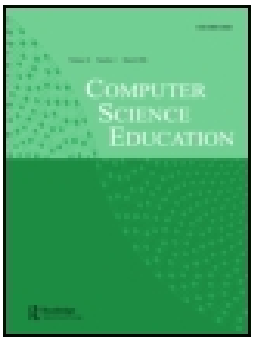

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Inclusive Making: designing tools and experiences to promote accessibility and redefine making

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ARTICLE

Inclusive Making: designing tools and experiences to promote accessibility and redefine making

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ABSTRACT

Background and Context: Making is celebrated for bringing exciting tools and learning opportunities to non-traditional designers. However, people with disabilities may find themselves excluded from many making activities and makerspaces. This exclusion is present in making and computer science more broadly.
Objective: We describe a university course that helps broaden their awareness of accessibility in computing and promote accessible making solutions. The course engages students in critical examination of making and allows them to instantiate their learning by designing accessible interfaces and experiences. We study the design of the course and its impacts on students.
Method: We use techniques from grounded theory to analyze data from surveys, projects, and case studies to elucidate the need and the impact of this experience.
Findings: The course filled an important need for students and people with disabilities. By applying a critical disability lens to making, participants developed expansive views of making, both in terms of what "counts" as making and who can participate in it.
Implications: Courses on accessibility address important societal and individual needs that are currently not met by CS curricula. Courses that address these needs should include critical discussions of the domain in question and involve various types of community partnerships. Including these course elements can expand the course's impact, lead to better project designs, and change perceptions of what is valuable in computing experiences.

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Introduction

Making and the Maker Movement have been celebrated for bringing exciting fabrication technologies to non-traditional designers and inventors (Blikstein, 2013; Dougherty, 2013; Martin, 2015). We position making as a specific form of computing that connects the digital and the physical (Blikstein, 2013; Martin, 2015). Put differently, making is an example of applied computer science, with many making experiences requiring computational thinking, artificial intelligence, robotics, and human computer interaction. These making activities are often facilitated by microcontrollers, 3D printers, laser cutters, and computer programing interfaces. Advocates point to these novel tools as resources for

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empowering people to become innovators and increasing student interest in computer science (Blikstein, 2013; Dougherty, 2013; Martin, 2015).

However, as is the case with computing in general, people with disabilities may find themselves excluded from the tools and activities of making in the absence of deliberate considerations of accessibility (Alper, 2013; Hurst & Kane, 2013; Siu et al., 2018). In this paper, the term "disability" is used to encompass a range of vision, hearing, speech, motor, neurological and cognitive impairments. One reason that making and computing present barriers for people with disabilities is that many designers and companies do not place the needs of people with disabilities as a central consideration. This may stem from a lack of awareness to issues of accessibility, or because they see designing accessible interfaces and experiences as the responsibility of a small subset of the design community (Rosmaita, 2006; Shinohara, Bennett et al., 2018; Shinohara et al., 2016). In this paper, we discuss Inclusive Making, a university course for upper-level undergraduate and graduate students that aims to address some of these shortcomings as situated within the United States of America (US) context.

Related work

Teaching accessibility in computer science

Accessible technology scholars have frequently lamented that students in CS are not learning enough about accessibility as part of their education (Putnam et al., 2016; Shinohara, Kawas et al., 2018). Some researchers have called for accessibility to be a recurring theme throughout CS curricula (Gellenbeck, 2005; Waller et al., 2009). Following the 1998 US Section 508 Amendment and the push for integrating ethics and social responsibility into existing computer science curricula, Gellenbeck (2005) describes ways that institutions might add accesibility-related content to first year computer science classes, as well as courses on web development, human computer interaction (HCI), and senior capstone projects. Gellenbeck (2005) also proposes that any accessibility content be realized across the entire term, as opposed to simply being an additional module within a course syllabus. This is suggested as a way to avoid inadvertently casting accessibility as an afterthought. Despite this recommendation, fewer than 1% of US computer science faculty report teaching accessibility course-wide (Shinohara, Kawas et al., 2018). Instead, among the 2.5% of faculty that report teaching acessibility, most teach it once a year as part of one or two class sessions.

The one area of computer science where teaching accessibility has been relatively prevalent is within HCI where scholars are keen for students to develop awareness of the different barriers associated with having a disability (Shinohara, Kawas et al., 2018). In contrast to the occasional mention of accessibilty, some HCI scholars have focused on developing and studying university-level courses that explicitly and centrally address accessibility. Studies associated with these courses have reported several learning benefits as a result of inclusivity-focused course designs. For example, when students take a design class that centers on accessibility requirements, they begin to see the heightened importance of accessibility (Poor et al., 2012). They also realize that accessibility should be every designer's responsibility and not solely the responsibilty of people with disabilities (Rosmaita, 2006; Shinohara, Bennett et al., 2018; Shinohara et al., 2016). Researchers have also noted the importance of engaging external stakeholders with disabilities (Gellenbeck, 2005). Taking this approach mitigates students' biases and misconceptions about disabilities (Ludi, 2007; Shinohara et al., 2016; Shinohara, Wobbrock et al., 2018). Altogether, this prior work suggests that through design work, especially that which entails external stakeholders, and on-going experiences, students should learn about the importance of accessible design and see it as part of their role as future developers. Nonetheless, this prior work does little to consider ways that perceptions and practices in CS should change to be more inclusive.

Culturally responsive computing and ethnocomputing

Integrating accessibility into computer science is broadly situated within a larger body of literature that considers culturally responsive computing (CRC) and ethnocomputing. CRC is a pedagogical approach that simultaneously uses culture to frame discussions of computing and uses computing to support existing culturally practices with the goal of developing student knowledge of computing. To date, most of this work has focused on engaging women and African-American, Indigenous and Latinx students in meaningful CS learning experiences (Scott et al., 2015). For instance, COMPUGIRLS engages Black and Latina girls in leveraging technology as a means for social activism and advancing civil rights. Using this approach has resulted in increased participation from girls of color, growing community support, and shifts in student perceptions of themselves and the role of computing (Scott & White, 2013). Related projects by other researchers have recorded similar findings (Fields et al., 2018; Kafai et al., 2014; Pinkard et al., 2017). Notably, however, many of these experiences are designed for K-12 students and are conducted in after-school contexts. In this paper we will explore CRC analogous experiences in the higher education context, something that has scarcely been explored in prior work.

Ethnocomputing extends CRC to also consider how bridging computing and culture might result in students learning more about individual cultural practices (Eglash et al., 2006). The centrality of learning about cultural practices, and not simply learning about computing, is one of the ways that ethnocomputing is distinguished from early CRC research (Kafai et al., 2014). More recent formulations of CRC similarly advocate for the role that computing can play in helping to sustain cultural practices (Scott et al., 2015). As an example of ethnocomputing, the Ethno E-textiles project (Kafai et al., 2014) leveraged e-textiles as a tool to help students learn about the history and practices of beading and decorative sewing among American Indigenous communities. An important part of their approach was to both leverage and problematize computing. They do this by teaching students how to use the technology, while simultaneously facilitating expansive conceptualizations of computer science. This is something that we build upon in the Inclusive Making course. Furthermore, across CRC and ethnocomputing, researchers have found increased interest and participation among women and people of color, even when the students do not identify with the specific ethnicity or culture being studied (Kafai et al., 2014). This, then, generally aligns with the observation that students from under-represented groups are often drawn to opportunities that combine computing with social and cultural issues (Fields et al., 2018; Kafai et al., 2014; Pinkard et al., 2017). However, existing work on CRC and ethnocomputing has principally focused on women and people of color and has not yet embraced the opportunity to center people with disabilities. Hence, an application of ethnocomputing to disability communities is one way that we position the current work.

As we consider this paper in relationship to prior work, we see four primary distinctions. First, as an important starting point, much of the prior literature in higher-education contexts does not report on why students enroll in courses on computing and accessibility. Having awareness of students' motivations can be useful for knowing how to design a course and towards making a larger argument for the needs that these types of courses satisfy. This, in turn, can result in improved learning experiences, and the proliferation of these learning opportunities. A goal of this paper is to chronicle self-reported reasons for being interested in a course on accessibility and making. While making and computer science are not synonymous, understanding motivations for taking courses on making and accessibility may translate into insights for courses on computing and accessibility more broadly.

