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Research paper

Making computing visible & tangible: A paper-based computing toolkit for codesigning inclusive computing education activities

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ABSTRACT

MCVT (Making Computing Visible and Tangible) Cards are a toolkit of paper-based computing cards intended for use in the codesign of inclusive computing education. Working with groups of teachers and students over multiple design sessions, we share our toolkit, design drivers and material considerations; and use cases drawn from a week-long codesign workshop where seven teachers made and adapted cards for their future classroom facilitation. Our findings suggest that teachers valued the MCVT toolkit as a resource for their own learning and perceived the cards to be useful for supporting new computational practices, specifically for learning through making and connecting to examples of everyday computing. Critically reviewed by teachers during codesign workshops, the toolkit however posed some implementation challenges and constraints for learning through making and troubleshooting circuitry. From teacher surveys, interviews, workshop video recordings, and teacher-constructed projects, we show how teachers codesigned new design prototypes and pedagogical activities while also adapting and extending paper-based computing materials so their students could take advantage of the unique technical and expressive affordances of MCVT Cards. Our design research contributes a new perspective on using interactive paper computing cards as a medium for instructional materials development to support more inclusive computing education.

1. Introduction

Over the past decades, paper-based computing has enabled new kinds of interactions and computational participation. Since Buechley et al. introduced paper computing as a new medium for innovative engineering education (Buechley, Hendrix, & Eisenberg, 2009), Qi and colleagues further showed how a paper electronics toolkit could broaden participation and expand its reach by appealing to new communities of educators and female crafters (Qi et al., 2018). Inspired by prior work that bridges the accessibility and rich expressivity of using paper to promote and diversify users; and paper computing work that recognizes the ubiquity, tangibility, and flexibility of paper (Han, Cheng, Strachan, & Ma, 2021), we aim to expand its creative and equitable educational possibilities. Here, we explore (1) how a paper computing toolkit might support teachers in learning about computing concepts and practices, and (2) whether the designed affordances of this toolkit (alongside design cards, other materials and equity learning practices) could be used by teachers to generate more inclusive activities and lessons for their students.

Here, we present MCVT (Making Computing Visible and Tangible) Cards, a paper-based computing toolkit intended to facilitate the codesign and authoring of pedagogical materials with teachers to envision and implement inclusive computing education. We present the key design drivers and learning design foundation that influenced the design and iterations of the toolkit, then share findings from a 5-day workshop to show how teachers created new design prototypes and pedagogical activities while also adapting and extending paper computing materials for their students to take advantage of the unique technical and expressive affordances of MCVT Cards. Based on post surveys and interviews, we share how teachers perceived the opportunities and challenges in using the kit as a pedagogical material.

Our work builds on codesign approaches for generating inclusive instructional materials with teachers by blending paper-based physical computing materials and card-based methods. This paper contributes an alternative to current physical computing educational materials (e.g., robotics and eTextiles) with a new paper-based computing toolkit

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as well as design insights on how the toolkit could benefit inclusive computing education through codesign with teachers.

2. Backgrounds & design rationale

2.1. Learning design foundation & process

2.1.1. Equity & inclusive computing education

Our research project began from a vision that all students should have the opportunity to be successful and find meaning in computing activities whether or not they plan to pursue computer science in the future. In the U.S., while students, teachers, and parents report a strong interest in CS education, a diversity gap remains across gender and racial groups in their exposure to computing learning opportunities (Margolis, 2008; Ryoo, Margolis, Lee, Sandoval, & Goode, 2013; Wang, 2017). Our aim is to contribute to inclusive computing education by creating new materials and learning activities that build from a foundation of equity, inclusion, and equity-oriented design processes (Gale et al., 2022). By inclusive computing, we take our definition from NCWIT (National Center for Women & Information Technology) where inclusion means "creating learning environments that are accessible and welcoming of students' identities, backgrounds, differences and perspectives without barriers or judgment" (Microsoft, 2019). While this definition is derived from a gender equity perspective, we define this more broadly to also include learners and educators from traditionally underrepresented racial groups in computing: African-Americans, Hispanic, and American Indian/Indigenous groups. Equitable and inclusive computing education is also envisioned from both the design approaches and new design medium that enable its learners to construct and engage in computational practices, give more learners' agency to leverage their cultural backgrounds, assets, and everyday knowledge; and open up new possibilities to try on new identities especially for those with little to no background in computing.

Thus to support a wider diversity of teachers and students including girls and those from traditionally underrepresented groups in computing, we aim to design in tandem inclusive learning activities and accompanying design processes that build on the experiences of students and teachers.

2.1.2. Codesign with students and teachers

Our design process began with not only identifying the specific content and practices deemed important by K12 CS standards, but more importantly leveraging codesign to help guide key design considerations. We employed codesign as our method (Roschelle & Penuel, 2006; Sanders & Stappers, 2008) to design for inclusion, community, and equity outcomes by inviting participation by experienced STEM teachers in marginalized communities. Codesign serves the purpose of fostering concurrent reflection on learning during the design of materials; and a reflection on educators' teaching practices with the (workshop) materials (Westbroek, de Vries, Walraven, Handelzalts, & McKenney, 2019). Teachers have agentic roles as codesign partners. This process can both improve the quality of materials, but also provide professional learning to support future classroom implementations (Bain, Anton, Horn, & Wilensky, 2020; Gomez, Lee, & Woodman, 2022; Mills, Angevine, & Weisgrau, 2020).

Materials used in codesign processes can range from taking curricular activities to make adaptations, starting with a given technology to build upon their own pedagogical approach; to guiding learning in new development of instructional materials (Hmelo & Guzdial, 1996).

2.1.3. Material design for inclusion

Designing for equity and inclusion in computing acknowledges that inequities within designed materials can reinforce gender bias or replicate narrow ways of demonstrating what counts as learning and understanding (Holbert, 2016; Kafai et al., 2014; Medel & Pournaghshband, 2017). Studies that suggest materiality and its affordances can affect equitable and inclusive education (Keune & Peppler, 2019; Litts, Searle, Brayboy, & Kafai, 2021). Designing material-rich, hands-on learning activities with a paper-based computing kit, we paid careful attention to enabling a codesign process with teachers to create inclusive pedagogical materials for their learners. Inclusive pedagogies and computing practices including instructional activities that invite the voices of learners and ways to share their knowledge can create openings and space for broadening participation and creative production (Gay, 2002; Litts et al., 2021; Pinkard, Martin, & Erete, 2020; Scott, Sheridan, & Clark, 2015). Participant educators can experience the possibilities and limitations of technology, work with prototype materials and partially designed artifacts, while the facilitator/researcher serves in roles as both a value provider and a direction setter so the outcome of codesign activities can advance both process and products.

2.2. Design drivers

From reviewing the literature, we articulated a set of design considerations that would be both descriptive and prescriptive for future designs (Han et al., 2021; Resnick et al., 2005). These design considerations also formed our design drivers for the MCVT toolkit.

