Advancing Creative Physical Computing Education: Designing, Sharing, and Taxonomizing Instructional Interventions

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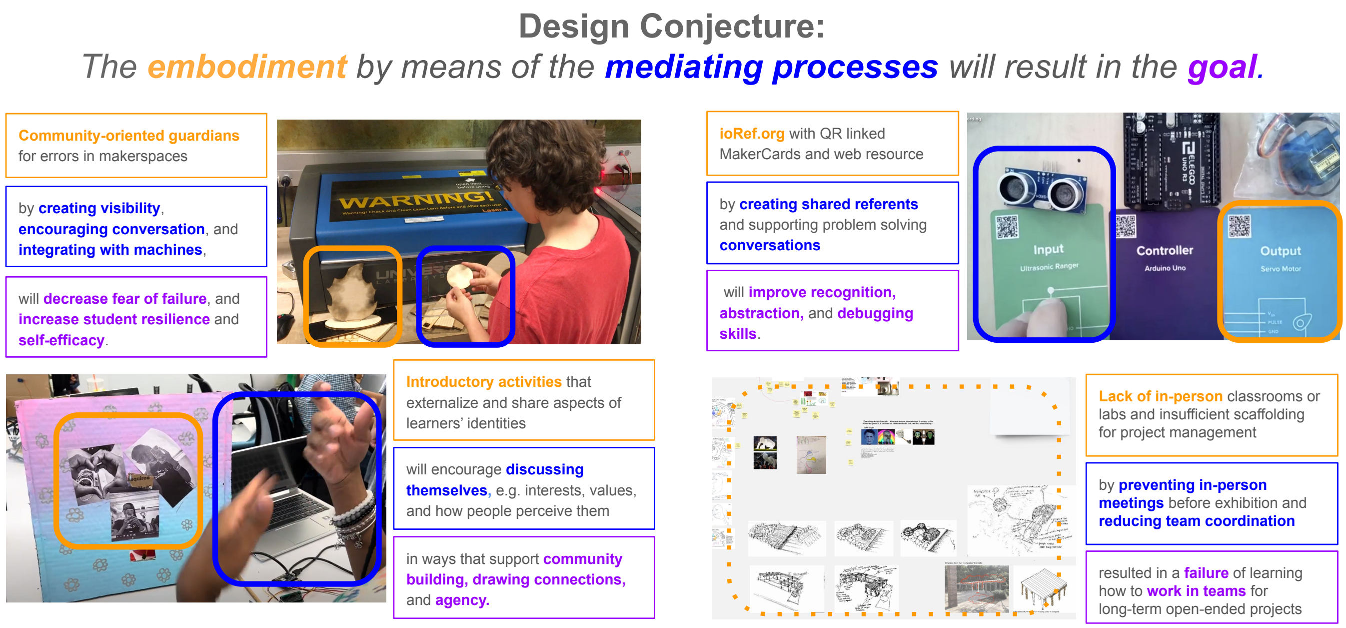

Figure 1: Workshop participants will share instructional interventions from their research or teaching. To facilitate discussion, these will be formatted as *design conjectures* [36], showing the embodiment, mediating processes, and goals of the intervention. Here we show four brief examples from the workshop organizers: Top left: symbolic representation of a burnt laser cutter piece mitigates effects of failure [38]. Top right: MakerCards support remote learning [23]. Bottom left: *Turing Wheel of Closeness* uses ultrasonic sensors in personal expression. Bottom right: an example of a challenge in remote course on physical computing and art [17].

ABSTRACT

Physical computing is a materially rich practice that connects across skills in STEM, design, arts, and creativity. It also offers learners a means of making personally meaningful, computational artifacts that support creative development, resonate with personal identities, and access a history of craft and culture. Yet, physical computing instruction remains a complex instructional practice that requires navigating computation and reasoning, engineering and mechanisms, and creativity and problem-solving between physical and virtual spaces. Spurred by the pandemic, the shift to remote instruction fostered a wave of creativity in physical computing instruction and new lines of inquiry around access and inclusion, resilient learning, and the creativity, craft, and culture found in

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physical computing. This one-day workshop will convene a network of researchers, educators, and designers to uncover, share and reflect on our creative instructional responses. We will develop a set of agendas for continued innovation and inquiry in creative physical computing education in post-secondary contexts. Our aim is to cross-pollinate research agendas and strengthen educational approaches in critical STEM and design practices.