Second, much of the existing attention on accessibilty in computing is limited to web accessibility and word processing within computer interfaces (Gellenbeck, 2005; Ko & Ladner, 2016; Richard E Ladner & Burgstahler, 2015). A goal of our work is to move the discussion of accessibility to the unique context of making and makerspaces. Inherent to the context of making is the objective that participants will engage in designing and inventing. Moreover, the ways that we combine making and accessibility are fundamentally about making interfaces and experiences that allow people with disabilities to make interfaces and experiences.

Third, considerable interest in accessibility is being advanced as a legal requirement (Gellenbeck, 2005; Rosmaita, 2006) and not as a human right. Only being motivated by legal guidelines can put unintended limitations on both the problem space and the solution space that students consider. For example, this work was conducted in the United States of America, which has its own accessibility-related laws. Other countries will follow noticeably different legal guidelines and definitions which could greatly change the legal motivation for developing accessible technology. Moreover, when we only address the legal requirements, we may allow for the underlying social stigmas and assumptions to remain (Barnes & Mercer, 2004;Oliver, 2013). Additionally, and related to the first objective above, it is unlikely that students pursue the study of accessibility because of their awareness of future legal requirements. Instead, students are also likely to have more nuanced and diverse motivations for learning about and implementing accessibility. Hence, our work is not satisfied with merely meeting legal requirements and instead is focused on disabililty rights. We endeavor to push people to question their assumptions about disability.

Fourth, and most importantly, previously described university courses overlook the benefits of engaging students in a critique of the specific field of study. CRC and ethnocomputing are examples of taking this approach in informal K-12 contexts, and with respect to race, ethnicity and gender (Eglash et al., 2006; Kafai et al., 2014; Pinkard et al., 2017; Scott et al., 2015). However, applying a critical studies lens has scarcely been used within university contexts. For example, courses seldom consider the history of discrimination that may exist within computing or question how accessibility should look within those disciplines. Applying a critical lens includes analyzing the tools, promises, and assumptions that may contribute to reasons why certain communities are excluded from participation (Blikstein & Worsley, 2016; Margolis & Fisher, 2003; Vossoughi et al., 2016). We argue that by critiquing the field as a whole, students are able to ask questions that go beyond usability (e.g., how a blind user might navigate a website) and can consider why a discipline privileges certain forms of interaction. They are also encouraged to recognize that how a field is defined need not be static or universal. This can potentially expand the scope of student work and push them to more deeply understand issues of accessibility.

Research questions and contributions

We focus on making, a relatively new area in physical computing that has been gaining popularity as a context for creativity, technological democratization, and learning. This emerging field is the context for Inclusive Making, an interdisciplinary university-level course that we developed for upper-level undergraduate and graduate students to design accesible making tools and experiences. The course takes place at a private university in the United States of America, and was initially funded through support from the university. We position this course as an intentionally designed learning environment that has the goals of pushing students to 1) critically explore making as a field that promotes democratization, 2) develop interfaces and activities that allow a broader population to participate in making and 3) design artifacts that positively impact accessibility and inclusivity. In examining our Inclusive Making class we focus on two related research questions:

(1) What motivations do students have for enrolling in a class on accessibility and making?
(2) What do students learn and practice about accessibility, making, and computer science in Inclusive Making?

In addressing these questions, this work offers a number of important contributions. First, by looking at student responses from a pre-enrollment survey we are able to articulate students' self-reported needs for courses on accesibility and making. There is unequivocally a societal need for more inclusive learning opportunities that motivates some students to pursue courses on accessibility. However, students also described a complementary need to engage in equity-oriented learning experiences that stem from individual identities. Second, we study the learning that students experienced during this course by examining class artifacts in the form of written assignments and group projects. Here we see ways that the experience pushed students in their knowledge of computing, in their awareness of accessibility concerns, and in their agency to redefine making. The examination of student artifacts and learning will also point to the importance of different course components. In particular, thinking about making and accessibility through a critical lens is a theme that resonates across different course activities, and complements the various ways that students partnered with community organizations. This discussion of the course's components (see Supplemental Materials online for the course syllabus) will ideally provide a blueprint for others to design their own courses on accessibility. These contributions can most easily be applied to other making focused courses, but also have relevance for courses that cover different aspects of applied or theoretical computer science.

Paper overview

In the first portion of this paper we describe the design of the course. This will begin with a Guiding Literature section, which highlights core ideas from making, Critical Disability Studies, and User-Centered Design. Following the Guiding Literature section, the Course Description section provides an overview of the course readings, expectations, and assignments. A more detailed description of the course can be found in the supplemental online materials. Instead of discussing each of the course readings in this paper, we present a taxonomy that the authors developed to discuss the different pieces of scholarship in relationship to one another. This taxonomy is particularly important for being able to apply a critical lens to making and issues of accessibility. In the latter portion of the paper, we transition to analyzing and discussing student reflections and group projects. These data highlight students' needs for this type of course, as well as ways that they experienced growth in their perceptions and awareness of accessibilty and making.

Guiding literature

We ground the design of Inclusive Making in three primary bodies of literature: making, User-Centered Design, and Critical Disabilities Studies. Making is the context that students in our class seek to make more accessible through design. User-Centered Design is a family of approaches that require students to work iteratively and collaborate with stakeholders. Critical Disabilities Studies serves as a political, historical, and academic lens that students use to consider the barriers that hinder people with disabilities from participating in the Maker Movement.

Making

As the title suggests, the contemporary Maker Movement (Dougherty, 2013) is one of the focal points of this course. Making activities tend to incorporate many elements of computational thinking, while also including aspects of art, design, and play. We think of making activities as "designing, building, modifying, and/or repurposing material objects, for playful or useful ends … " (Martin, 2015, p. 2). While making does not maintain a singular or universal definition, scholars tend to agree that making activities should support collaboration, play, growth- and asset-based framing, and being failure positive (Blikstein & Worsley, 2016; Dougherty, 2013; Martin, 2015). Alongside these values, making usually involves a variety of crafts and fabrication tools such as 3D printers and laser cutters (Blikstein & Worsley, 2016; Martin, 2015). The utilization of these different technological tools provides the most salient connections between making and computer science. Many making advocates posit that digital fabrication tools may support revolutionary forms of learning. For example, Blikstein (2013) describes how digital fabrication tools can accelerate invention and design cycles and eliminate manual dexterity as a barrier to translating an idea into a physical product. He also notes the ways that making supports the translation of abstract ideas from mathematics into concrete representations that learners can manipulate. Martin (2015) points to similar benefits as well as the opportunity for learners to get closer to the practices and habits of mind of professional designers. Still others have highlighted how the tools of digital fabrication can help more individuals become producers of technology rather than just consumers of technology (Anderson, 2012; Blikstein, 2013; Hatch, 2014). In this way, the Maker Movement has been celebrated as democratizing by bringing novel digital fabrication technology to those outside of the mainstream technology development industry.

However, the promises of making are not equally enjoyed by all members of society. Recently, researchers have been raising awareness to issues of racial, ethnic, socioeconomic, and gender equity within making (Blikstein & Worsley, 2016; Buechley, 2013; Vossoughi et al., 2016). This conversation, though to a lesser extent, is also attending to other aspects of diversity, particularly as it relates to people with disabilities (Alper, 2013; Hurst & Kane, 2013; Worsley et al., 2018). Hence, despite the messaging around democratization, within many communities making continues to be an activity that is exclusively available to wealthy, able-bodied, male, and racially dominant populations (Blikstein & Worsley, 2016; Buechley, 2013; Vossoughi et al., 2016).

The relative lack of accessibility in making is especially unfortunate since the proposed promises could be particularly beneficial for people with disabilities and help advance the notion of Design for User Empowerment (Ladner, 2014). Many digital fabrication technologies provide a means for easily creating different forms of multimodal media, which can be useful to people with sensory impairments. This is an affordance that Stangl and Yeh (2015) pursue by partnering with local organizations to create 3D-accessible picture graphics using a combination of traditional craft technologies, digital fabrication tools, and microcontrollers. Moreover, the availability of digital fabrication tools, open source software, and online communities could allow people to design and repair their personal assistive devices, which could help decrease the rate of attrition of said devices (Buehler et al., 2016; Hurst & Kane, 2013).

