Making at a Distance: Teaching Hands-on Courses During the Pandemic

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ABSTRACT

Classes involving physical making were severely disrupted by COVID-19. As workshops, makerspaces, and fab labs shut down in Spring 2020, instructors developed new models for teaching physical prototyping, electronics production, and digital fabrication at a distance. Instructors shipped materials and equipment directly to students, converted makerspaces to job-shops, and substituted low-tech construction methods and hobbyist equipment for industrial tools. The experiences of students and instructors during the pandemic highlighted new learning opportunities when making outside the makerspace. Simultaneously, the shutdown raised new questions on the limits of remote learning for digital fabrication, electronics, and manual craft. This panel brings together experts in making to discuss their experiences teaching physical production in art, design, and engineering during the pandemic. Panelists will discuss their teaching strategies, describe what worked and what did not, and argue for how we can best support students learning hands-on skills going forward.

CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models**.

KEYWORDS

digital fabrication, remote learning, pandemic

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1 INTRODUCTION

Maker Culture has widely impacted practices beyond hobbyist tinkering: ranging from education [17] to professional design and manufacturing [25], to Human-Computer Interaction (HCI) research [18]. The growth of Maker Culture has led to research and development efforts to produce widely available and affordable technologies for the production of physical objects and interactive devices, ranging from Arduinos to desktop 3D printers. Makerspaces, Fab Labs, hardware incubators, and hackerspaces are now globally widespread [10], and are important sites of HCI innovation [16]. Maker spaces and communities have enabled a rhetorical shift in technological design and production, by placing people in the active role of "makers" rather than the passive role of "users"[23]. The growth in access to technologies for physical making has occurred alongside a progressive educational agenda advocating hands-on, project-based, and student-centered learning. As a result, educators have taken advantage of digital fabrication tools and physical computing [3, 24]. Student engagement with computational design or digital fabrication through tasks such as circuit board design, computer-controlled milling, laser cutting, or automated knitting has offered rich interdisciplinary learning experiences across art, design, and engineering [13, 19, 21, 22].

As the pandemic shut down campuses worldwide, access to labs, workshops, and tools for making became very limited. Educators who taught hands-on courses had to quickly pivot [11]. In courses that had previously relied on on-campus makerspaces, instructors rapidly adopted a range of strategies including relying on simulation, sending students kits of electronics [4], and having each student set up their own home 3D printers and other equipment [14]. Providing access to hands-on production thorough hobbyist equipment, kits, and services enabled educators to preserve some of the learning outcomes of in person workshop based courses [1], while suggesting new learning opportunities in the process. Simultaneously, remote making instruction created substantial additional labor for instructors. These courses also created new challenges for students who had to operate equipment, debug electronics, and construct physical projects in isolation in their homes.

Despite progress made towards a vaccine, it is likely that university instruction will remain permanently altered as a result of the COVID-19 crisis [26]. Even before the pandemic, massive open online courses (MOOCs) such as Coursera or edX quickly gained popularity. HCI research has already explored what going "beyond being there" [12] could mean for hands-on instruction such as with shared physical design spaces [15] or electronics breadboards [8]. Yet, until the onset of the pandemic, remote physical making courses were relatively rare in higher education. Examining the experiences of educators who taught courses with digital fabrication, physical computing, and manual craft during Spring, Summer and Fall of 2020 offers an opportunity to reflect on the implications of remote making on an unprecedented scale.

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The idea for this panel stemmed from a study the moderators undertook during the Summer of 2020 that surveyed university instructors of digital fabrication and physical computing courses who taught remote courses in art, design, and engineering [1]. This study revealed concrete strategies different educators undertook depending on their discipline and access to resources, while highlighting the ongoing struggles both students and faculty experienced through the transition. Drawing from this initial study, we see value in engaging experienced educators in a dialog on how the pandemic can inform future efforts in education and HCI making research. In doing so, we seek to provide insight into practical remote teaching approaches; discuss their strengths and drawbacks; and discuss how different approaches affect learning outcomes, access, and equity. We have convened a group of panelists who represent decades of experience in teaching, research, and outreach in making across art, design, and engineering. By discussing the challenges and lessons of teaching outside the makerspace in 2020 with the CHI community, we aim to facilitate dialog on how educators, institutions, and researchers can best support students in learning through physical making in the years to come.