- *D1: Enable Easy Entrée and Exploration:* This design driver includes making the kit easy and exciting to get started with new kinds of making and ideas without being burdened first with learning code syntax or programming instructions. Creative learning is promoted by tinkering and making (Resnick & Rosenbaum, 2013), selecting easy-to-pick-up and easy-to-interact parts, and materials to enable beginners to participate in constructing their narratives. To support easy entree, we also carefully annotated in the cards cut lines, holes, and shapes to make explicit what learners could manipulate and hide unimportant elements to surface ideas and areas where users could explore.
- *D2: Make Computing Investigable:* We aim to enable learners to investigate the underlying computing system concepts determined from materials and forms. This includes exposing human–computer interactions, making computing systems and their functionality more transparent, so curious learners can better connect representations of a computing system and/or trace how computational behaviors work so they can modify them depending on their goals (Perner-Wilson, Buechley, & Satomi, 2010; Resnick, Berg, & Eisenberg, 2000).
- *D3: Support Extendibility:* We aim to enable users to substitute parts in the kit with parts and materials they have on hand, and extend it using existing, widely-accessible systems. Also, by selecting the parts interchangeable, we aim to support freely swapping parts for each sensor and actuator. Designs should encourage practices of reconfiguration (Kuijer, Nicenboim, & Giaccardi, 2017) and repurposing that build on learner resourcefulness, creativity, modification, and hacking of malleable systems (Santo, 2012). These qualities for material flexibility and adaptability should inspire and expand the range of expressive ideas and projects for beginners.
- *D4: Personalizable stories:* We aim to put personal, learner-voiced narratives at the center of projects and put to use the knowledge that learners bring with them from their cultures and communities. The backgrounds of learners including their interests, histories, personal stories, strengths, or other assets should be resources for participating and engaging in the production of computational artifacts. Opening up space to more voices also moves practices closer towards equity and inclusive design.

- *D5: Visible Forms and Transparent Functions:* Another important design driver is transparency of functions to see the inner workings of technical and computational systems including electrical and mechanical systems through hands-on making, design, and experimentation. We draw our inspiration from glassboxing that refers to the layering of interactive paper-based computing materials to mesh computational construction and design support. We imagined a kit where selected components were purposefully made more transparent, so learners can investigate, interrogate, understand, and appreciate their parts, purposes, and complexities (Clapp, Ross, Ryan, & Tishman, 2016; Perner-Wilson et al., 2010).

2.3. Design medium

As a medium to materialize our design drivers, we referenced the literature base and adapted prior paper-based computing and card-based methods to develop the MCVT toolkit.

2.3.1. Paper-based physical computing

With many available options, physical computing toolkits are continuing to thrive as a new pathway to inclusive computer science education (Blikstein, 2013; Hodges, Sentance, Finney, & Ball, 2020). In this study, we focus on a growing body of craft-based kits from Arduino-based robotics kits and micro:bits with block coding. For instance, Buechley, Eisenberg, Catchen, and Crockett (2008) introduced textile-based craft with Lilypad Arduino as a means to learn and practice computer science, along with many other researchers who have demonstrated learning about circuits through e-textile materials (Peppler & Glosson, 2013), broadening participation and perceptions about computing (Kafai et al., 2014; Richard, Kafai, Adleberg, & Telhan, 2015), promoting equity in exploring CS curriculum (Fields, Kafai, Nakajima, Goode, & Margolis, 2018), and more.

Our design uses paper as the primary medium for physical computing. Paper is a popular, low-cost prototyping material commonly used in physical computing practices. In the context of learning through making, a critical benefit of using paper and paper-like materials is that it invites expressive exploration with arts and rich storytelling based on the existing culture of papercrafting. This enables teachers to give more space for students to envision ideas, create personal narratives, or make their own adaptations while introducing relevant technologies and core concepts. HCI researchers have discussed how paper with craft-friendly conductive materials can enable paper computing as a new medium and presented numerous techniques to support building circuits on paper, for instance, by using conductive tape (Qi & Buechley, 2010), stickers (Hodges et al., 2014; Qi, Huang, & Paradiso, 2015), or an inkjet printed circuits on paper (Cheng et al., 2020; Kawahara, Hodges, Cook, Zhang, & Abowd, 2013; Klamka & Dachselt, 2017; Olberding, Soto Ortega, Hildebrandt, & Steimle, 2015)—to name just a few. Leveraging paper-based computing materials and techniques that are approachable for youth allowed us to extend using paper as a static medium and link it with the affordances of computing technologies. This bridge of paper and digital technology gaps is also aligned with one of the key features of unique interaction design noted in Han et al.'s systematic literature review (Han et al., 2021). Further, this review discusses education and learning as one of the main application areas of paper-digital interfaces. For instance, Alessandrini, Cappelletti, and Zancanaro (2014) presented guidelines to develop paper-based interfaces for underrepresented groups such as children with an autistic spectrum disorder. Özgür (2017) demonstrated applying handheld robots that interact with paper sheets for classroom activities. Yet, none of the work mentioned in the review used paper-based computing materials for creative learning through expressive and exploratory making as well as codesign facilitation. Outside of specific user groups or classroom contexts, Oh, Hsi, Eisenberg, and Gross (2018) developed computational tools to enable the making of computationally-enhanced mechanical papercrafts for creative learning. In a similar spirit, Qi et al. (2018) presented a paper electronics kit to support interdisciplinary learning through building interactive papercrafts and discussed how it attracted female-dominant communities of educators and crafters. In the MCVT kit, we likewise adapt paper as a primary medium based on its accessibility and rich personalization space. However, our focus is on designing the toolkit to engage teachers in codesign activities, ultimately for inclusive computing education more broadly.

2.3.2. Card-based methods and systems

"Cards" are a familiar tool for design researchers and practitioners to support innovation processes methods (Roy & Warren, 2019) as design probes (Boehner, Vertesi, Sengers, & Dourish, 2007; Gaver, Dunne, & Pacenti, 1999; Hutchinson et al., 2003) and tools for both cooperative and contextual inquiry (Druin, 1999; Karen & Sandra, 1993). Cards can support creativity and critical reflection, helping designers envision possible design solutions as well as the values and constraints through which communities view design solutions (Friedman & Hendry, 2012). In a survey of card-based design tools (Wölfel & Merritt, 2013), Wölfel & Merritt discussed that future work needs ways to allow customization and extend physical cards into digital technology.

While we used "cards" first as a tool for inclusive design of expressive computational artifacts, we also used cards as a handy, concise physical format to structure an intended design processes, as with MakerCards for planning and conceptual support (Hornecker, 2010; Root, Heuten, & Boll, 2019), IDEO method cards that act as probes (IDEO, 2003), Interactive Thread cards (Mackay, 2004), and Envisioning cards (Friedman & Hendry, 2012). We hypothesize that this method can support both expressive, personally-meaningful computational production by youth, using the kit as-is, as well as facilitate hands-on, codesign processes through which teachers can develop and adapt materials that best respond to what they know about their students and communities.

Our MCVT Cards bridge these uses of cards in HCI design processes, which use paper as template and substrate to support novices in the design and construction of creative, computational artifacts. While we draw inspiration from recent work such as MakerCards (Root et al., 2019) by QR-codes on cards to connect web resources including tutorials for wiring and coding, we approach using cards both as an accessible form factor for computational practices and as a tool to facilitate codesign of pedagogical materials with teachers for inclusive computing education. Our use of cards as the tool for creations and as the means for codesign facilitation contributes to the research on card-based methods.

3. Making Computing Visible & Tangible (MCVT) toolkit

Our MCVT toolkit includes a set of printed paper cards, a microcontroller, and a set of conductive and non-conductive craft materials (see Figs. 1, 3, 4). The printed cards include informational cards as well as cards that serve as building templates for sensors and actuators. The four different card types are as follows:

- *Make*: These cards support building five sensors (digital contact, analog potentiometer, analog pressure input, flex input, capacitive touch) and three actuators (LED, speaker, motor) with how-to assemble instructions and tailored representations showing circuit forms and functionality to enable sensor materials to be layered and constructed upon each of them.
- *STEM Connect*: These informational cards show pictures and text to explain underlying principles of how each of the sensors and actuators works and include QR codes to link the web pages providing additional learning resources.
- *In the World*: These informational cards show pictures and text to introduce real-world application examples of each sensor type embedded in a social context along with QR codes that connect relevant Youtube video links.