In other instances, more craft-oriented forms of making are providing important ways for people to practice expressivity and collaborative design with friends, family members, and colleagues (Lazar et al., 2016, 2017). This craft orientation represents elements of making that do not fall squarely into computer science. Additionally, we note that while we are encouraged by the researchers and practitioners that are currently realizing empowering making experiences for people with disabilities (Brady et al., 2014; Klipper, 2014; Makezine, 2016), these opportunities are nestled within a very small number of large US urban centers.

In sum, making, like other areas of computing, offers a set of values, tools, and subsequent benefits to society. However, a relative scarcity in maker tools and makerspaces that are accessible to people with disabilities poses problems of representation, funding, and participation (Vossoughi et al., 2016). This problem is analogous to issues that pervade the broader field of computer science. In our course, students are familiarized with the tools and practices of making while deconstructing this short history through a Critical Disability Studies lens as so they can help shrink these inequities.

Critical disability studies

To support our students' critique of making, and to explore why it is not yet accessible to many people with disabilities, we drew on Critical Disability Studies. Critical Disability Studies deconstructs the ways that society discusses and frames disability (Levitt, 2017; Mankoff et al., 2010; Oliver & Sapey, 1999;Oliver, 2013). Over the history of disability studies, there have been several models of disability (Goodley, 2016; Wobbrock et al., 2011). The medical model (or individual model) is the earliest model and is the reason that many people still refer to disabilities as disorders. The medical model suggests that there is a problem with people with disabilities, and people should work to correct that condition so the individual can be "normal" (Davis, 1997, 2013; Goodley, 2016; Oliver, 2013; Wobbrock et al., 2011). This perspective explicitly reflects ableism, the idea that people are inferior because of their disabilities (Davis, 1997, 2013). It also falsely assumes that people with disabilities long for the experiences of able-bodied people (e.g., Mankoff et al., 2010).

Challenging these ideas, the social model focuses on the personhood of people with disabilities, as opposed to focusing on impairment (Barnes, 2012; Barnes & Mercer, 2004). The social model argues that disability is socially constructed, and that systems, institutions, and contexts are the source of disabilities (N. A. Davis, 2005; Barnes, 2012; Levitt, 2017; Wobbrock et al., 2011). The social model does not deny the existence of physical impairments, rather it focuses on disability being the result of an interaction between the physical reality and other socially determined factors such as material designs and social or political powers (Oliver, 2017). Equipped with the lens of Critical Disability Studies and the social model of disability, students undertook an iterative design process.

User-centered design

Similar to prior work on teaching accessibility in CS, we guided students with the ideas and techniques of User-Centered Design (UCD). UCD utilizes an iterative design process where designers regularly interact with users (Gould & Lewis, 1985). The UCD process begins with need-finding and developing empathy for the lived experiences of users. The users are the experts, and the designer must learn from the users prior to and during the generation and testing of prototypes (Rubin & Chisnell, 2008). One extension of UCD that is well aligned with Critical Disability Studies is ability-based design (ABD) (Wobbrock et al., 2011), which pushes back on the notion of "dis-ability." Wobbrock et al. (2011) argue that the very term engenders isolation and marginalization since human characteristics are not typically described based on what they lack. For example, they note that we do not refer to people who are short as having "dis-height" or people who are low on money as having "dis-money." By shifting the discussion from dis-ability to ability and following the principles of ABD, they argue that designers will more creatively develop solutions that invite full participation. Designer will also recognize that challenges of poor performance of a device are a function of the designed solution, not the user. These are important perspectives that shape the eventual designs and how designers go about engaging people with disabilities in the design process.

Collectively, this guiding literature covers the theories that we operationalized in the design of Inclusive Making. UCD is a family of design approaches that can help design effective accessible solutions for making (or other fields of computing). However, we argue that in order to learn how to do so effectively, students (designers) should deconstruct making through the lens of Critical Disability Studies. By doing so, students may not only address user-specific issues, but also identify and deconstruct the various barriers it presents. In the following sections, we share the design of Inclusive Making in terms of the readings, assignments, and ground rules.

Course description

Motivated by the aforementioned literature, we designed Inclusive Making to engage students in designing for and thinking about accessible solutions for making. Concretely, this entailed:

(1) an introduction to some of the ideas, tools, and practices of making,

(2) an understanding of disability studies and why certain communities might be excluded from making,

(3) and a design process through which the students could include individuals with disabilities in making.

Course readings

Making, UCD, and Critical Disability Studies come together to form the foundation of this course. During the term, we discuss the work of several influential scholars from across the making, UCD, and Critical Disability Studies disciplines. These course readings were selected to highlight a diverse group of scholars doing work that pertains to core ideas in making and accessibility. Broadly speaking, much of the literature was authored by individuals who are underrepresented in CS. This includes several women, people of color, and people with disabilities. A listing of the course themes discussed each week and associated readings can be found in Table 1.

To help facilitate discussion across readings, the authors developed a taxonomy that encapsulates the high-level barriers, opportunities, and perspectives situated at the nexus of making and accessibility. This taxonomy was inductively developed based on the collection of readings included in this course. Many of the categories parallel the

Table 1. Course readings and topics by week.

Topic	Readings
Introduction	(Freire, 1978)
Making, Accessibility and Design	(Blikstein, 2013; Dougherty, 2013; R. Ladner, 2014; Levitt, 2017; Papert & Harel, 1991)
Equity, Diversity and Inclusivity in Making	(Blikstein & Worsley, 2016; Hurst & Kane, 2013; Martin, 2015; Vossoughi et al., 2016)
Multimodal Sensors, Actuators and Virtual Reality	(Hamidi et al., 2019; Leong et al., 2015; Worsley et al., 2018)
Making and DIY + Making, Dementia and Older Adults	(Hurst & Tobias, 2011; Lazar et al., 2017; Wobbrock et al., 2011)
Making and Visual Impairment: Making for people who are blind	(Bennett et al., 2018; Shinohara, Bennett et al., 2018; A. Stangl & Yeh, 2015)
Making and Wheelchairs	(Bigham & Carrington, 2018; Carrington et al., 2016; Carrington et al., 2015)
Innovations for assisting users with Motor Impairments	(Mott et al., 2018; Mott et al., 2016)
Inclusive Games	(Bar-El et al., 2018; Ringland et al., 2017; Ringland et al., 2016)

technological, political, economic, social, and cultural factors summarized in Alper (2017). However, the current taxonomy also includes categories for pedagogical and informational barriers. The complete list and description of each category in the taxonomy follows.

(1) Technological – instances where interfaces pose a barrier to use or a unique set of opportunities (e.g., non-screen reader compatible 3D design tools (Hurst & Kane, 2013; Stangl & Yeh, 2015))
(2) Social – instances that result from a set of societal norms or expectations that implicitly or explicitly result in inaccessibility (e.g., ableism (Wobbrock et al., 2011))
(3) Cultural – instances that result from a set of norms or practices of a sub-group of society that implicitly or explicitly result in inaccessibility (e.g., maker culture (Blikstein & Worsley, 2016; Vossoughi et al., 2016))
(4) Economic – instances where the cost of the technology makes it difficult for users to purchase or utilize (e.g., cost to purchase or repair assistive technology – (Stangl et al., 2018)) or where monetary gains or losses are a driving factor (e.g., corporate interest in Makerspaces (Blikstein & Worsley, 2016; Vossoughi et al., 2016))
(5) Political – instances where political motivations or policies materially impact access to different resources and experiences (e.g., (Alper, 2013; Vossoughi et al., 2016))
(6) Pedagogical – instances that reflect perceptions or lack thereof of effective teaching or learning (e.g., focusing on facilitation (Blikstein & Worsley, 2016))
(7) Informational – instances where individuals are not aware of the availability of certain technologies, opportunities, or policies (e.g., students not being taught about accessibility (Shinohara et al., 2016))

These categories represent the first level in the taxonomy and were used to help students organize ideas and thoughts from the readings. Most of the course readings touched on many barriers, and the taxonomy helped articulate some of the core ideas and how those core ideas relate to other papers. Additionally, underneath each taxonomy category, students could identify sub-categories that appropriately partitioned a barrier into different dimensions. For example, the Technological category might consider the sub-categories of designing, using, or customizing, each with distinct challenges and opportunities. Similarly, the Pedagogical category might include questions about facilitation strategies, or the relevance of a given learning experience. In short, the taxonomy provides a structure for students to think about the different pieces of literature in relationship with one another. Furthermore, the taxonomy can help students situate their respective projects (described in more detail later) within the larger discussion of accessibility and technology while also recognizing elements of the problem space that their projects do not explicitly address.

