab that studies how computational tools – combining cognitive science, machine intelligence, and interactive media – can improve teaching practice, learning outcomes and learner engagement. My research and teaching interests include personalized learning, learning analytics, cyberlearning environments, educational digital libraries, scholarly communications, human-centered computing, and interdisciplinary research methods for studying cognition. I have written 140 articles on these topics, including over 80 peer-reviewed scholarly publications.

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Introduction

Engineering design challenges illustrate how computational tools are integral to scientific inquiry. Yet, difficulties remain, particularly during a global pandemic, of how to develop challenges that are meaningful and relevant for middle school students in ways that promote design, engineering, and computational thinking. The shift to remote learning has been especially challenging for activities that require students to physically engage with the materials.

This paper describes 1) the research context including certain modifications made due to the COVID-19 pandemic, 2) the implementation experience of five middle school teachers who enacted a curricular unit using programmable sensor technologies (called the sensor immersion unit) in the Fall of 2020, when their schools were engaged in synchronous remote instruction due to the COVID-19 pandemic, 3) the adaptations researchers and teachers made to the instructional unit to address challenges that emerged during remote instruction, and 4) how these adaptations can influence future in-person instruction.

Research Context

This project is part of a partnership between the University of Colorado Boulder and a large southwestern school district that aims to integrate computational thinking (CT) into middle school science and STEM classes using programmable sensor technologies. These sensors enable students to use real-time data streams to support their scientific investigations and allow for data collection outside of the traditional classroom environment (e.g., throughout their school). Over the last four years, researchers and teachers worked together to design computationally rich units and a new professionally learning model. The professional learning model supports middle school science and STEM teachers, many of whom have limited experience with computational thinking, to implement these units in their classrooms.

Professional Learning

We designed a professional learning approach, called the CT-Integration Cycle (Biddy et al., 2021; Gendreau Chakarov et al., in press), that supports teachers to design, adapt, implement, and reflect on instructional activities that use programmable sensor technologies. This professional learning model usually consists of an in-person summer workshop series and four full-day workshops throughout the school year. Due to the COVID-19 Pandemic, the summer workshop shifted to a remote platform, and the school year workshops shifted to 90-minute biweekly meetings after school. During the summer workshops, we provided sensors to all of the teachers and guided them through how to use the technology with their students. We also reviewed multiple project-developed units, so that teachers would be prepared to use them if they elected to. During Fall 2020, the workshops focused on supporting remote learning and addressing challenges teachers encountered as part of our units and their teaching in general.

Sensor Immersion Unit

The project team has developed four CT-integrated units that use sensor technology to investigate scientific phenomenon or complete engineering design challenges. The units vary in length ranging, from one to three weeks. The first instructional unit that teachers implement, sensor immersion, introduces students to the programmable sensor technologies they will use in units throughout the year. Teachers and researchers collaboratively designed this unit during the 2019-2020 school year (Gendreau Chakarov et al., 2020). Students use low-cost programmable sensor technologies that are composed of a microcontroller, alligator clippable environmental sensors (e.g., a sound or soil moisture sensor), and a speaker and LEDs to create simple displays of collected data. Students program the microcontroller using a block-based programming language to manipulate and display data streams collected using the sensors. The goals of the unit focus on equipping students with necessary technical and intellectual skills to use sensors in future investigations. In addition to learning skills about how to wire and program the sensors, students practice using them to collect, analyze, and display large streams of information. Beyond these computational and technical goals, students internalize how the technologies support the transition of their role in STEM or science class from data collectors to producers of the data for their scientific investigations (Hardy et. al., 2020). The unit also positions students as experts to one another during group work, allowing them to practice authentic collaboration.

Participants

During the present 2020-2021 school year, there are 15 science and STEM teachers participating in the study. Five of these teachers elected to implement the sensor immersion unit during Fall 2020: two returning teachers and three new teachers. At that time, all of the teachers were leading fully remote lessons and for most, implementing the unit was too challenging logistically. By arranging school pickups, two teachers distributed the programmable sensor technology to almost all of their students, two teachers distributed it to approximately half of their students, and one teacher did not distribute the technology. The four teachers who distributed the technology attempted to provide it to as many students as possible. These teachers all taught STEM as an elective and as such had a good deal of flexibility in terms of their how and what they could teach. The STEM elective teachers decided to implement the unit with only one of their classes in order to ensure a sufficient amount of equipment for each student to have access to. The one teacher who did not distribute the technology was a science teacher who decided to implement the sensor immersion unit with all his classes. For equity reasons, the teacher did not want only a subset of students to have access to the physical components of the technology.