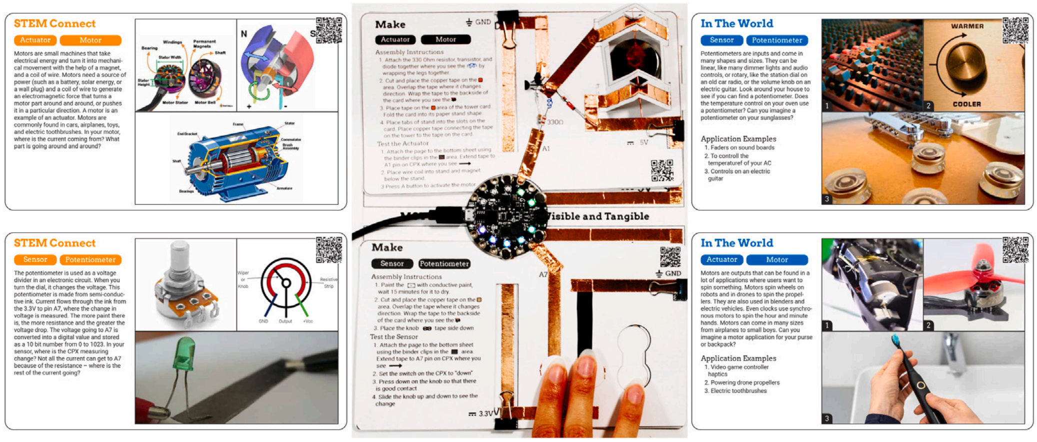

Fig. 1. MCVT card set example: (center) Base card layered with a visible and tangible potentiometer sensor input below and a motor actuator output above. (Left) "STEM Connect" and (right) "In the World" cards for each input and output are shown alongside.

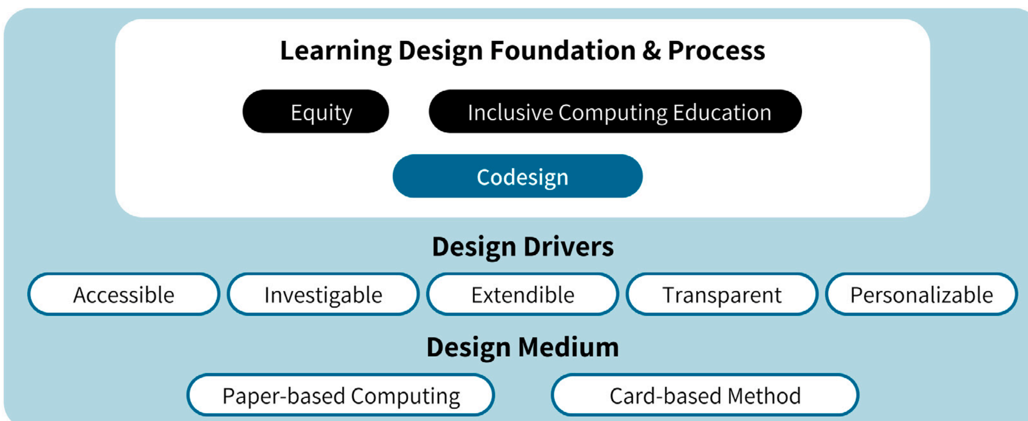

Fig. 2. Overview of our design approach to the MCVT toolkit.

- *Design*: These blank cards are intended as creative launch points for designing one's own interactive projects, sensor inputs, and actuator outputs.

Our rationale for creating the STEM Connect and In the World cards are informed by studies in CS education that researched pedagogical practices to improve designing for inclusive computational participation (Ryoo, 2019). Key pedagogical practices that had the greatest impact on youth's interest and engagement with CS included demystifying CS by showing its connections to everyday life.

The cardkit is connected to the project website (mcvtlab.com), which contains the designated webpages for each card: (1) the list of materials and parts in the kit, (2) assembly instruction and troubleshooting videos and downloadable digital files for each card, (3) videos and images of application examples that are added to the In the World and STEM Connect cards, and (4) the MakeCode editor for individual codes of sensors and actuators and the combined code uploaded to the Adafruit Circuit Playground Express (CPX) board in the kit. Each of the printed cards contains QR codes that links to the relevant webpages.

4. Toolkit prototyping

To design and build the MCVT kit, we employed an iterative design process over 22 months that involved research-through-design, preliminary design studies with children and educators culminating in a weeklong codesign workshop study with teachers (Table 1). In this section, we first describe our initial prototyping process and preliminary studies with youth and first codesign session with educators in order to develop the kit.

4.1. Initial prototypes through research-through-design

Our approach to reflecting the design drivers (Fig. 2) in initial prototyping originated with research-through-design in HCI (Gaver, 2012; Zimmerman, Forlizzi, & Evenson, 2007). We adopted a practice-based, designer-research position that emphasizes first-hand insights emerging through creating working prototypes (Gaver, Krogh, Boucher, & Chatting, 2022). Two of the co-authors have taught an introductory level of physical computing courses at university for over 4+ years. They led this initial exploratory design process, reflecting their experiences as a teacher to facilitate their classroom activities with novices, and produced the first prototype that combined three selected sensors (contact switch, pressure, and capacitive sensors) into one card (Fig. 5A). However, through our own exploration, critique and internal testing with lab members, we found that this is hard to investigate when any errors occur due to the overlapped part of the connections. Further, through our conversations, we realized that dividing each sensor into separate cards could be more efficient in facilitating classroom activities.

After several sketches and rough prototypes, we developed the second prototype (Fig. 5B). By separating sensors, we were able to use more spaces in the cards and break down the instructions. At the same time, to avoid the repetitive process of connecting to the ground and power of the controller, as well as teaching the fundamentals of

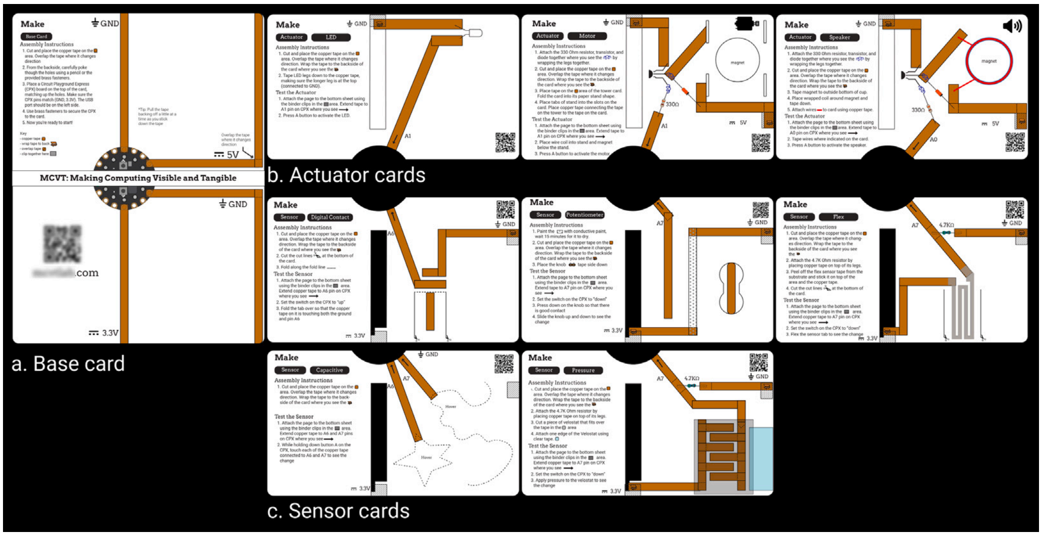

Fig. 3. The MCVT "Make" cards: (a) Base card where the CPX board is attached and connects the power and ground of circuits; (b) Actuator cards: (from left) a LED, a motor, and a speaker outputs; and (c) Sensor cards: digital contact, analog potentiometer, flex, pressure, and capacitive touch sensor inputs.