General course structure

Inclusive Making is cross listed in Engineering and Education. Within the Engineering program, the course satisfies the undergraduate CS project course requirement. Within the Education program, the course satisfies the undergraduate diversity requirement. The class meets once a week for three hours and features a mixture of lectures, group discussions, out-of-class assignments, and in-class activities.

In-class activities

The course normally meets in an open, multi-purpose classroom and occasionally meets in the first authors' laboratory space for digital fabrication activities. The varied in-class activities give students the opportunity to collaborate with their peers, participate in hands-on projects, apply design techniques, and discuss the guiding literature. Most of the hands-on, in-class activities use household arts and crafts supplies such as Popsicle sticks, felt, paper plates, pipe cleaners, and hot glue. Many of the in-class activities allow students to express their ideas by creating shareable objects (Papert, 1980) and help students consider the unstated assumptions that can be present within making activities. They also help the students think about working alongside or in collaboration with someone with an impairment, as students will often complete these activities collaboratively, with one person using a blindfold, ear plugs, or their non-dominant hand. For example, we adopted an activity developed by a blind doctoral student who explores the design of accessible programmable Maker kits. In this activity, some students wore a blindfold while trying to learn how to program a new robotic toy. The blindfolded student had a chance to question their assumptions about visual impairments. Those working with them could put into action some accessibility best practices: verbally describing a visual and guiding someone's hand through a new tactile experience. During another in-class activity, students took a favorite children's book and designed an accessible version of that book by incorporating 3D graphics and auditory augmentation (Stangl & Yeh, 2015). When completing activities with simulated impairments (e.g., earplugs, blindfolds or one-handed), we are clear to indicate that what the students are experiencing does not accurately represent the lived experience of someone with a disability. We also emphasize that the purpose is not to traumatize the participants or have them pity people with an impairment (Silverman, 2015). Instead, we position the activities as an opportunity to rely on one or more of their other senses and reflect on the various usability assumptions that go into technology design.

Out-of-class assignments

The in-class experiences are complemented by three out-of-class assignments that embed students in the spaces for which they design. These include volunteering at an organization that provides accessibility-related services, visiting two or more makerspaces, and talking with someone that identifies as having an impairment.

The volunteering activity encourages students to develop relationships with local organizations. Students received a list of organizations and contacts but were also encouraged to reach out to and work with other organizations. Students wrote a short reflection paper after their visit, which, in many cases, helped motivate ideas for their final projects.

Dialogue with a community member serves as a chance for students to confront unjustified social stigmas associated with disability and to ground their ideas in an actual person, as opposed to simply referring to abstract groups of people. The assignment made clear that this was not an interrogation or interview, but an opportunity for dialogue with someone. Students were encouraged to do this over coffee or a meal as they saw fit. Students, again, submitted a reflection piece from their experience. One important observation from these reflection pieces was that a number of students reconnected with extended family members who identify as having disabilities, something that transformed the need for increased inclusivity from being a distant challenge for "other" people to having relevance to people that they know and care about.

The makerspace visits were an opportunity for students to gain more awareness of different makerspaces that serve the local community and consider the salient need to make the spaces more accessible. Reflecting on different types of spaces and their level of accessibility was one of the early topics of discussion in the class and aligned with the first design provocation.

Group projects

The various in-class and out-of-class assignments help students develop ideas they can apply in their design projects. Over the course of the term, students work in groups to submit three projects based on three design provocations. Groups were self-selected and ranged in size from two students to five students.

> *Design Provocation 1: Navigating a makerspace through the senses* - Makerspaces provide several ways for individuals to interact with digital technology. However, many of these experiences are currently limited to a small set of modalities. Please design and develop a prototype that allows the user to experience and/or navigate a makerspace through non-traditional senses. Ultimately, we are looking for novel ways for participants to experience a given makerspace.

> *Design Provocation 2: Beyond Vision* - We often rely on our visual perception systems to execute tasks within a makerspace. For this assignment, you will do one of the following: 1) design an interface that allows someone with a visual impairment to more easily design using a specific technology, 2) design something for an individual with a visual impairment, or 3) develop a set of activities that allow someone with a visual impairment to learn something new within the makerspace.

> *Design Provocation 3: Upgrade* - For the third project, students are asked to extend their design from either of the first two provocations or to develop a new idea.

During the second iteration of the class, a parallel design project track was added. Instead of completing the provided design provocations, students worked with a local organization to design a technology or a set of activities that would engage that organization's members in making based on the organization's specific needs. Students who chose this track submitted five project updates, which included: (1) problem statement and preliminary ideation, (2) three low fidelity prototypes, (3) additional ideation and high fidelity prototype, (4) results from user testing, and (5) final report.

Ground rules and expectations

Because of the interdisciplinary nature of the course and a general sensitivity about discussing accessibility, the course instructors developed a proposed set of ground rules for guiding class discussions. These ground rules included: 1) actively listening to other's comments and ideas, 2) speaking up when we perceive an injustice or bias, 3) valuing different opinions and viewpoints, 4) being gracious in correcting peers and

Table 2. Basic demographics of course participants across three years of implementation.

	1	2	3
Male	13	12	18
Female/Non-Binary	16	19	6
Black, Asian, Latinx, Indigenous, Mixed	16	20	13
Engineering	16	28	22
Education	13	3	2
Undergraduate	21	19	14
Graduate	8	12	10
Total	29	31	24

faculty, 5) being prepared to be challenged, and 6) reaching out to faculty when uncomfortable. We discussed these ground rules with course participants during the first class session and asked them to contribute modifications and additions. Overall, these ground rules and expectations aimed to create a space that would be safe and open for discussion and critique.

Participants

The three course iterations included different trends in enrollment. Table 2 includes an overview of the enrollment information by year along dimensions of gender, ethnicity, and enrollment program. Even though students were required to enroll through the university's engineering program or through the education program, students represented a variety of departments. Across the undergraduate and graduate students, there was representation from Computer Science, Engineering Design, Political Science, Social Policy, Cognitive Science, Psychology, Earth and Planetary Sciences, Anthropology, Business, Music, Latinx studies, and Asian-American Studies.

Methods

Our data and analytic approach are motivated by our two research questions:

(1) What motivations do students have for enrolling in a class on accessibility and making?
(2) What do students learn and practice about accessibility, making, and computer science in Inclusive Making?

To answer the first research question, we look at students' pre-enrollment surveys to investigate why students wanted to enroll in the course. To answer the second question, we examine student final projects and student written reflection assignments.

Application survey

Prior to enrollment in the course, interested students completed a short application that provided basic information, such as to identify as an undergraduate or graduate student, their primary departmental affiliation, and why they were interested in taking the course.

We used these questions to learn about who is interested in participating and why. At the time of survey completion, student identifying information was included with each response. This identifying information was removed prior to data analysis. Within our analysis of this data, we borrow techniques from grounded-theory (Charmaz, 2014) to code the responses and identify emergent themes. We refined those themes through repeated examination of excerpts and based on our goal of picking up on important nuances within the data. Once the set of themes was agreed upon, each author coded each student response with the corresponding theme(s). After individually coding the responses, the authors discussed the codes and reached consensus on which theme(s) applied to each response.

Excerpts from student assignments

Students' written assignments helped demonstrate their thinking and growth throughout the class. We used these excerpts as a window into student perceptions about their interactions with local organizations and individuals with disabilities. Within our analysis of these excerpts, we specifically looked for student reflections that noted or demonstrated a change in their perceptions of disability, making, or computing. In this way the excerpts should be treated more as case studies, as we followed an analytic approach in which we were looking to highlight specific occurrences and ideas. Though the university institutional review board (IRB) office deemed this work non-human subject research, the authors obtained written consent from students before including their anonymized excerpts in this paper. Students did not receive any incentives for providing written consent.