2 MAKING IN HIGHER EDUCATION

Physical design and production plays a prominent role in higher education. A growing number of universities have established interdisciplinary fabrication workshops where students can design and prototype physical objects through digital fabrication, electronics, and physical computing [27]. These spaces support interdisciplinary instruction in art, computer science, design, mechanical engineering, architecture, and other fields. University makerspaces often have equipment that is also used in industrial manufacturing; however, some educators have also focused on incorporating manual tools and traditional craft materials [3]. The rise of fabrication laboratories (fab labs) in higher education corresponds with the rise of the Maker Movement—a social movement that emphasizes hands-on making through both traditional and emerging tools and technologies [7]. The Maker Movement has driven the wider adoption of makerspaces—community centers that combine access to technological tools with community support and peer-learning [17], which has driven innovation in lower-cost digital fabrication equipment and physical computing platforms [20].

Learning digital fabrication, physical computing, and electronics production provide practical skills in science, engineering, and design while also offering ways to engage students with interest in art and craft. Early advocates of fab labs and makerspaces in formal education have argued that hands-on interaction with materials can offer a tangible way of thinking through important and expressive ideas [9] with significant advantages for interdisciplinary and contextualized learning, powerful experiences, and team building [2].

Despite these opportunities, integrating makerspaces into formal education has created distinct challenges. Social interaction and discourse, especially for forming community and maker attitudes, have been found to be crucial for learning in K-12 [6] and other [17] makerspaces, and there are concerns that maker technologies and resources have predominantly benefited a privileged slice of the population while failing to engage diverse or under-served communities [5].

The COVID-19 pandemic and resulting shutdown posed specific challenges for university courses that were structured around physical making. In an initial survey of courses centered on digital fabrication, instructors explored a range of different strategies, including simulation through CAD and CAM, shipping individual machines to each student, online ordering from online fabrication vendors, and converting the university makerspaces to a service with teaching assistants serving as fabricators [1]. In some physical computing courses, instructors relied on shipping components directly to students, while relying on remote communication technologies to help students debug at a distance [4]. In the process, instructors had to experiment on ways to balance financial resources, feasibility constraints, and safety concerns, with their original learning objectives. This initial foray into remote instruction of physical making raised many key issues for instruction in higher education.

Given that educators are continuing to teach digital fabrication and physical computing at a distance, it is timely and critical to examine how different strategies shape student learning and engagement in comparison to in-person making courses. Remote learning has exacerbated existing inequities in formal education; subjects involving physical making require substantial material and human resources, and are therefore particularly at risk for perpetuating inequities among under-served and under-resourced students. Individual educators as well as university administration must carefully consider how to support remote making in forms that are equitable and just.

The pandemic is also accelerating some existing trends in maker culture. Remote courses have further decentralized access to the means of technological production and the pandemic and created new opportunities for the application of personal fabrication technologies. In light of these trends, HCI researchers must consider how making education and research will shift, even after we return to the lab.

3 PANEL GOALS AND OUTCOMES

This panel will engage panelists on four critical topics for remote instruction of physical making: impacts to learning, the potentials of at-home equipment, equity, and implications for making education in the future.

First, we will examine the ways different models for remote instruction of physical making shape student learning outcomes. For instance, we will ask panelists to discuss what they see as the critical learning opportunities of digital fabrication and physical computing, and how their approach to teaching these subjects remotely shaped students' access to these opportunities. By bringing together panelists from art, design, and engineering, we will examine how these objectives differ across disciplines.

Second, we will discuss the opportunities and limits of substituting hobbyist equipment, ad-hoc materials, and manual craft methods for industrial tools and machines. For example, can hobbyist equipment emulate student experiences with industrial equipment in shared workshops? What new workflows were possible when students were working at home with their own tools and materials? How might the experience of at-home making lead us to question the value of high-tech or expensive fabrication technologies in favor of affordable and manual forms of making?

Third, we will examine the risks that remote making instruction poses for student support and equity. What forms of of instructor support were critical to facilitate at-home forms of making? What factors lead to inequity in remote instruction with physical making? How can educators and institutions better support equitable outcomes in future remote learning situations with physical tools and materials?

Fourth, we will explore the implications of remote making for future maker communities and HCI research in personal fabrication. Namely, how might we re-envision the makerspace or lab when students have access to hobbyist equipment in their homes? What are critical elements of these spaces that were lost during the shutdown (if any)? Should we teach making remotely in the future, and if so, what new technologies could better support educators and students in the process? How should institutions invest resources in maker courses and makerspaces going forward?

4 PANEL ORGANIZATION

The panel will be organized into the following elements:

- Introduction: the moderators will provide an overview of hands-on making instruction and some approaches to teaching it remotely during the pandemic (10 minutes).
- Statements: each panelist will provide detail on the hands-on making classes they have taught, or are currently teaching during the pandemic, including learning goals and strategies employed. After each statement, the other panelists will have an opportunity respond (30 minutes).
- Discussion: the panelists will engage in a discussion facilitated by the moderators. Moderators will first engage panelists in a discussion of the trade-offs of different remote learning strategies structured around questions from the four topics defined in Section 2 (learning outcomes, at-home making, equity, and implications for future making). Following this, moderators will open the panel to questions from the audience (45 minutes).
- Summary: the moderators will summarize the discussion (5 minutes).