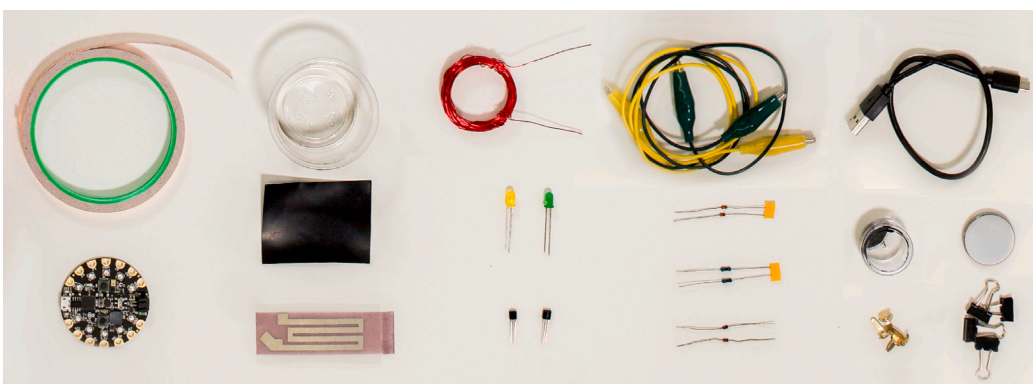

Fig. 4. Materials and parts included with cards in the MCVT kit.

Table 1
Overview of design phases of the MCVT Kit development process.

	Exploration [Section 4.1]	Preliminary studies [Section 4.2]	Feedback & Codesign [Section 4.3]	Codesign & Workshop Study [Section 5]
Goal	Initial prototyping & kit design in lab	Solicit children's feedback in design	Represent teacher perspective; Codesign new materials	Represent teacher perspective; Codesign new materials with equity pedagogies
Participants	Research team, lab members, 9 undergraduates	6 youth	2 teachers of diverse learners	7 teachers of diverse learners
Method	Observation, Research through Design	Observation, session recordings, conversations, interviews	Codesign sessions, interviews, teacher-created artifacts, teacher portfolios	Codesign sessions, pre-post surveys, video, interviews, artifacts
Design Revisions	Created basic MCVT kit with Base and sensor cards	Developed new sensor cards; Added Design, ITW, STEM cards	Implemented revisions to Make and Design cards; New ideas for modularity and inclusive activities	Implemented inclusive design revisions (bigger size, simplified card design, open Design card); Added actuators and web resources

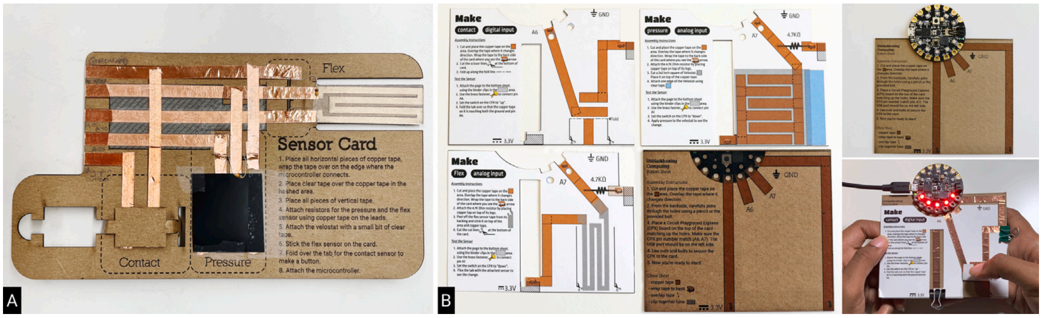

Fig. 5. Early prototypes developed through research-through-design.

building a circuit by closing the loop, we added a "base" card where each of the sensor cards could be placed and connect to the board.

4.2. Pilot testing with youth

To test our initial assumptions on the kit's usability and whether the kit supports middle school-level learners, we conducted a weeklong pilot study with six African-American youth (3 boys/3 girls, ages 11–14). We focus on this level of education because less than a third of middle school students in the Atlanta region where the primary researcher resides engaged in any computing activities (Guzdial, Ericson, McKlin, & Engelman, 2012). Students were recruited through a campus program focused on youth from underserved communities in STEM. Black Americans were also the predominant non-white race in the region where the primary researcher resides. Like most design research during early COVID-19, the workshop was conducted remotely. Prior to the start, parents picked up a kit from the university and signed study participation consent and assent forms. Two instructors facilitated a 5-day online synchronous workshop (each day 4 h) while two researchers documented and made observations. Participants were asked to prepare at home a computer with a camera and internet access, craft tools such as scissors, tape, coloring supplies and any extra craft materials they preferred. We provided our prototype kit that included at the time only sensing cards.

With the framing "What lights you up?" students were introduced to the kit. Participants learned how to make sensor cards from live demonstrations from the instructor and from the instructions on the card itself. Throughout the workshop, youth were invited to provide design critique of the kit materials. After card construction, participants worked on their own projects. Sources of data included session recordings, conversations, chat streams, student projects, a pre/post survey, and post-workshop one-on-one recorded interviews with youth conducted by research team members. At the end of each day, instructors and researchers debriefed and shared their observations into a document.

We identified recurring themes. First, the kit which layered craft-friendly conductive and non-conductive materials on paper templates was age-appropriate and invited expressive and personally-meaningful computing projects. Youth successfully created base cards, then layered on top a sensor card of choice they made along with hand drawn paper extensions and custom cardboard cutouts. Each project was unique, covering both serious topics, with messages about fighting world hunger, renewable energy, depression during COVID-19 and foster care advocacy, and more playful, speculative ideas, like zombies hunters and the origins of the color orange (Fig. 6). Youth remarked in interviews that the openness of cards enabled them to figure things out and design in a way that felt personal. Second, the DIY approach of using materials instead of premade parts helped learning through the transparent process, yet it also carried risks causing frustrations during the construction. Nearly all of the students commented positively about this aspect of making circuitry but also expressed challenges they encountered from dealing with the fragile materials, in particular connection issues. For instance, copper tape used to construct circuits and the small LED stickers required hands-on finger dexterity. In addition, this kit prototype included nuts and bolts to electrically connect the CPX with the base cards and it caused frustration as the loosened connection could not be easily seen and repaired.

4.3. 10-week codesign with focal teachers

To bring insights for the next kit iteration, we conducted 10-weeks of codesign with two teachers working in secondary level CS education. We sent out a recruitment flyer using different networks including school districts, county offices of education, professional societies, and community email lists to reach local teachers. Teachers filled out a prescreening online survey about their availability to participate, but also demographic information about the diversity of children they worked with in the past. From 22 teachers, we selected two who taught STEM activities during school, worked with primarily African-American or Hispanic students and led both CS classes as well as extracurricular clubs for girls.

Teachers were sent the prototype kit. Virtual meetings with the teachers began early in the year and continued for ten weeks with each session lasting an hour and half every two weeks, with the interim weeks spent on asynchronous testing and development. After introducing the kit materials and discussions on inclusive computing education, we worked through kit components one by one, using a cycle in which the teachers (1) tried out the cards, themselves, taking on the role of learner to understand what learning opportunities, emotions, and challenges arise when constructing the sensor cards, then working on personal projects; (2) critiqued the focal components, based on their experience, as well as how they anticipated their students would use the component; (3) designed the focal component and/or activity, drawing in their knowledge of student interests and prior computing experience; and (4) tried out their new cards with their students. One virtual session was also spent introducing early drafts of actuator cards and soliciting feedback to guide continued development. In addition to the facilitated workshop activities and discussions, teachers created portfolios and notes. Researchers also conducted interviews to understand teachers' experiences with the kit and in CS education more generally.