Student projects

We examined final projects produced by student teams as well as their design process. The design process was documented in the form of project submissions that chronicled the different steps each team took to complete their different design iterations. Similar to the survey responses, student project artifacts were coded using techniques from grounded-theory (Charmaz, 2014). First, the researchers open-coded the projects and identified a set of themes. With the initial set of themes in place, we reviewed students' project materials to verify that the themes accurately characterized all the student projects. Next, the codes were refined to provide more succinct and complete categories. Each project was coded by each author. Any differences in codes were resolved through further discussion until we reached consensus. In selecting the projects that we will highlight in the observations and findings section, we were intentional in choosing those that epitomize key characteristics or practices that we believe become increasingly possible when engaging in and designing interdisciplinary and inclusive learning experiences.

Observations and findings

The presentation of observations and findings will follow the sequence of our two research questions. We begin with a discussion of students' interests in taking the course.

We then transition to discussing what students learned about accessibility, making, and computer science, more broadly, by presenting student projects and written reflections. Together the discussion of student projects and assignments make evident the ways that students instantiated and reflected upon their learning.

Student interest in Inclusive Making

In this section, we look at data from the application surveys that asked students about why they want to take the course. In sum, 92 students completed the survey, which included the 84 students who completed the course. The remaining 8 students dropped the course. Using these survey responses, we report the frequency that different motivations emerged, and go into depth on the identity dimension of student responses.

Coded responses from pre-enrollment survey

Our coding of student responses surfaced seven primary categories that we summarize in Table 3.

The first several categories, Individual Awareness, Making and Social Good, seem to closely align with the overall framing of the course and the general pursuit of learning. Students want to gain more skills and are drawn to the elements of social good and making, which are highlighted in the title of the course. It would be easy to stop with these three codes, which offer a logical picture of student interests. However, as we looked at the responses in more detail, we saw an additional level of nuance that heavily draws on the Identity code. Namely, some of the responses coded as Individual Awareness, Making and Social Good, also contained an identity element. The following section will use excerpts from student responses to describe this identity component in more detail and put it in conversation with some of the other categories.

Computing, identity, and purpose – individual motivations for participating

While we will not discuss this point at great length, a review of the gender, ethnic, and disciplinary diversity of course participants highlights one way this course promotes greater inclusion. It attracts students from a broad set of disciplines, generally has been at gender parity, or with a slight majority of women, and has always been majority non-

Table 3. Categories of student-generated reasons for wanting to enroll in Inclusive Making.

Code	Description	Count
Individual Awareness and Learning	Students described a will to learn more about inclusivity to improve their knowledge and ability to incorporate inclusivity in their work.	41
Making	Students noted their interest in learning more about the Maker Movement, and/or the opportunity to do hands-on projects as part of their coursework.	34
Social Good	Students expressed a will to use their learning in ways that promote social good.	30
Identity	Students talked about their need to engage in this type of course because of their individual identities	16
Interdisciplinarity	Students noted the interdisciplinary content, and the opportunity to work in interdisciplinary teams as particularly appealing.	9
Course Format	Students mentioned the course format, either in terms of the variable in-class activities or the 3-hour, single session per week format as attractive.	3
Degree Requirements	Students indicated that Inclusive Making fulfilled specific degree requirements.	3

white. This contrasts with the demographics of the computer science undergraduate population, which is approximately 70% male and approximately 12% people of color. Student excerpts from the course application help elucidate some of the ways that elements of this course appeal to non-dominant students and speaks to connections with their identities.

> I'm interested in this class because I'm very passionate about using technology to drive changes we want to see in society. I want people to embrace diversity and inclusivity, and I think technology has the power to bring people together in that regard. Technology reflects its creators - I'm a woman in STEM and sometimes, I find that to be a rarity. In order for society to improve, I think we need a diverse group working on a diverse group of projects for a diverse group of users. Also, I feel like as CS students, we lose touch with why CS is so important to begin with. This class will be a powerful reminder to me on what I'm working toward, and what type of software engineer I want to become. I will be able to work toward solutions that actually affect people's day to day lives in an important way.

This student's interest in the course stemmed from her identity as a woman in STEM and her passion for diversity and inclusivity. Even though these are key elements of her identity and interests, she felt as though much of her prior experiences with computer science have pulled her away from what she deemed to be important and meaningful. She saw the Inclusive Making course as an opportunity to return to that driving passion and to put her knowledge of computer science to use by positively contributing to others' lives.

Other students also expressed being interested in the course because of the ways that it connected to their identity. Specifically, one student wrote:

> I am fascinated by the idea of Universal Design and making the world accessible for people with disabilities. As a student with a disability, I have had to navigate the school and have found some spaces to be accessible, but others to very much not be.

This student identifies as having a disability and seems to resonate with the need to develop spaces that are more inclusive for all students. Note: We did not ask students about if they identified as having a disability, though several students did mention their disabilities during in-class discussions. This student has experienced first-hand what it is like to be excluded because of their disability and wants to be able to address that. At the same time, when we take this student's response in the context of the previous excerpts about the lack of computer science courses that focus on inclusivity, the Inclusive Making course represents a chance for this student to move in from the margins and have their experience discussed and validated. Moreover, it is a chance for the student to bring together different elements of their identity and engage in scholarship which centers on an element of their identity that has otherwise been overlooked by the computer science curriculum.

Still for others the experience has more to do with their identity as privileged. They recognize their need to learn more about inclusivity before transitioning to the working world.

> I feel that not every technology design class I've taken provided enough of a focus on inclusivity and equity in design. As this course is my last CS course at [redacted], I believe that it will be the perfect bookend to my career as it will be able to fill in for that lacking, providing me with extremely valuable knowledge that makes sure no one is left out based on

> age, size, gender, or ability in the technology we design. I not only believe this course will be interesting and an outstanding experience, but I also feel it's an extremely important part of my education and preparation for the real world. As a student who has had some privileges in his life, I feel learning about designing for all is extremely valuable. Furthermore, as someone going into the field of software engineering and design, I feel that it is of the utmost importance that I am able to keep in mind these values and the knowledge I gain from the course when creating technology after I graduate.

The student's comment suggests a need for more exposure and action in the area of equity in design. It is unfortunate to consider that students could leave an undergraduate computer science curriculum without having concrete experiences with designing for inclusivity and equity.

In conclusion, we see students enrolling in the Inclusive Making course for a variety of reasons. Some see this course as a chance to combine their passions for social justice and equity with their love of technology. For others, the course excites them because they will be working with a diverse group of students and organizations. Some want to develop practical skills and knowledge to design software solutions that are inclusive and accessible, something that is scarcely addressed in other coursework. A few students also noted the course format and the fulfillment of degree requirements as motivating factors. Underlying many of these reasons is a connection to student identities. Importantly, the identity component emerged for both dominant and non-dominant students and demonstrates that this type of class can have meaning across student populations. Having examined student motivation for participating in the course, we now transition into articulating what students learned in the class, and how that learning was instantiated.

Instantiations and reflections of student learning

Our discussion of student learning will focus on two student-generated data sources: students projects and their reflections from out-of-class assignments. The projects help situate how students realized their ideas about accessibility and making, while the reflections provide a window into their own perceptions of how their views changed as result of specific assignments.

Student *projects*

Twenty-seven final projects were completed through the three offerings of Inclusive Making. This is in addition to intermediate projects groups of students submitted for the different design provocations. Broadly speaking, the student projects can be put into three categories: multimodal interfaces for designing, tools or experiences that raise awareness, and projects that aim to redefine making. Thirteen projects fall into the Multimodal Interfaces for Designing category, ten into the Tools or Experiences for Awareness category, and four in the Redefining Making category. In the interest of space, we present a selection of projects that exemplify the learning opportunities which emerged through the course. Moreover, the projects highlight the breadth and depth of students' conceptualizations of making and accessibility and the varied levels of technological complexity that students practiced.

Multimodal interfaces for designing. Projects in this category very explicitly took to heart the challenge to design interfaces that enable people with disabilities to participate in practices of making. The four projects that we describe aimed to support people with visual impairments and subsequently utilize a combination of tactile and auditory components.