CCS CONCEPTS

• **Social and professional topics → Information systems education**; **Computer science education**; • **Hardware → Sensor devices and platforms**.

KEYWORDS

physical computing, higher education, creativity, design, STEM, learning

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1 INTRODUCTION AND BACKGROUND

Physical computing is a materially rich practice that incorporates and teaches STEM skills including computation and reasoning, engineering and mechanisms, interaction and experience design, and creativity and problem-solving [4, 9, 28, 29]. Creative physical computing – including tinkering, hacking and creative remaking – provides personally meaningful frames for learners of all ages while developing technical fluency required to innovate with digital materials and code. In line with the conference theme, creative physical computing offers opportunities for a diversity of learners to have agency in exploring "why design?", through personal engagment across disciplines and as a situated process that brings computational and craft materials together in new ways. For example, creative physical computing supports contextually-relevant learning and community impact like empowering participatory sensing and citizen science [11, 14, 22, 27], community based design [7, 11, 34], social and environmental activism [2, 20, 24], entrepreneurship [12, 21], arts and creative expression [5], craft and textiles [6, 13, 18, 30], accessibility and inclusion [2, 24, 31–33]. Given the ubiquity of digital-physical systems, there is much need and opportunity to understand what effective teaching and learning looks like in physical computing, particularly in a post-pandemic world [4, 8, 25, 26].

Yet designing physical computing instruction practices is challenging and complex, especially when teaching novices. Novices must build conceptual knowledge, perceptual skills, and technical know-how simultaneously (e.g., computational thinking, electronics and circuitry, craftspersonship). They must learn to work across digital and physical workspaces and processes, where the intersection of norms, processes, and expectations from multiple domains compound the complexity. Learners of physical computing also contend with questions surrounding *why they are designing* and how their design is situated and contextualized. These challenges occur across a range of instructional environments—from formal higher education to informal summer and after-school programs—creating barriers to adoption for both educators and students alike.

There is also a critical need to better understand how instruction can support diverse participation within physical computing despite systemic gender, class, race, ethnic, and ableist biases; often physical computing educational initiatives inherit and must seek to transform contexts that were not designed to welcome diverse ways of knowing, doing and being [3, 15, 35, 37]. Efforts such as Race's Non-visual Arduino and Soldering workshops [32, 33] suggest ways to give agency and access to those who have been systematically excluded from electronics. Hedditch and Vyas's online makerspace for migrant women [16] and Kafai et al.'s use of electronic textiles as a medium to promote both equity and STEM competencies [19] highlight opportunities for empowerment and design justice. Instruction must also respond to growing environmental and ethical challenges posed by physical computing and the hobbyist electronics movement, including obsolescence, waste streams, right to repair, and material ethics [10].

Addressing these challenges is key to the success of physical computing education, and we are in a period of opportunity for instructional innovation. Spurred by the pandemic, the shift to remote instruction has fostered creativity in how we design and enact physical computing instruction. It has forced us to reexamine "why design?": from how we design our instructional practices, to why we engage learners in computational design, to how we help them examine and critique their own practices and artifacts. Instructors across undergraduate, high school, and informal settings have wrestled with how this materially rich and complex instructional practice might be facilitated in remote, online and at-home modes, and new lines of inquiry have begun to emerge [9, 23, 39]. This creates a **timely opportunity to bring the physical computing education and research community together to share and reflect on our instructional practices and design approaches, and to develop a set of agendas for continued innovation and inquiry in creative physical computing education**.

In particular, we see a need for increased conversation and coordination around the following topics: *Resilient Learning*: How do we teach perseverance, independence and interdependence, and the ability to work with complexity and uncertainty in digital-physical systems? *Accessibility*: Who has access to makerspaces and interdisciplinary physical computing learning domains? How can new technologies and culturally responsive/sustaining experiences broaden access across physical accessibility, cultural accessibility, and economic accessibility? *Cultures of Space*: What values and dynamics are intentionally nurtured by instructors and community members in the spaces where physical computing happens? How does the design of the space express or shape these values? *Creativity and Craft*: What role do "creativity" and "craft" play in physical computing curricula? How are they conceptualized, taught, or made explicit? When are they left implicit? *Post-Pandemic Learning*: Since the COVID pandemic, what new forms of teaching physical computing were created and which endure? What do we wish to retain? How can new approaches help us reach broader audiences, engage students at their own pace, or in their own locations and contexts?