The result of this codesign stage led us to several key insights and revisions. Regarding the kit materials, teachers had difficulties creating reliable circuits with the copper tape. One solution to this that came from codesign activities was development of larger sensor cards with simpler circuit shapes, making construction easier. Codesigning with the teachers also brought adaptability into the foreground. Instead of presenting the teachers with full activity write-ups, we instead presented examples of past projects alongside blank design cards—cards that fit into the CPX and base card, but left the design prompt and circuit design open. This allowed teachers to create the themes and prompts to fit their student interests, and for circuit design to best fit

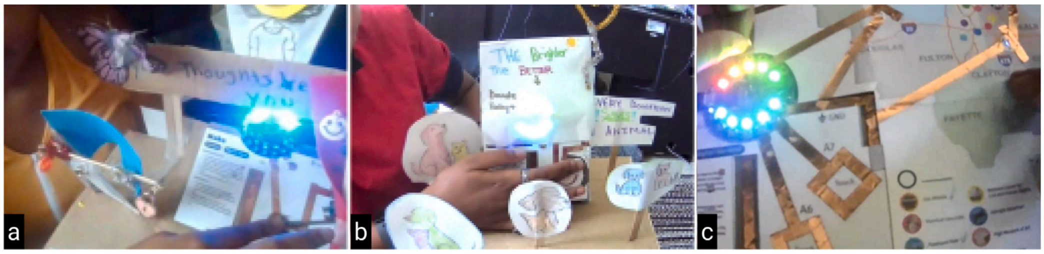

Fig. 6. Students' projects using the kit prototype from a pilot study: (a) depression during the pandemic, (b) fundraising for animal shelters, and (c) my favorite places in the metro area adapting the "Design card".

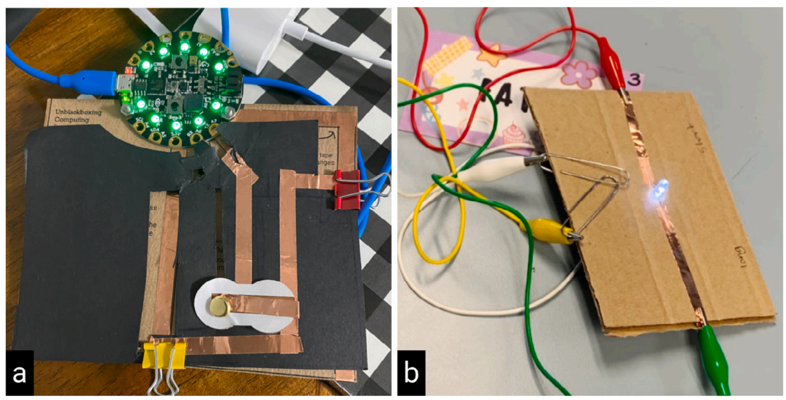

Fig. 7. Examples of teacher-led creations: (a) simplified potentiometer card, and (b) LED card exploration.

the design goal. For example, one teacher inspired by the potentiometer card created a new design for a linear input potentiometer, which made it easier for her middle school students to build, and served her goal of making a gauge that students could interact with to display how they were feeling (Fig. 7a). The open design cards also required teachers to step away from the initial scaffolds and rebuild circuits, presenting an opportunity to demonstrate and strengthen what they were learning about physical computing. The teachers discussed their preference for approachable materials and components for their students.

5. 5-Day codesign & workshop study with teachers

To understand affordances of technologies needed for teachers to enable them to support inclusive computing education and work with teachers to codesign pedagogical materials using the MCVT kit, we conducted a 5-day in-person and blended synchronous and asynchronous codesign workshop with seven teachers. The workshop had three primary goals: to engage teachers in codesign to develop inclusive CS activities; to equip teachers with equity-oriented pedagogies to support their learners; and to foster inquiry into how computing systems can relate to everyday computing and influence future CS interests and student trajectories. For this paper, we asked what opportunities and challenges arise, and how (if at all) teachers leverage the unique affordances of the kit with paper computing materials when designing materials and planning pedagogical activities for their students. We share the results as a case study.

5.1. Methods

5.1.1. Participants

Seven public school teachers (all female, with teaching experience ranging from 2 years to 25+ years) participated in the weeklong codesign study using the updated MCVT kit during the summer of 2022. Teachers included formal educators who either coordinated or led CS instruction in their local schools or STEM-related activities in afterschool programs that served K12 children. With exception to one elementary educator, a majority of teachers taught middle and high school students that served predominantly Hispanic and Native American children. To lower the barrier to participation, the workshop was free, all materials and meals were provided, and modest compensation ($180) was offered for attending the study.

5.1.2. Materials

Teachers were provided with the complete MCVT kit which included eight sensor & actuator cards: Make cards (Fig. 3), a CPX microcontroller, and conductive and non-conductive craft materials (Fig. 4). Supplemental web video tutorials were also provided to show routine assembly.

5.1.3. Study procedure

Over a weeklong workshop, the first and last days (M, F) were in-person while three days were remote (Tu, Wd, Th) for a total of 20 h of synchronous and asynchronous sessions. Like the youth workshop, the teacher workshop was framed by asking "What lights you up?" as a starting point for personally-meaningful and agentive making. Teachers were engaged in different codesign roles as a learner, designer, teacher, and critic; and asked, "How can new physical computing activities and materials be designed to support inclusive computing education for youth and educators?"

The workshop began with sharing about each person's background in teaching computing and computing related activities. Teachers also created a papercraft to share about their identities, values and the assets they brought to the workshop. Each day, teachers engaged in making with the MCVT kit while researchers introduced one computational concept, one computing practice, and an equity-oriented pedagogical practice. Teachers were also given time to build and tinker with one focal sensor input and one actuator output. Designers shared sample completed projects created by undergraduate intern students using MCVT cards, provided as examples of what might be possible as working systems (e.g., interactive piano, car with moving axle, sound speaker). Workshop sessions included small breakout groups for deep work, brainstorming project ideas, time for critique and discussion, and troubleshooting. The workshop culminated in teachers sharing the project they created with the MCVT kit in their role as learners, sharing out both accomplishments and challenges in using the kit for themselves as teachers, "plussing" peer projects, and voicing anticipated challenges for future uses in their classrooms.

5.1.4. Data & analysis

Sources of data included researcher reflection notes from sessions, pre- and post-workshop surveys, and interviews. The post survey contained eleven prompts intended which asked them to reflect on (1) the MCVT kit design; (2) advantages and/or disadvantages of using paper-based computing materials; (3) MCVT kit to support inclusive computing education; (4) the usefulness of the informational cards ("In the World" and "STEM connect"); and (5) usefulness of the "Design" cards. The surveys were then followed by an interview to probe more deeply their responses to the survey. All interviews were audio recorded and transcribed. For the analysis, an initial coding scheme was derived based on our research questions and study protocol. A transcript was randomly selected and coded by a single researcher, and throughout this process, the coding scheme was updated. Then two of the coauthor researchers coded five transcripts independently, met in person to resolve disagreements, and revised the scheme to accommodate emergent themes. Finally the first researcher coded the remaining one transcript from the post interview and the survey data. Applying thematic analysis (Miles & Huberman, 1994), we identified five themes responding to the questions and grouped opportunities, adaptations, and challenges for each theme.