The first two projects in this category address the challenge of doing computer-aided design or creating vector graphics among people with visual impairments. The first, called Drawback, is a tactile drawing and sketching application. Drawback (Figure 1) allows a user to feel the designs that they have made using haptic feedback on a touchscreen. The application utilizes Mozilla's vibration API to make certain pixels vibrate and includes a drawing mode, a feeling mode, and an erasing mode. After a user has drawn something with their finger or a stylus, they can select the feeling mode to better ascertain if the drawing is as expected. Once the desired drawing has been achieved, the user can export their design to be laser cut, for example.

A second project related to computer-aided design is Accessible Carvey (Figure 2). The Carvey is a desktop computer numerical control (CNC) mill that can be used for precision cutting of wood and plastic. For someone with a visual impairment, designing and building with the Carvey is difficult because most computer-aided design software is not accessible using screen readers. The web interface used to setup and transmit design files to be printed is also inaccessible. Accordingly, this team developed a workflow that starts with drawing with a digital pen and the assistance of the Sensational Blackboard, a low-cost device for creating raised graphics and text. The digital pen allows for easy transfer into a PDF that is uploaded to the Carvey web interface. The team then created a tactile interface that mirrors the web-based Carvey interface so users can independently make decisions about 1) the depth at which their design should be cut, 2) the type of material to be used, and 3) where on the material the design should be positioned.

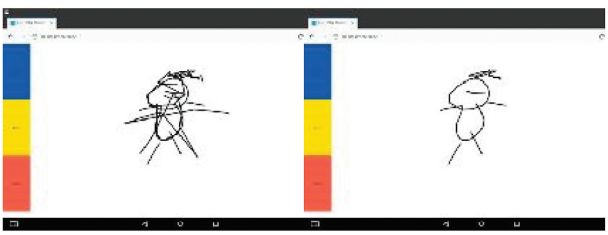

Figure 1. Screenshots of Drawback.

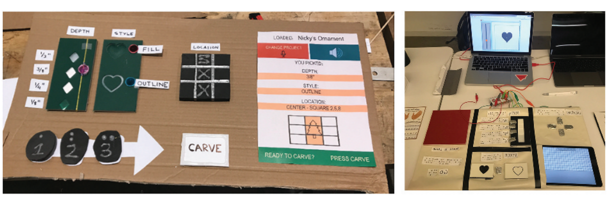

Figure 2. Images of Accessible Carvey Prototypes.

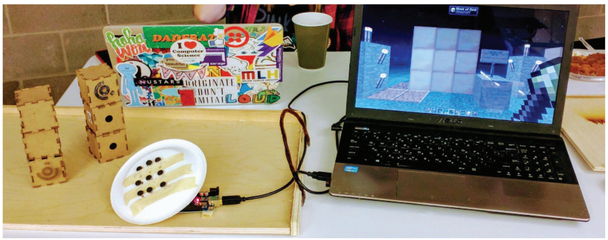

Figure 3. Image of Tangicraft prototype.

Students used a combination of cardboard, crafts materials, and the Makey Makey (Collective & Shaw, 2012) to create this prototype.

A third project was motivated by the observation that many children with visual impairments are excluded from participating in playing video games. While the gaming industry has made some efforts to correct this, one project team was particularly keen to explore a prototype that would make the popular video game, Minecraft, more accessible. This team developed a project called Tangicraft (Figure 3), which provides alternate means for building and sensing in Minecraft (Bar-El, Davison, Large, & Worsley, 2018). Tangicraft allows students to build simple designs using wooden blocks that have fiducial markers. The fiducial markers can be read by a web-camera which allows for the physical design made with wooden blocks to be recreated, in real-time, within the game environment. For sensing what blocks are on the screen in front of the player, a 3 × 3 grid of vibration motors is used. The 3 × 3 grid corresponds to the 3 × 3 grid of spaces directly in front of the player's avatar. If a given space in the grid is occupied, the corresponding vibration motor will vibrate. Tangicraft is also an example of a project that students continued to develop following the Inclusive Making course and presented at research conferences.

The last example is from a pair of students who worked with a local organization which provides arts-related services to adults with visual impairments. The two students are doctoral candidates in an interdisciplinary computer science and social sciences program.

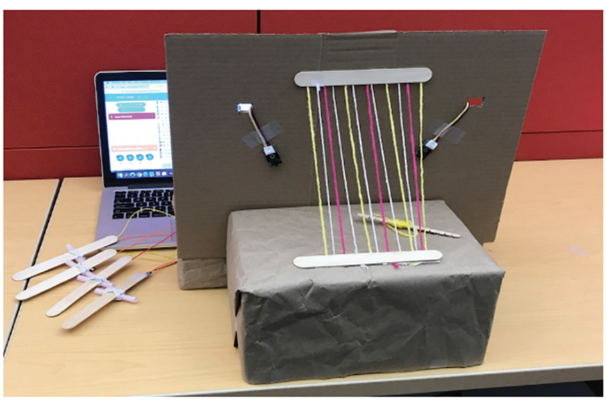

Figure 4. Image of Computer-Aided Weaving Prototype.

The adults that they worked with enjoy weaving as part of an activity offered by the organization. However, the adults often need help deciphering when to start a new line on the loom. This team created a prototype that connects short-range proximity sensors to the end of the loom to count the number of times the shuttle has passed (Figure 4). This allows users to know when they reach the end of the line. Again, this project team looked to expand this work into a larger project to support individuals at this specific community organization. The students extended this work as part of their qualifying examinations in Computer Science and recently published a conference paper (Das, Borgos-Rodriguez, & Piper, 2020).

Designing tools and experiences to increase awareness. In addition to creating tools that support design among people with disabilities, students also completed projects to increase awareness of accessibility. The first project in this category is Extensibility. Extensibility is born out of a collaboration that students developed with a national organization that serves people with visual impairments. The project team and organization determined that creating tools that help app developers make more accessible applications would be the best form of collaboration at that time.

Extensibility is a Chrome browser extension that includes a set of tools to help developers make more accessible web and mobile applications. The tool includes three main capabilities: flagging missing labels, making the screen black for evaluating navigation, and indicating headers and links. These three capabilities bring to the forefront challenges that someone with a visual impairment might experience when navigating an application and helps developers become more aware of these design considerations.

Another group of students designed a set of experiences for middle school students to complete in a local makerspace. They created and facilitated three activities that helped youth develop empathy for people with different abilities. For example, students completed simulated impairment activities, analogous to those in the class. During these activities, the middle school youth would do a collaborative making activity but not use one of their senses. Feedback from the middle school students included many realizing that they held unjustified assumptions about what it means to have a disability.

Redefining making. The final category of projects involved students who wished to problematize canonical definitions of making and worked with community partners to redefine what making meant for their community.

One project within this category, called Co-Makers, was for a community organization that works with children on the autism spectrum. After extensive conversations and interactions with the organization's leadership team, the project team learned the centrality of puzzle activities within the organization. Accordingly, this group made a reusable puzzle board that participants could use to make customizable puzzles for themselves or others. The puzzle board was laser cut from clear acrylic. Participants used dry erase markers to draw the desired picture on the acrylic. The drawing could then be erased and the acrylic reused for another custom puzzle. While these participants are not using 3D printers or laser cutters themselves, they had the opportunity to engage in creative expression and make personally meaningful, shareable objects.

Figure 5. Picture of Uncreative Making.

The final project that we will discuss is Uncreative Making. The students selected this name to draw attention to the almost automatic assumptions that people have about what it means to be creative, and ways that "real" making is expected to satisfy a normative definition of "creative". The project was led by two students who worked closely with an elementary school that only serves students with disabilities. Many of the students in this school have developmental and physical impairments that require special assistance from trained adults. Through ongoing volunteering and conversation with teachers, this project team created a game in which two people control the same remote-controlled car (Figure 5). The main purpose of the game it to take turns sending the car back and forth. The car moves along a walled track that the Inclusive Making students created in the university's machine shop using common woodworking tools. The teacher and project team developed this solution based on the realization that, for some, making should actually mean repetitive processes as opposed to complex and divergent projects. This insight offers a counterpoint to previous arguments about the shortcomings of trivial activities with Maker tools (Blikstein, 2013; Blikstein & Worsley, 2016). Blikstein (2013) and Blikstein and Worsley (2016) refer to the "keychain syndrome" – an unfortunate name that carries an unnecessary and negative medical connotation – as instances where students are incentivized to complete "fast, scripted, perpetually 'introductory'" (Blikstein & Worsley, 2016, p. 67) activities. These "trivial" activities are positioned in contrast to projects that are complex and developed over long timeframes. For many of the students participating within partner organizations, there was a need to reimagine both the use and value of terms like "trivial" and "creative".

