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

Daragh Byrne School of Architecture Carnegie Mellon University Pittsburgh, PA, United States

Marti Louw Human Computer Interaction Institute Carnegie Mellon University Pittsburgh, PA, United States Kayla DesPortes Department of Administration, Leadership, and Technology New York University Steinhardt New York, New York, United States

Sarah Sterman Department of Computer Science University of Illinois Urbana-Champaign Urbana, IL, United States Noura Howell Digital Media Georgia Institute of Technology Atlanta, GA, United States

Cesar Torres Department of Computer Science & Engineering University of Texas at Arlington Arlington, TX, United States

Designing, Sharing, and Taxonomizing Instructional Interventions. In Designing Interactive Systems Conference (DIS Companion '24), July 1–5, 2024, IT University of Copenhagen, Denmark. ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3656156.3658396

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

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 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 \rightarrow Information systems education; Computer science education; • Hardware \rightarrow Sensor devices and platforms.

KEYWORDS

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

ACM Reference Format:

Daragh Byrne, Kayla DesPortes, Noura Howell, Marti Louw, Sarah Sterman, and Cesar Torres. 2024. Advancing Creative Physical Computing Education:

DIS Companion '24, July 1-5, 2024, IT University of Copenhagen, Denmark

© 2024 Copyright held by the owner/author(s).

ACM ISBN 979-8-4007-0632-5/24/07.

https://doi.org/10.1145/3656156.3658396

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

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 a larger scale, 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 Figure 1). These will be refined and shared on the workshop website as a public repository of physical computing education insights around what has and has not worked well.

Design Conjecture: The **embodiment** by means of the **mediating processes** will result in the **goal**.



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].

(2) **Bring together researchers and practitioners** interested in designing new creativity support tools and creative learning interventions for physical computing, to foster crossinstitution 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 (venue TBD).
- (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.

REFERENCES

[1] [n.d.]. HOW TO GET WHAT YOU WANT. https://www.kobakant.at/DIY/

- [2] Cynthia L Bennett, Abigale Stangl, Alexa F Siu, and Joshua A Miele. 2019. Making nonvisually: Lessons from the field. In Proceedings of the 21st international ACM SIGACCESS conference on computers and accessibility. 279–285.
- [3] Sagit Betser, Rebecca Ambrose, and Lee Martin. 2023. "Excited to crash the party": Girls self-author their identities as makers in a girls-only design/build space. Equity & Excellence in Education 56, 1-2 (2023), 159–171.
- [4] Tracey Booth, Simone Stumpf, Jon Bird, and Sara Jones. 2016. Crossed wires: Investigating the problems of end-user developers in a physical computing task. In Proceedings of the 2016 CHI conference on human factors in computing systems. 3485–3497.
- [5] Erik Brunvand and Paul Stout. 2011. Kinetic art and embedded systems: a natural collaboration. In Proceedings of the 42nd ACM technical symposium on Computer science education. 323–328.
- [6] Leah Buechley and Hannah Perner-Wilson. 2012. Crafting technology: Reimagining the processes, materials, and cultures of electronics. ACM Transactions on Computer-Human Interaction (TOCHI) 19, 3 (2012), 1–21.
- [7] Glenda Amayo Caldwell and Marcus Foth. 2014. DIY media architecture: open and participatory approaches to community engagement. In Proceedings of the 2nd media architecture biennale conference: World Cities. 1–10.
- [8] Imke de Jong and Johan Jeuring. 2020. Computational thinking interventions in higher education: a scoping literature review of interventions used to teach computational thinking. In Proceedings of the 20th koli calling international conference on computing education research. 1–10.
- [9] Kayla DesPortes and Betsy DiSalvo. 2019. Trials and tribulations of novices working with the Arduino. In Proceedings of the 2019 ACM Conference on International Computing Education Research. 219–227.
- [10] Kristin N Dew and Daniela K Rosner. 2019. Designing with waste: A situated inquiry into the material excess of making. In Proceedings of the 2019 on Designing Interactive Systems Conference. 1307–1319.
- [11] Carl DiSalvo, Illah Nourbakhsh, David Holstius, Ayça Akin, and Marti Louw. 2008. The Neighborhood Networks project: a case study of critical engagement and creative expression through participatory design. In *Proceedings of the tenth* anniversary conference on participatory design 2008. 41–50.
- [12] Renee Dopplick. 2015. Maker movement and innovation labs. Inroads 6, 4 (2015), 108.
- [13] Shreyosi Endow, Mohammad Abu Nasir Rakib, Anvay Srivastava, Sara Rastegarpouyani, and Cesar Torres. 2022. Embr: A Creative Framework for Hand Embroidered Liquid Crystal Textile Displays. In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems. 1–14.
- [14] Bjørn Fjukstad, Nina Angelvik, Maria Wulff Hauglann, Joachim Sveia Knutsen, Morten Grønnesby, Hedinn Gunhildrud, and Lars Ailo Bongo. 2018. Low-cost programmable air quality sensor kits in science education. In Proceedings of the 49th ACM Technical Symposium on Computer Science Education. 227–232.
- [15] Sarah Fox, Rachel Rose Ulgado, and Daniela Rosner. 2015. Hacking culture, not devices: Access and recognition in feminist hackerspaces. In Proceedings of the 18th ACM conference on Computer supported cooperative work & social computing. 56–68.
- [16] Sonali Hedditch and Dhaval Vyas. 2023. Design Justice in Practice: Communityled Design of an Online Maker Space for Refugee and Migrant Women. Proceedings of the ACM on Human-Computer Interaction 7, GROUP (2023), 1–39.
- [17] Noura Howell, Shawn Protz, Jasmyn Byrd, Miguel Castellanos, Alexis Elkins, Jessica Hall, Micah Holdsworth, Lalith Mallikeshwaran Rajagopal Sambasivan, Chris Noel, Oluwarotimi Osiberu, et al. 2022. Feeling Air: Exploring Aesthetic and Material Qualities of Architectural Inflatables. In Adjunct Proceedings of the 2022 Nordic Human-Computer Interaction Conference. 1–6.
- [18] Ben Jelen, Anne Freeman, Mina Narayanan, Kate M Sanders, James Clawson, and Katie A Siek. 2019. Craftec: Engaging older adults in making through a craftbased toolkit system. In Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction. 577–587.
- [19] Yasmin B Kafai, Deborah A Fields, Debora A Lui, Justice T Walker, Mia S Shaw, Gayithri Jayathirtha, Tomoko M Nakajima, Joanna Goode, and Michael T Giang. 2019. Stitching the Loop with Electronic Textiles: Promoting Equity in High School Students' Competencies and Perceptions of Computer Science. In Proceedings of the 50th ACM technical symposium on computer science education. 1176–1182.
- [20] Stacey Kuznetsov, Eric Paulos, and Mark D Gross. 2010. WallBots: interactive wall-crawling robots in the hands of public artists and political activists. In Proceedings of the 8th ACM Conference on Designing Interactive Systems. 208–217.
- [21] Silvia Lindtner, Garnet D Hertz, and Paul Dourish. 2014. Emerging sites of HCI innovation: hackerspaces, hardware startups & incubators. In Proceedings of the SIGCHI conference on human factors in computing systems. 439–448.
- [22] Jen Liu. 2017. Field Computing: Wearable Devices for Citizen Science. In Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction. 451–456.
- [23] Miranda Luong, Daragh Byrne, and Marti Louw. 2021. Makercards: Designing an electronic component discovery tool to support remote physical computing education. In *Interaction Design and Children*. 476–482.