5 PANEL MODERATORS

The panel moderators are active in the CHI community and have published work on STEAM learning with hands-on making. They are also active makerspace and fab lab organizers. Both are assistant professors in interdisciplinary departments who taught digital and computational fabrication during the pandemic by having their students set up mini-makerspaces in their homes with hobbyist-grade 3D printers [14]. They have experience moderating panels, and crucially have experience moderating panels through video conferencing while fielding audience questions from chat.

Nadya Peek is an Assistant Professor of Human-Centered Design and Engineering at the University of Washington. She directs Machine Agency, a research lab focused on harnessing the precision of machines for the creativity of individuals through open source tools, small scale automation, and human-centered controls. She teaches HCDE 533 Digital Fabrication, a master's level course where students learn digital fabrication skills for rapid prototyping, and HCDE 439 Physical Computing, an undergraduate course on circuit design and production.

Jennifer Jacobs is an Assistant Professor in Media Arts and Technology and Computer Science at the University of California, Santa Barbara. She is director of the Expressive Computation Lab — a group that develops computational tools that enable artists, designers, and engineers to integrate computational automation and abstraction with physical materials and manual skills. In her class, MAT549X Computational Fabrication, students use programming languages to design for and control digital fabrication machines.

6 PANELISTS

This panel convenes several high profile researchers who are well known for their contributions to teaching physical computing and digital fabrication. Each panelist has taught one or more courses with hands-on making over the course of the pandemic. Images from class work is shown in Figure 1. The moderators have recruited these individuals via personal networks in the HCI and digital fabrication research communities. All panelists have confirmed participation.

Wendy Ju is an Associate Professor at the Jacobs Technion-Cornell Institute at Cornell Tech and in the Information Science field at Cornell University. Formerly Dr. Ju was Executive Director of Interaction Design Research, and an Associate Professor of Interaction Design in the Design MFA program at the California College of the Arts. Her work in the areas of human-robot interaction and automated vehicle interfaces highlights the ways that interactive devices can communicate and engage people without interrupting or intruding. Dr. Ju has innovated numerous methods for early-stage prototyping of automated systems to understand how people will respond to systems before the systems are built. Her monograph on *The Design of Implicit Interactions* was published in 2015. As faculty at Cornell Tech, she teaches *Developing and Designing Interactive Devices*, where students learn physical and electronics prototyping, microcontroller development, and device design.

Neil Gershenfeld is a Professor at MIT where he directs the Center for Bits and Atoms, a unique laboratory breaking down boundaries between the digital and physical worlds. He is the author of numerous books on the subject of digital and physical integration including *Designing Reality (2017)* and *Fab: The Coming Revolution On Your Desktop–from Personal Computers To Personal Fabrication (2005)*. He's been described as the intellectual father of the Maker Movement, founding a growing global network of over one thousand fab labs that provide widespread access to prototype tools for personal fabrication. Dr. Gershenfeld chairs the Fab Foundation, a non-profit supporting the fab lab network, and leads the Fab Academy, a distributed class on rapid prototyping taught globally in over 60 node labs to hundreds of students. As faculty at MIT, Dr. Gershenfeld teaches *How To Make (Almost) Anything*, a course that engages students in the design and production of physical devices through hands on learning of computer-aided design, digital fabrication, electronics prototyping, and software development.

Tom Igoe is a Professor at NYU's Tisch School of the Arts, where he has served as the area head for physical computing courses in