The seven projects mentioned above provide a snapshot of the type of work that students developed over the course of the class. Many of the projects involved extensive computer programming, digital fabrication, user experience design, and, perhaps most importantly, collaboration with community partners. These are all skills that computer science students should be practicing as part of a CS curriculum. Additionally, developing these technical and practical skills occurred alongside evolving perceptions of disability and various ways of making. As we transition to looking at student reflections, we see these evolving perceptions of disability and making in more detail.

Student reflections

In this section we touch upon a couple student reflections from out-of-class assignments that emphasize important shifts in student perceptions about people with disabilities and what it means to practice making.

Schooling the technology "expert". Recall that one of the early assignments for the class involved students volunteering with a local organization that served people with disabilities. The week prior to that volunteering visit, one team approached the first author at the end of class to express some apprehension and uneasiness about volunteering at this specific organization. Their uneasiness centered on the role that they would play as volunteers, which essentially amounted to them eating lunch with some of the residents. In short, the students did not feel as though they were going to be doing anything of value. Upon hearing about their discomfort, we encouraged the students to volunteer as planned and reflect on the underlying reasons for why they felt uneasy. The students pushed through their discomfort and completed their volunteering visit and reflection as assigned. Below, we include a short excerpt from the student's visit reflection submission. In this reflection, the student refers to Peter, a blind resident at the partner organization.

> Peter showed us how voice assist works on the iPhone. This was a real eye opener. Although it took longer than usual, Peter navigated the phone very seamlessly. He then updated all of our phones to make sure that we're on the latest version … The visit left me feeling inspired.

In simple terms, the student describes being both inspired and surprised by what the young man with a visual impairment could do with his smartphone. This story, however, becomes increasingly powerful when we consider that the student who wrote this reflection has considerable experience with multimodal technology, having done work with indoor location tracking systems, immersive virtual reality, computer vision, speech recognition and more. In short, this student had significant knowledge about many types of multimodal technologies but was still unaware of the suite of assistive technologies available on most smartphones. This is both troubling and exciting. It is troubling from the standpoint that some computer science students are not aware of assistive technologies, but exciting from the perspective that the students were inspired and educated by someone about whom they likely had several assumptions. The students had viewed the volunteering visit as an opportunity for them to offer something to the organization, only to realize that the organization had something important to offer to them.

Expanding perceptions of making. Some students in the course describe similarly impactful insights from their assignment to visit a local makerspace. For instance, one student visited a local crafting community and wrote that the organization "would not have fallen into the definition of makerspace that I walked in with on the first day of class." When the student entered the course, they had a narrow conception of what a makerspace looked like. Their perception skewed towards the popularized view of makerspaces that are techno-centric. However, after only a week in the course the student had developed a more nuanced conception of making and was conscious of this shift.

Another student grew to recognize that part of the argument for making has less to do with technology and more to do with people:

> [T]his experience was incredibly insightful for me when thinking about Making as a pedagogical process that transcends tooling and subject matter and enables students to use a new way of thinking …. I think this [technocentric] view would be incredibly simplistic and really miss a lot of the aspects of what 'Making' is in this space and how 'Making' is perceived differently by this particular community. … Creation was an important part of course, but the support of the community, before, during, and after creation, seemed to be what kept people coming back. Introducing machines into that space to substitute for people would likely take some of that welcoming community away from them.

The student pushes back against a techno-centric perspective of making that would ignore the important role that people play in creating and sustaining that specific making community. This redefinition of making is a powerful and important objective of the course that ripples through how students approach their final projects and how they engage with community organizations.

As we move into the discussion section, we will identify some overarching observations that synthesize the different data points and situate the need and opportunity presented by this type of learning environment. This will include connecting between student learning and the course design, while also connecting the above data with a broader discussion on teaching accessibility in CS.

Discussion

The survey data, projects, and written reflections presented in the previous section provide explicit answers for our two driving research questions about why students decided to enroll in the Inclusive Making course, and what they learned and practiced in terms of technological skills and beliefs about accessibility. Taking a step back, the data also brings forth some important ideas about how to design and implement classes on accessibility within the computer science context. These ideas range from strategies for framing the learning experience to more detailed approaches for promoting meaningful learning in areas of diversity, equity, and inclusion.

Recognizing and designing for the needs

Drawing on application surveys, we saw that students have varied motivations for enrolling in Inclusive Making. Many of the students were drawn to the course because of reasons related to growing their individual awareness of inequity, wanting to use CS for social good, and because they were interested in making. Underlying many of these broad ideas, however, were motivations grounded in students' own experiences and identities. To this point, student responses demonstrated that the necessity for courses on accessibility goes beyond just thinking about the needs of people with disabilities to also include ways that students can meaningfully bring their different identities to the forefront of their learning experiences. These findings mirror prior research on the importance of culturally responsive computing (CRC) for improving interest and engagement among students from non-dominant groups (Fields et al., 2018; Scott et al., 2015). However, ethnocomputing and culturally responsive computing have scarcely been discussed or applied in higher education, or to the area of accessibility. Instead, CRC and ethnocomputing have tended to focus on dimensions of race, ethnicity, and gender in K-12 informal contexts. The data from this work suggests that there is a clear opportunity to leverage similar strategies when designing courses on accessibility and CS at the university level.

It is important, though, to recognize that simply thinking about accessibility as a motivating factor for taking this course would be shortsighted. When developing courses on accessibility the topic area also matters. In the case of Inclusive Making, there were many students who were explicitly attracted to the course because of the hands-on, making orientation of the course. There may equally be students who are turned away from such a course. Hence, organizations should think about finding multiple entry points into courses on accessibility (Fields et al., 2018; Scott et al., 2015).

Finally, while only a small number of students indicated that degree requirement fulfillment was a motivating factor, this is a component, or need, that should not be overlooked. When accessibility-related courses fulfill important degree requirements, the university signals to students that this is a topic area that is meaningful and worth studying (Gellenbeck, 2005). Without this, organizations may signal that the area of accessibility is not of central importance and could unintentionally put students interested in accessibility in a position where they are deciding between efficiently completing their degree or taking elective courses.

Applying a critical lens across different forms of making and computing

The second research question looked at ways that students learned, practiced, and demonstrated mastery of core computer science and accessibility concepts. We explored this research question by looking at a variety of students' projects and written reflections. We saw that students created a multitude of solutions for issues of accessibility and making. The projects demonstrate both the breadth and depth of the computer science that can be pursued within this context. For example, the Multimodal Tools for Designing category required clever integration of software and hardware components that spanned from low-tech prototypes to fully functional high-fidelity prototypes. In terms of breadth, student projects ranged from technological tools to learning experiences and activities motivated by underlying goals of promoting creative expressions and collaboration.

Finally, projects in the Redefining Making category, challenged notions about what making can and should look like among people with disabilities and more broadly. When coupled with reflections from student written assigments, students evidenced increased awareness of their own assumptions and biases, and self-realized shifts in thinking. Collectively, the data speak to the important ways that students were able to practice computer science, and realize deep learning and growth in accessibility and making.

In addition to highlighting a variety of applications, the projects are an example of how applying a critical lens can have applicability across several different interpretations of making. Instead of adhering to a single definition of authentic and valuable making practices, students were encouraged to design innovations that range from being highly techno-centric to extremely low tech. Moreover, whereas some students were intent to adhere to traditional instantiations of making, which include 3D printing and laser cutting, other students highlighted the ways that local communities might already be practicing making. Despite these differences, students were consistently pushed to apply a critical lens. Within the more technocentric frame, students had to think critically about the assumptions that go into the design of different devices and how to design more inclusive interfaces. On the other hand, students whose projects were low tech, engaged in a process of interrogating the underlying meaning and value of making activities. This same idea can translate to the field of computer science more broadly. While some may debate the legitimacy of computational thinking and CS Unplugged activities relative to writing assembly or programming an algorithm, there are opportunities to apply a critical lens across the full range of computer science, and computer science-related activities. Applying a critical lens is a significant departure from existing courses that tend to view the content of the discipline as a given and do not venture to critique or understand the history of the field and the various barriers that exist. Within the Inclusive Making class, when students applied this more critical lens, their ideas became more thoughtful, efficacious, and innovative. We suggest that taking a similar approach across computer science courses and disciplines could be fruitful.