Addressing these questions in practice requires both generablizable research to understand issues and validate interventions, as well as work to adapt and transfer insights and techniques to specific contexts. Often interventions in physical computing education are designed for a specific, local context, and it may not be immediately clear how to bring such interventions into other makerspaces or courses, or even which aspects can be modified. **In this workshop, we will facilitate conversations and collaboration to move forward our community's capacity to design and share specific instructional interventions and general insights in research and practice.** To do so, the workshop community will **collectively create specific examples of instructional problems or goals and the interventions in space, tools, or curriculum we have used to address them.** We will then analyze these interventions to identify their purposes, commonalities, connections, and challenges, and design future interventions and shared research agendas. This approach allows us to ground our discussions in concrete examples and situated knowledge, while preparing our community to work together in extending interventions beyond their initial programs, understanding their impact on learning at larger scales, and fostering collaboration among diverse practitioners for coordinated interventions with broader reach.

2 WORKSHOP GOALS

This **one-day workshop** seeks to draw together and build a network of research-practitioners involved in teaching creative prototyping and experimentation at the intersection of computational thinking, electronics and the design of novel interactive hardware and devices. The workshop will build conversation on challenges that remain for learning science, design-based research, and technology education in fostering students abilities and interests in physical computing. The participants will report and share innovations, instructional practice, and creativity support tools that would be important to disseminate more broadly. This will help to identify priority areas for future educationally-focused research, around transferability of interventions as well as research at scale, while maintaining sensitivity to specific contexts of educational engagements. The ultimate goal is to transform from a disparate network of researchers and teaching faculty into a physical computing research-practice network and enable sustained innovation and collaboration. The primary objectives are to:

(1) **Form a collective understanding of the current and shared pedagogical strategies and challenges** to teaching physical computing in upper secondary, post-secondary education, and in hybrid modalities through concrete examples. Each workshop organizer and participant will contribute an analysis of one aspect of their physical computing educational efforts, in a short form structure around a conjecture mapping framework for design-based education research [36] (see Fig 1). These will be refined and shared on the workshop's website as a public repository of physical computing education insights around what has and has not worked well.
(2) **Bring together researchers and practitioners** interested in designing new creativity support tools and creative learning interventions for physical computing, to foster cross-institution partnerships in studying and applying pedagogical interventions. This will contribute to forming a multidisciplinary community to shape future inquiry, tool-making, and inclusive instructional approaches to physical computing, with a focus on transferability of knowledge and validation of approaches at various scales.

3 ANTICIPATED OUTCOMES AND POST-WORKSHOP PLANS

After the workshop, we plan to continue the dialog with attendees and broaden it to others in this space.

(1) **Workshop Report / Journal Special Issue:** The workshop organizers will draft a workshop report and circulate to attendees for comment, synthesizing the categories, connections, and new interventions developed by the workshop participants. Subsequently, we will collectively develop the report into a pictorial synthesizing themes among instructional interventions. Depending on participant interest, we will also coordinate a journal special issue / edited volume.
(2) **Online Resources:** The workshop website will shift from foregrounding the single workshop event to curating a gallery of physical computing lesson plans, pedagogical strategies, and reflections on teaching effectiveness (akin to Kobakant [1]). It will serve as a public archive, housing interventions, case studies, position papers, literature, and ongoing work and discussions beyond the workshop.
(3) **Continuing Interactions:** After the workshop, we will continue to build the network of researchers and practitioners and enhance the gallery of physical computing resources by hosting a series of online *space tours* that showcase diverse approaches to physical computing instruction. Virtual tours will be open to anyone, advertised on the workshop website, and recorded and archived on the website. Four to five spaces will be selected to provide a tour that focuses on the use and organization of materials, key instructional moves, and problems of practice. The organizers will assist in creating high-quality artifacts for discussion and archiving.

In summary, creative physical computing has grown in the last decade and represents a rich, interdisciplinary learning space with many transferable competencies. Physical computing, and the benefits it brings for learners, are not without its deep challenges – across teaching diverse cohorts and multiple skills in tandem, fostering resilient learning, building access, inclusion, and space for diverse identities to fit in this educational paradigm. As such, this workshop seeks to address the challenges faced in helping to educate and support learners in broadening computational design through creative physical computing.

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