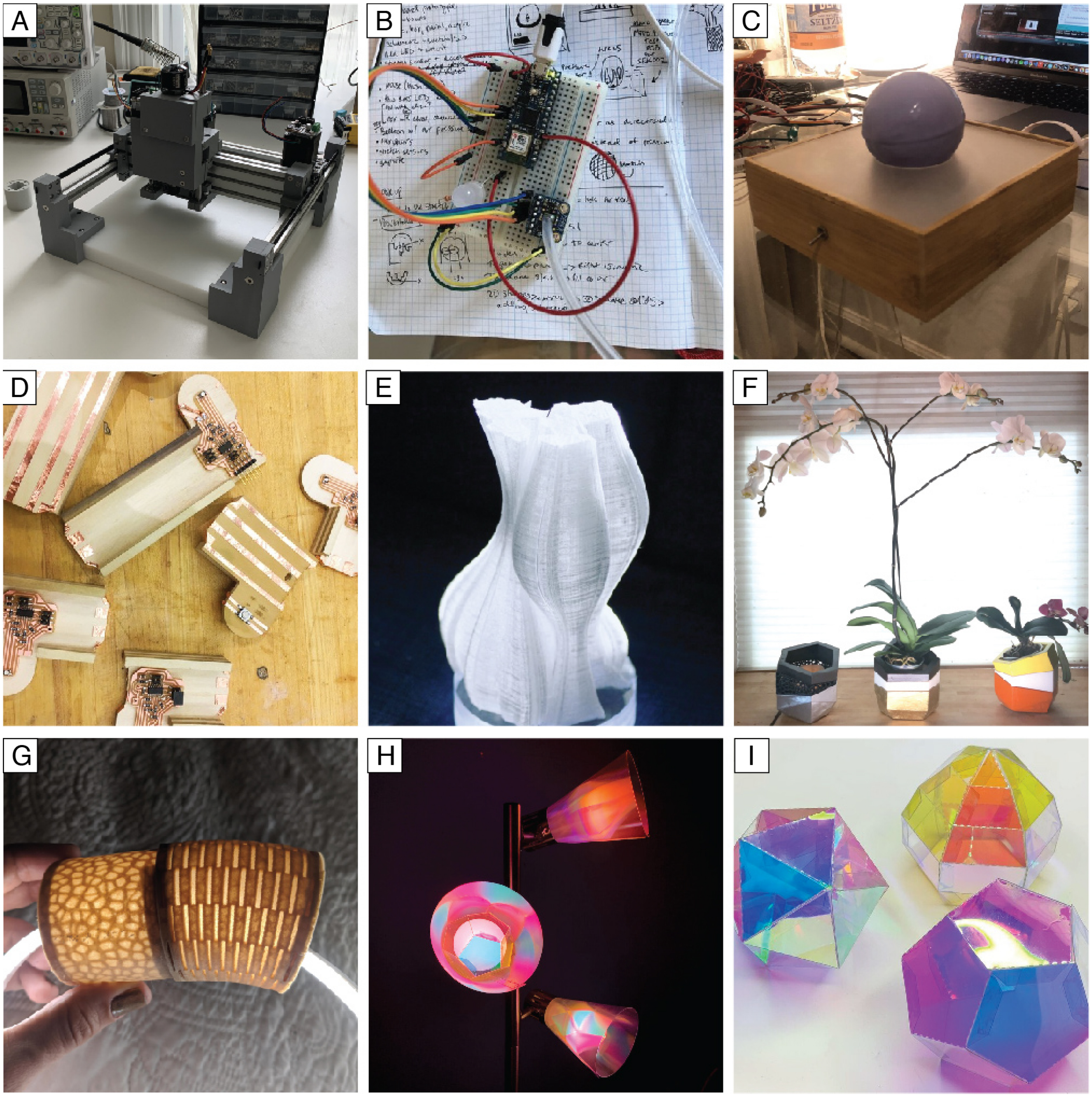

Figure 1: Student work from the panel's classes including MAS 863 How to make (almost) anything, ITP Device Design, ITP Tangible Interaction, MAT598X Computational Fabrication, HCDE 533 Digital Fabrication, and ITP Light and Interactivity. A) Jake Read, B-C) Pippa Kelmenson, D) CNC-milled and copper tape circuits by Emily Salvador, E) 3D-printed sculptures by Weidi Zhang, F) Digitally-fabricated planters by Kevin Philbin, G) 3D-printed modular lamps by Della Sigrest, H-I) Vinyl-cut folded lamps and 3D structures by Aidan Lincoln.

the Interactive Telecommunications Program (ITP) since 2001. His research interests include networks, lighting design, the environmental and social impacts of technology development, and monkeys. He is co-founder of Arduino, an open-source micro-controller environment that has fundamentally shaped electronics prototyping practices in both the Maker Movement and in higher education. He has written four books on electronics and physical interaction including *Physical Computing (2004)* and *Making Things Talk (2007).*

In his courses at ITP students learn to consider the motivations and actions of the people for whom they're designing as the foundation for physical interaction design. He teaches a wide range of courses spanning physical computing including *Introduction to Physical Computing*, *Tangible Interaction*, and *Connected Devices and Networked Interaction*.

7 AUDIENCE AND LOGISTICS

All panelists are based in the United States, which limits the perspective this panel can provide. We made the decision to focus on North American-based participants because we will be convening this panel through video conferencing rather than in person. Having discussants in similar time zones is important to ensure a lively panel. The moderators are prepared to engage the audience through chat, curating questions they will relay to the panelists. We anticipate that our panel will attract audience members who conduct in HCI research in personal fabrication, physical computing and making as well as faculty and students in making courses.

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