5.2. Findings

The goals of this study is to understand (1) how a paper-based toolkit might support teachers in learning about computing concepts and practices, and (2) whether using the affordances of this toolkit (alongside design cards, other materials and equity learning practices) could be used to codesign inclusive activities for their students. Below, we present our findings based on five themes: (1) paper-based, modular system; (2) replicability and extendibility of paper cards; (3) crafting to broaden participation; (4) connecting real-world examples; and (5) "Design" cards for customized learning (see Appendix for teacher interview data).

5.2.1. Paper-based, modular system makes easier entrée and extendibility

Teachers readily engaged from the beginning in exploring combinations of sensors and actuators to make different interactions possible. Teachers valued how the kit allows diverse designs without additional purchases of special parts. Some of the teachers who had prior experiences of using different physical computing kits and parts (e.g., Arduino or Micro:bit board-based kits) found the mix of interchangeable and replaceable materials of the MCVT kit to be approachable.

Another designed affordance that teachers valued was that cards could be layered and extended. Exploring the cards as learners, teachers successfully created base cards, then layed on top a sensor card and/or an actuator card of choice they made along with expressive papercraft extensions to create their own projects. As learners, teachers found the design to be helpful and easy to use with, and also valued how the kit would enable easy entrée for beginners. They saw that the layers allowed the CPX board to be pre-loaded with code, while at the same time, leaving room to extend it further by changing the codes or connecting more cards. A teacher shared her plan on how she will facilitate different levels of her classes:

> *T2: I think it's a nice introductory coding because they're not having to create the code. It's already there. Just edit it. So they can go through and learn the code and learn the step-by-step... I'm going to also change it to have level two students work on the Python and the music and the speakers. And level one students just do the basic stuff.*

5.2.2. Cards made from paper enable replication and extension

During the workshop, we invited teachers to think both about how the cards might work for their students, and how they might extend or "hack" the cards by adding to or modifying them. Teachers embraced this as a part of their training and design stance from the beginning. The teachers found cards to be both approachable and accessible, while they also made many design adaptations.

When considering how a card-based kit might work with students, they regarded the paper-based aspect as a great benefit for beginners as it simplifies the process. Seen in both post-survey and interviews, a key affordance teachers described was low stakes experimentation. The low-cost and replicability of the paper-based cards makes the learning experience more forgiving if a student wants to start over, and lets individual students work on their own cards. In particular, because cards are developed as a half of a letter size (8.5" × 11") out of cardstock paper with minimal cutouts, teachers felt it would be easy to replicate using a copy machine or a printer in their schools. Everyone commented positively about the replicable aspects of paper:

> *T1: So, really, I liked the cards and I really appreciate the paper models because it's something that we can duplicate fairly simply minus the cutouts.*

> *T3: I thought it was really easy to use. It can be easily produced. That's what I thought was really cool. You actually made them producible so that I could just, you know, copy them... and if I want to make them thicker like with the card stock, I can actually do that. We have thicker card stock at our school.*

> *T4: As a teacher, I think that part [of using paper] is very, I say, useful and easily accessible because we can always reprint those.*

Teachers also took their role as codesigners seriously by providing frank input about ways to improve cards. The fragile materiality of the cards often demanded careful making when applying or removing copper tape to not destroy the paper. Constructing circuits using copper tape and small parts required more hands-on finger dexterity and time than screen-only CS experiences and could be especially challenging for younger students. Because some teachers have limited supplies of paper as well, they also proposed ways to make the cards more durable and reusable, for instance, by laminating or applying a page protector. Making the cards reusable was not just about saving materials. Teachers also wanted to save their time and energy for preparing classroom activities. Teachers suggest digitalization of the card design which also enables modifications and extensions.

Throughout the construction, teachers actively shared ways to improve the overall cards' usability. For instance, color-coding cards was one way to group each of the sensors and actuators: red background for potentiometer sensor card set including Make cards, In the World/STEM Connect cards, and yellow for the pressure sensor card, etc. Teachers also suggested adding more graphics in the instruction to help readability for students.

Fig. 8. Teachers' projects showing how they made adaptations and also inspired new designs.

5.2.3. Crafting and tinkering with paper computing to broaden participation

Teachers explored the kit as learners, first with Make cards, and then proceeded to their projects using the Design card activities which sparked creative thinking and made connections to their own interests, such as gardening and music (Fig. 8 c). Throughout the process, the crafting aspect of using the kit was discussed as a compelling means to engage diverse students by providing a chance to connect one's own ideas, have fun, and do something different. In particular, one teacher (T5) stated that the physical nature of the activity using the MCVT kit would attract learners with different talents that might not surface in other CS experiences. Thus, paper computing afforded new opportunities to, in the words of T5 "honor all the learners" in their approach to learning:

T5: ... they [girls] are grouped together... they like to tell stories with coding... a lot of the girls, they didn't do well with the code.org activities. It would take them longer to do the puzzles and stuff. But when I gave them that hands-on and they're better with their fine motor. I think there were girls that just blew me away at how fast and accurate they could do the paper circuits... Like I remember this one little girl, [name] ..she's a bilingual girl, and she's below grade level. And she was the first one done in the last year [during a paper circuit activity]. ... Everyone, look at what she's doing!! Yeah. I think that that's what, like, when we keep talking about those inclusive opportunities or how we honor all the different learners. And it's important, because, yeah, the kids that are best at code.org are not the best at Scratch. The kids that are good at Scratch and code.org, are not good at the circuitry. So it's, I think it's just so important that I can just give the students as many opportunities as they can to see where they're, where they're good at.

5.2.4. Connecting the real-world examples is critical for learners

Regarding how cards supported learning (Q1), both the STEM Connect and In the World cards provided teachers with the background they sought for themselves, as learners, and their students. During the workshop and in interviews, teachers mentioned drawing on these cards when they wanted to know more about why they were building and learning these things. In their classrooms, teachers envisioned applying the In the World cards as an introductory material prior to starting the hands-on exploration with the Make cards. They felt that making everyday connections and real world examples would be especially important for motivating students previously disengaged from CS learning. Teachers noted that connecting to real-world examples is particularly important for students from marginalized communities, who may see computer science as distant or irrelevant to their everyday concerns.

To extend the cards and make the connection to students' lives and their engagement in CS even stronger, teachers suggested better leveraging students' digital experiences with their phones and video games. Bridging the online materials such as YouTube videos for application examples through QR codes printed on the cards are regarded as convenient resources to facilitate class activities. Teachers mentioned because nowadays everyone brings their phones to the school, teachers can ask students to pull the website with videos using their phones. Teachers also mentioned making the cards "more catchy" by integrating age-appropriate graphics, like video games.

5.2.5. Open 'design' cards provide room for agency through customization and reflection

In developing the Design cards as an empty page without any prompts, our initial intention was to position teachers as designers while also learn from how they customize the cards for their students. While we intended the open design cards to be used as codesign scaffolds, we found teachers wanted to use them to also foster agency and creativity in their students. Teachers favored providing an empty page to invite students' own ideas for their projects or to encourage students to review what they learned from scratch.

Some of the teachers also described using the Design cards for their projects to prep the class. They envisioned applying the cards to build projects that could help them build rapport with or connect to their students better before getting into the learning activities, for instance, by "integrating various cultures" (T6) or checking in students' daily status. However, not all teachers valued the openness of the cards. One teacher (T1) stated that the empty space was rather daunting for her, "causing anxiety because it was just a blank piece of paper".