- [24] Janis Lena Meissner, John Vines, Janice McLaughlin, Thomas Nappey, Jekaterina Maksimova, and Peter Wright. 2017. Do-it-yourself empowerment as experienced by novice makers with disabilities. In Proceedings of the 2017 conference on designing interactive systems. 1053–1065.
- [25] Kevin Oliver, Robert Moore, and Michael Evans. 2017. Establishing a virtual makerspace for an online graduate course: A design case. *International Journal* of Designs for Learning 8, 1 (2017).
- [26] Nadya Peek, Jennifer Jacobs, Wendy Ju, Neil Gershenfeld, and Tom Igoe. 2021. Making at a distance: teaching hands-on courses during the pandemic. In Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. 1–5.
- [27] Jennifer Preece. 2016. Citizen science: New research challenges for humancomputer interaction. International Journal of Human-Computer Interaction 32, 8 (2016), 585–612.
- [28] Mareen Przybylla and Ralf Romeike. 2014. Physical Computing and Its Scope– Towards a Constructionist Computer Science Curriculum with Physical Computing. Informatics in Education 13, 2 (2014), 241–254.
- [29] Mareen Przybylla and Ralf Romeike. 2015. Key competences with physical computing. KEYCIT 2014: key competencies in informatics and ICT 7 (2015), 351.
- [30] Jie Qi and Leah Buechley. 2014. Sketching in circuits: designing and building electronics on paper. In Proceedings of the SIGCHI conference on human factors in computing systems. 1713–1722.
- [31] Lauren Race, Chancey Fleet, Joshua A Miele, Tom Igoe, and Amy Hurst. 2019. Designing tactile schematics: Improving electronic circuit accessibility. In Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility. 581–583.
- [32] Lauren Race, Claire Kearney-Volpe, Chancey Fleet, Joshua A Miele, Tom Igoe, and Amy Hurst. 2020. Designing educational materials for a blind arduino workshop. In Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems. 1–7.
- [33] Lauren Race, Joshua A Miele, Chancey Fleet, Tom Igoe, and Amy Hurst. 2020. Putting tools in hands: Designing curriculum for a nonvisual soldering workshop. In Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility. 1–4.
- [34] Pedro Reynolds-Cuéllar and Daniela Delgado Ramos. 2020. Community-based technology co-design: insights on participation, and the value of the "co". In Proceedings of the 16th Participatory Design Conference 2020-Participation (s) Otherwise-Volume 1. 75–84.
- [35] Jean J Ryoo and Angela Calabrese Barton. 2018. Equity in STEM-rich making: Pedagogies and designs. Equity & Excellence in Education 51, 1 (2018), 3–6.
- [36] William Sandoval. 2014. Conjecture Mapping: An Approach to Systematic Educational Design Research. Journal of the Learning Sciences 23, 1 (Jan. 2014), 18–36. https://doi.org/10.1080/10508406.2013.778204
- [37] Edna Tan and Angela Calabrese Barton. 2018. Towards critical justice: Exploring intersectionality in community-based STEM-rich making with youth from nondominant communities. *Equity & Excellence in Education* 51, 1 (2018), 48–61.
- [38] Cesar Torres, Sarah Sterman, Molly Nicholas, Richard Lin, Eric Pai, and Eric Paulos. 2018. Guardians of practice: A contextual inquiry of failure-mitigation strategies within creative practices. In *Proceedings of the 2018 Designing Interactive Systems Conference*. 1259–1267.
- [39] Ana Villanueva, Ziyi Liu, Yoshimasa Kitaguchi, Zhengzhe Zhu, Kylie Peppler, Thomas Redick, and Karthik Ramani. 2021. Towards modeling of human skilling for electrical circuitry using augmented reality applications. *International Journal* of Educational Technology in Higher Education 18, 1 (2021), 1–23.