Implementation

Implementing a sensor-based unit remotely that was designed to be hands-on and inquiry-based led to a variety of challenges for the five teachers who chose to use and adapt it. The first challenge to remote implementation came at the beginning of the unit. The sensor immersion launch usually involves students interacting with physical data displays in their classrooms created with the programmable sensor technologies they will be studying. Students touch the sensors, see if they can make the display change, press buttons on the system, etc. These interactions help students to draw an initial model of the data display and inspire questions about the structure and function of the display that drive the remainder of the unit. Although the teachers all created data displays to show their students, still students' hands-on interaction with these displays is impossible in a remote setting.

During the summer workshops, researchers and teachers discussed the best way to encourage students to look carefully at the teachers' data displays and generate questions about them. Two options emerged: 1) teachers could create a video where they interact with the display in different ways and 2) teachers could interact with the display in real-time on video during the lesson. Of the five teachers who implemented the unit, X created a video, Y interacted with the display in real-time, and Z did both. While these activities could not replace students getting to physically interact with the display themselves, they did prove generative for electing student questions and often showcased interactions that students might not have tried on their own.

The second challenge that emerged was encouraging small group discussions when students collaborated in breakout rooms. Students were tasked with assembling and programming the sensors together in breakout rooms. Issues arose around students not talking in breakout rooms, students not knowing how to support one another, and the struggle to recognize when a student needed help. To address these challenges, the research team worked with four of the five implementing teachers to discuss breakout room norms and then use those norms to create a short video of a model breakout room conversation. Before recording the exemplar video, teachers reflected on a list of suggested best practices from the research team, discussing how those practices applied to their students and what additional practices they wanted to add. After this mini co-design stage, the teachers recorded an exemplar of breakout room participation where the teachers played the part of students and demonstrated how a small group should collaboratively work through a programming tutorial. One of the teachers came up with the idea to create this sort of video and other teachers agreed to become involved, expressing that the experience would be personally meaningful and the video could be useful to show to their students. In addition, two of the after-school workshops in Fall 2020 focused on issues related to encouraging student talk during remote learning. In one workshop the teachers considered how to use the model breakout room video as a discussion prompt with their students. In the other workshop, teachers developed a shared resource list describing the different tools they had found to be successful in addressing some of these issues.

The third challenge revolved around supporting students to build and program the physical data displays in order to visualize the information captured by their sensors. In particular, teachers found it hard to help their students debug the physical components of the system. The equipment was often difficult to see on camera, which made it challenging to determine whether and why a student had made a mistake. Given the synchronous nature of instruction, debugging often required the teacher to help one student or group of students at a time. While similar demands on teachers' time often come up when engaging in debugging during in-person instruction, common tactics such as having students ask each other for help before asking the teacher do not work as well in remote instruction. In addition, the online tutorials designed to assist students in creating their physical data displays did not always match the classroom data display created by the teacher. This inconsistency sometimes led to confusion about what students should measure and why (e.g., one teacher did not use the carbon dioxide sensor in her display, but the tutorial guided students to create a carbon dioxide alarm). Lastly, not all students had access to the programmable sensor technologies, so it was difficult for them to tell if their program actually generated the display they had in mind. To address this issue, one teacher had students send her their code so she could test it for them.

Anticipating where students might encounter challenges with the data displays, both the research team and the teachers created a number of additional resources for the unit. The research team created resources that included wiring diagrams to scaffold the assembly of the sensor components and personalized tutorials for building the displays. During one workshop, teachers created videos demonstrating different steps in the creation of the physical data displays (e.g., one teacher created a video that demonstrated how to securely alligator clip the sensor to the microcontroller). All of these resources became part of a collaborative resource library that teachers could access throughout the school year.

Reflection

While many of the adaptations during the implementation were constructed in direct response to challenges that emerged during remote instruction, these changes may have important implications for teachers once in-person instruction resumes.

First, the majority of teachers who implemented the sensor immersion unit remotely in Fall 2020 allowed their students to take the technology home with them. Having access to the sensors allowed students to collect data from their homes and neighborhoods, which can make the data streams more interesting and relevant. This at-home experience also creates a more variable data set since information is collected throughout the community instead of taking place only in school. Teachers and administrators are often hesitant to let students take home equipment, but none of the teachers in the study had issues getting students to return the materials. Moreover, teachers reported that their students returned the equipment in good condition. Second, the expanded resource library addressing common challenges will provide additional support for students who take part in the sensor immersion unit in their classrooms. These resources may enable them to more successfully and independently tackle difficulties that arise during their investigations. Lastly, developing shared norms around small group communication remains relevant no matter the context. Regardless of whether instruction takes place remotely or in person, student discourse is a critical element of the sensor immersion unit and teachers now have a wider variety of tools and skills to promote student-student conversations.

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