6. Discussion & conclusion

The goal of this research is to explore how equity and inclusive computing could be enabled by a new paper-based computing toolkit that is usable by teachers to design materials for a future facilitation of learning with their students. This MCVT card collection consists of a set of functional "Make" cards that can be used to create sensors and actuators; context information cards ("In the World" to show real-world application examples; "STEM Connect" cards to explain how things work), and open "Design" cards. The kit is intended to both introduce computing system concepts and facilitate codesigned pedagogical materials with teachers for use in their classrooms. While we did not focus on the analyses of learning computing concepts in this paper, our iterative design and development process was informed by prototyping and preliminary testing with youth and teachers who created new ways to interact with the toolkit. From these iterations, we grew more aware of the balance and tensions involved in pushing forward new developments while trying more participatory approaches to design with users. From a weeklong codesign study with teachers using the kit, we learned how teachers perceived the opportunities and challenges of using the kit in designing inclusive pedagogical materials.

Transparent forms of technologies, concepts and connections for tinkerability: Reflecting on our consideration of making computing investigable, we saw the advantage of starting from material exploration and extending across scientific concepts and everyday connections. Prior cards are designed for transparency of function and invitations to user making with technical guidance to support remote learners (Root et al., 2019), whereas MCVT cards serve additional purposes to enable learning through making using the cards as a substrate and situating cards as a codesign facilitation tool. Building and testing sensors and actuators helped expose concepts of conductivity, circuitry and code that underlie computing systems. Teachers recognized that making both computational components and everyday uses of CS technologies visible can help learners see connections at multiple levels.

Across conversations and observations with teachers about equity and accessibility of high quality computing experiences for their students, one cross-cutting theme was the importance of tools that would be accessible in their schools and communities. In the MCVT kit, they embraced that materials were readily available from many sources, and the flexibility to adapt both computational components and the craft materials to make use of supplies they already had on hand.

The glassboxing approach intended to support visible forms, transparent functions and tinkerability also had drawbacks, particularly in terms of being able to access multiple layers of electrical connections and the fragility of materials. While paper circuits support a friendly, low barrier to entry to learn computational thinking (Lee & Recker, 2018), constructing circuits using copper tape and small parts required more hands-on finger dexterity and time than usual hardware-based computational practices. As this challenge raised a conflict with the value of making the kit accessible for easy entrée and exploration, the teachers' perceptions of opportunities and challenges helped us find a fine balance where a glassboxing approach could be usefully applied towards making stronger tangible and visible connections to computing ideas and the overall experience is age-appropriate for middle school students.

Developing a paper-based computing toolkit for design and codesign towards equity: The MCVT kit could be considered an authoring tool: a set of glassboxed materials and technologies for creating lessons where teachers learn while making their own paper computing activities for themselves as well as for their students. Thus, the card toolkit serves a dual purpose: as a paper computing medium for learning through exploratory making and as a tool for codesigning pedagogical materials as teachers envision, create, adapt, and redesign materials to meet the varied needs of their students.

We saw that the MCTV kit prompted teachers to be learners and reflect on their own expertise. Teachers were engaged in exploring the making of sensors and actuators as learners first. Paper computing allowed for learning by tinkering, exploration and going deeper. Teachers also discussed how the projects felt personally meaningful to them and remarked on how they will use them as facilitating their classes.

The first design cycle of the MCVT kit coincided with the COVID-19 pandemic forcing intentionality in gathering user voices, encouraging codesign, and in this case teachers, serving multiple roles as codesigners, learners, critics, and teachers. Bringing users into these multiple roles is important when designing for inclusive CS education because teachers have an irreplaceable role in design and implementation; they have unique knowledge of their students and communities that design of materials must take in account, and they must be able to adapt materials and facilitate interactions with students. However, bringing them into these multiple roles has unique challenges, because CS teachers in [country name], and particularly those in schools serving communities of color, have widely varied background and so may not have prior training in the computational concepts underlying materials being designed, and may not be comfortable in the role of 'designer'. Findings from our study raise new questions about how much should a kit and activities be ready to use "out of the box" or balance flexibility for teacher customization should be determined to enable users to have agentive roles as designers.

When reflecting on our process towards creating better inclusive designs for computing education, we acknowledge that the design session with youth and codesign workshops with teachers could be considered as spaces for open conversation and co-production to enable participants to bring their cultural knowledge and pedagogical practices in conversation with the kit's technology design. In this sense, we were able to create a site for equity to progress where values, new knowledge, and ideas are shared and worked upon together. This is akin to "Code on Country" where culturally responsive design practices create spaces conducive to indigenous ways of knowing and ethical sharing of traditional knowledge situated in technology design and cultural practices . To this end, we aimed to use the MCVT kit both as a toolkit for learning by design and as a facilitation tool to support teachers in codesigning, adapting and redesigning materials. While we leveraged prior work in paper-based computing and card-based methods, to our best knowledge, this project is the first attempt to develop a toolkit that could be used for both (1) creative computational practice for learning and (2) codesign facilitation with teachers to become effective adaptors of materials, attuned to abilities and interests of their students. Our study contributes evidence that this potential can help other designers and educators engage in work that brings inclusive CS education into the material, as well as interaction level. Recognizing that these codesign practices could better support design processes, rather than deliver a finished toolkit to users, we aim to empower and equip teachers with a kit of materials – the MCVT Cards and toolkit – so they can be localized and adapted and/or re-designed into lessons for introducing computing concepts and computational practices.

We note that our main codesign study with teachers was based on a weeklong experience, which was limited time to learn both the content and technical aspects, especially for teachers new to physical computing. Also, teachers' codesign work and discussions were based on their knowledge of practice with students instead of an actual classroom implementation. We plan to design our next codesign study with a small group of teachers to be long-term and include the preparation and classroom implementation to inform inclusive computing education.

Selection and participation of children

The pilot study was submitted and approved by [Anon University]'s Institutional Review Board before youth were recruited via online advertisement through the university-based K-12 STEM outreach program, local community organizations and by word of mouth. An online form collected information about gender, race, and computing backgrounds participants between the ages of 11 & 14. While no participants were excluded from the study, a priority was given to novice learners in computing and from traditionally underrepresented groups in STEM. Six African-American participants were enrolled in the study reflecting the largest racial minority in the State and region of Atlanta. The workshop was free and gift cards were offered as compensation for participation in follow up interviews.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: HyunJoo Oh reports financial support was provided by National Science Foundation. HyunJoo Oh serves in the editorial board of the International Journal of Child-Computer Interaction for which we are submitting.

Data availability

The authors do not have permission to share data.

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Appendix

Tables A.1–A.5 show examples for each finding covered in 5.2.1–5.2.5. T1-7 stands for teacher 1–7 from post-interviews and S1-7 does the same for post-surveys.

Table A.1
Example teacher statements that reflect modular system.

	Theme	Example statements
A	Opportunity: **Novel design without add-ons**	*T3: You actually need more than one micro:bit to get certain things to work. We need to kinda purchase all the series of extra carriers. And those are kind of pricey. And then with this program [MCVT kit], you just need the cards which you can reproduce yourself. And then the tape, and actually the tape, it's not like that expensive. And then, you have that little parts for the lights and all of that kind of stuff.*
B	Opportunity: **Accumulative approach/Layering**	*T7: It [the design] made it a very more straightforward and streamlined process… I like the idea of having the base part and then being able to put the cards on top of it to complete this circuit. So being able to have that base part and then utilizing the activity cards on top of it... I think, for me, it was really helpful… It's the way that my brain works.* *T2: I think it's a nice introductory coding because they're not having to create the code. It's already there. Just edit it. So they can go through and learn the code and learn the step-by-step. This is what it looks like without having to totally created on their own. So that's what I liked about it. …And, I think, I'm going to also change it to have level two students work on the Python and the music and the speakers. And level one students just do the basic stuff.*

Table A.2
Example teacher statements that reflect 'paper-based' cards.