Articulating different ways for connecting with community partners

Our final point of discussion relates to the importance of partnering with community organizations. Prior work has emphasized the role of community partnerships and hands-on learning (Gellenbeck, 2005; Ludi, 2007; Shinohara et al., 2016; Shinohara, Wobbrock et al., 2018). Our observations echo these findings, and evidence the learning that can stem from engaging with local stakeholder organizations. This learning included being introduced to new technologies, considering expanded conceptualizes of making, and confronting different biases and assumptions. Importantly, this was realized across a few different approaches to community partnerships. Hence, this paper extends prior work by explicitly describing different ways for partnering with local stakeholders. Within the Inclusive Making course, students engaged with local stakeholders by participating in informal dialogues over coffee or a meal, visiting a local makerspace, volunteering with advocacy groups, and working through term-long, co-designed projects. Each of these types of activities proved to be influential to student learning and development. We suggest that these are simply some of the ways that students can engage local individuals and community organizations in complement to common approaches in user-centered design. In advocating for engagement with local organizations, we must also reiterate that these activities were conducted alongside the other course activities that were outlined in this paper and in the supplemental online materials. Moreover, the Critical Disability Studies lens, and discussions that complemented some of the course readings, helped prepare students to engage with these different organizations in ways that were ethical and respectful.

Implications

A goal of this paper is to provide a preliminary blueprint for practitioners and researchers to use in creating new courses, or within their existing course work. Beginning with prior work, guiding literature and course description, and subsequently moving into an analysis of student surveys, projects and written reflections has hopefully left readers with several thoughts and ideas. To help readers meaningfully distill this information, particularly thinking about researchers and practitioners interested in teaching accessibility in their CS courses, we outline three high-level implications of this work.

Making as a potentially useful learning context

One implication to draw from this paper is the opportunities presented by using making as a context for learning about accessibility. Prior work has heavily focused on web accessibility and designing human-computer interfaces that allow people with disabilities to participate as consumers of technology (Hurst & Tobias, 2011; Ko & Ladner, 2016; R. Ladner, 2014; R.E. R.E. Ladner & May, 2017). In contrast, the Inclusive Making course advances an approach that can potentially disrupt the cyclical nature of inaccessible making tools by facilitating people with disabilities to be technology designers. Because making is inherently about engaging participants in the process of designing and inventing, the projects that the students undertake are an attempt to bring people with disabilities into the making sphere as designers, and not merely consumers of web content, for example. Just as students and organizations explored different forms of making, we encourage practitioners to also be expansive in how they think about using making as a context for learning accessibility. The student projects described in this paper made evident the breadth of approaches making affords and the expansive opportunities that it provides for students to learn and practice important ideas in computer science and accessibility.

Importance of taking a critical lens

Perhaps the most important implication of this course design is the learning that can result from having students apply a critical lens to computer science as they also engage in projects related to accessibility. As we previously noted, this is a significant departure from prior courses that treat the content of the discipline as a given and do not interrogate the history of the field and the various barriers that exist for different people groups. For example, a course on designing accessible interfaces for sports would seemingly benefit from also interrogating the history and assumptions of engagement in sports. Some questions might include why society values sports, what types of abilities sports participation privileges and the history of different sports. Taking this approach can support profound student learning and development, and drive innovation within the discipline of computer science.

Taxonomy discussing and framing work on making and accessibility

Finally, tractably applying a critical lens to a given field can be challenging without a supporting framework. These challenges can emerge in the discussion and instantiation of student projects and ideas. The taxonomy that we described in this paper proved to be important for helping students limit the scope of their projects and consider synergistic and competing arguments and theories across the different bodies of research. We therefore suggest that other scholars and practitioners use this taxonomy, or develop a similar taxonomy, as a tool to support this type of interdisciplinary learning. Such a tool proved to be an important component of the course.

Limitations

As we consider these implications, we must also acknowledge various limitations. One apparent limitation is student self-selection to enroll in the course. We see the self-selection as a reflection of the need for this type of course, but also note that students who self-selected still had eye-opening experiences. Even though these students may have already been sympathetic to the needs of people with disabilities, they still carried many prejudicial assumptions about people with disabilities and benefited from their experience in the course. This points to the need for issues of accessibility to be more broadly addressed within computer science, which is something that we advocate. Inclusive Making has addressed this first step, and we hope that others will continue in efforts to make these types of critical and interdisciplinary experiences more mainstream across computer science.

A complementary limitation is that we do not have information about students who elected not to enroll in this course. While nearly one hundred students have taken Inclusive Making, there are far more students who elected not to take the course. Reasonably, many of the reasons that students provided as motivation for enrolling in this course might equally be reasons that some students chose not to enroll. For example, some students may have seen the title and assumed that studying inclusivity or making was not for them. In future work it may be instructive to better understand why some students may be turned off by the course.

We also recognize that because students were applying to participate in the course, their responses to the application questions may have been written to intentionally reflect ideas that they thought would resonate with the course instructor. Even so, we suggest that the student motivations described mirror prior work on students from non-dominant backgrounds (Fields et al., 2018; Scott et al., 2015; Searle & Kafai, 2015). Namely, many students are motivated by the opportunity to connect their learning with issues of equity, social justice, and inclusion. However, we believe that more research should be completed to examine the generalizability of these motivations, especially as it relates to accessibility.

Another limitation is the lack of longitudinal data about student decisions and work in the area of accessibility. Anecdotally we have received emails from students about the important role this course played in their overall career trajectories but wish to consider this further in on-going research. It is important to note, however, that our goal is not that everyone who participates in the course pursue opportunities in accessibility. We want students to take their experiences and employ them across a broad set of career opportunities.

On a related point, the paper does not chronicle, or describe in detail, the changes that emerged across the different iterations of the course. Nor does it identify which projects came from specific course offerings. This omission is intentional because our goal is to focus on the general importance and experiences students had with the course. The fact that there were three iterations is included as a point of information for the reader, and not a central element of our argument.

Finally, we have provided limited information about how this course impacted community partners. We have individual cases of on-going interaction with the different organizations but have not conducted formal interviews or provided surveys to concretely assert what impact the partnership had on their organization. We suggest that the willingness of these organizations to continue working with us is a positive indicator of their excitement for the work but maintain that this is an important area for future consideration.

Conclusion

In his seminal text, *Pedagogy of the Oppressed*, Paulo Freire writes:

> More and more, the oppressors are using science and technology as unquestionably powerful instruments for their purpose: the maintenance of the oppressive order through manipulation and repression. The oppressed, as objects, as "things," have no purposes except those their oppressors prescribe for them.(Freire, 1978)

In the case of people with disabilities, the cycle of oppression has left them without the tools with which to participate in the "revolutionary" and "democratizing" aspects of the Maker Movement. This shortcoming with making, which can be viewed as an applied subset of computer science, is also present throughout CS. Without effectively educating students about the needs and opportunities at the intersection of computing and accessibility, we risk overlooking the needs of people with disabilities and, in turn, many of our students. By developing a course that bridges making, User-Centered Design, and Critical Disability Studies we can begin to realize some of the promises of making, broaden participation in computing, and promote more inclusive learning environments. More broadly, as we design courses that apply a critical lens to accessibility and computer science, we can prepare future generations to be more inclusive and forward-thinking in how they practice computer science. Just as there is no universal solution for all organizations, there is similarly no singular course design that will work across all contexts. The core course components that we described in this text can serve as guidance in creating such courses. Similarly, the observation that these types of courses can concurrently fulfil the needs of students, community organizations and society at large, suggests that we should be exploring interdisciplinary courses on accessibility more broadly within the CS education community. Hence, we implore other researchers and practitioners to engage in a similarly iterative process of authentically engaging with their local organizations, students, and instructional institutions to create spaces that challenge and grow our understanding, awareness, and actions towards ending oppression in its many and varied forms.

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No potential conflict of interest was reported by the authors.

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