	Theme	Example statements
C	Opportunity: **Easy to replicate**	*S3: Paper-based can easier be replaced if a student wants to start over. Each student can have their own paper-based materials- they don't have to share. Hands on for everyone!* *S5: I am interested in perhaps having a copy of each of the paper templates for each build, without the instructions, so that students can use their own cultural designs, ideas, artistry to make projects their own.* *T1: So, really, I liked the cards and I really appreciate the paper models because it's something that we can duplicate fairly simply minus the cutouts.* *T2: I want more cards and so I didn't use my blank ones (design cards) that were in my kit so I could copy them.* *T3: I thought it was really easy to use. It can be easily produced. That's what I thought was really cool. You actually made them producible so that I could just, you know, copy them… and if I want to make them thicker like with the card stock, I can actually do that. We have thicker card stock at our school.* *T4: As a teacher, I think that part [of using paper] is very, I say, useful and easily accessible because we can always reprint those.*
D	Adaptation: **Distribute digitally**	*T4: I'd go digits… copy or.. I'm trying to introduce to them (students) the digital version… (as sharing her screen to show her digital file) So I made this in Canva. This is a design platform and it's free for educators. Also introduce this like when you do this again.. my design template is here. I don't need to worry about, about, like, how do I do it.* *T5: I mean, it's just because it's so fast and everything set up and try. It's just what I want… Even if I have your model of cards, I can make a simple, simpler card. Have those tools that I can recreate for this.*
E	Challenge: **Fragile**	*T3: They seem to be a little too flimsy like when I was trying to make certain things like the speaker and the motor, I wasn't able to actually get it to fully work because of that connections… I went back to do my project, started working with lights and noticed some of my connections weren't connecting correctly… So, the only thing that I'm going to try and do different is make it the cardstock which is the thicker.* *T5: I did have a little more limited supplies of it, or something to reuse… or, you know, and then, then I was thinking like I could have cards that are partially done. So the kids will be more successful. Like if I do the first two steps and then they're just still there. I was just thinking about how they can be more successful and more independent at the beginning and they get on with the troubleshooting and they're having fun.*
F	Adaptation: **Add colors or graphics**	*T4: There has to be, like something, like a graphic image… Kids don't pay attention to just text. [pointing at a resistor in the text instruction on the card] What does it actually look like? It should show here [pointing at where the resistor needs to be attached in the circuitry].* *T4: ... a video game controller or something like that. Yeah, they [students] are trying to just find real-world examples that are associated with kind of what they're, what I don't want to say, what like the hype is, but things that they're interested in so that they can retain that while they're learning. Because I think if a child, I mean, as an adult, like it might be something cool and it makes me kind of want to gravitate towards that… That's gonna entice me to put a little bit more thought and concept into my project.*

Table A.3
Example teacher statements that reflect crafting and tinkering.

	Theme	Example statements
G	Opportunity: **Creative and expressive work**	*T7: I loved the crafting integration into the workshop… it allows all children to go back into their creative thought process and troubleshooting, but to develop something on their own.* *T2: I need to add more of this type of work to my classroom, to engage, I think it's more engaging, when they can touch and feel and make their cards do something, even as that simple of a card.… I know inclusivity is not just females, but that's a big one. I have Native American and Hispanic students, white students... And so I'm trying to turn on all lights for all students... and so, for me, any kind of fun is better. I find students are more engaged when they are doing, rather than just seeing.*
H	Opportunity: **Unique mode of engagement**	*T5: … they [girls] are grouped together, and they like to tell stories with coding… It would take them longer to do the puzzles and stuff. But when I gave them that hands-on and they're better with their fine motor. I think there were girls that just blew me away at how fast and accurate they could do the paper circuits… I remember this one little girl, [name of child]. she's a bilingual girl, and she's below grade level. And she was the first one done in the last year [during a paper circuit activity]. And I was like, Everyone, look at what she's doing!! Yeah. I think that that's what, like, when we keep talking about those inclusive opportunities or how we honor all the different learners. And it's important, because, yeah, the kids that are best at code.org are not the best at Scratch. The kids that are good at Scratch and code.org, are not good at the circuitry. So it's just so important that I can just give the students as many opportunities as they can to see where they're, where they're good at.* *T4: This is something different from what they usually do... Something that is not the usual is what I tried to integrate because I don't want them to be comparing themselves... I'm in a rural community. And it's that idea is either the parents work in a farm or they're from the Native American place. They would not be here on Friday because they're going to ditch work. They're going to clean the ditch and stuff like those. Oh, this is something different from what they normally do. And it doesn't look like a classroom experiment. It looks like a fun thing to do.*

Table A.4
Example teacher statements that reflect *STEM Connect* and *In the World* cards.

	Theme	Example statements
I	Opportunity: **Connect to everyday worlds and/or prior experience**	*T2: Kids are more engaged when they know why. When they know why, specially high schoolers, because… (they will be like) this is just busy work. Actually, it is not busy work. This is, like, this is like learning notes before you learn a scale, before you put together music, right? This is like learning the ABCs. Before you sing the song ABC. And you have to have before you start spelling words and before you start making sentences. And so if they can see that, and you can, you can explain why they're learning something or why you're having them to do certain things, then they're like, okay.* *T5: Whatever is at the beginning of the lesson, maybe show a short video clip of something related to the card and having to have a discussion or a game or something at the beginning where we are thinking about those concepts in the real-world. Like, what do they know? What, how does it, what are the inputs are?... So they [students] are activating their prior knowledge. They're thinking about the stuff before too… So, really, you know, computer science is everything. So, how can we be, how can I really start having them think like we are integrated, like they're not supposed to be separate areas of life.* *T3: Because they have a hard time doing that, especially with the students that I teach because they're low income… [explaining how lots of students today have expensive devices] Most of the parents that are low-income aren't like that. They hop from apartment to apartment, they live with their family… the kids don't have that connection to the (technology) world.*
J	Opportunity: **Adaptation: Connect to digital resources**	*S4: I loved that everything was laid out in the design with instructions on the cards - but then also having videos that showed the step by step process.* *S5: Maybe watch a video clip of real world application (that the students have prior knowledge of) as a bell ringer/hook and have a group discussion/game suing these Cards.* *T5: for my kids, they're not gonna, you know, just asking them to read it, or something like isn't gonna, that's, you know, I have... But, if it's there and I'm like, and then engage it with a little video. And then, I could, then at the end of class or at the end of the unit or something, we could revisit that*

Table A.5
Example teacher statements that reflect 'open' Design cards.

	Theme	Example statements
K	Opportunity: **Keep cards blank**	*T3: I think they should look like that. You can, then, you can design your own... for project purposes, those kind of the design card, kind of the, the empty card would give space to fill in your ideas.* *T7: I really, I really love the idea of having design cards because I think.. So, the way that I envisioned, like if I was teaching middle schoolers, I don't think a week would be long enough to teach the whole kit with them... So in my head, I kind of saw it as a multiple week type thing. But what I tried doing with each, each card that we went through, we have that the template card, but then also creating like a card from scratch. You know, like my own design card for each one. Because I think being able to teach the concept and then allowing kids to go back and design the way that they see it. I mean, I thought was a really cool way of doing it.*
L	Opportunity: **Build rapport or be responsive to students**	*T5: I'm trying to integrate the social emotional learning... And then have the kids use it as they come into the classroom. Like standing there and picking...how are they feeling? ... if you're in a blue zone, that means you're tired, sick, sad... in a green zone, you know, you're there, you're present. Yellow zone as someone pissed you off...and you're mad. And red is, like, I am going to, like, you better do something... So, they [students] come in, they would touch the capacitive or light up the proper color. And then, like, I wanted it to play the music like, for blue, it'll be like sad music... We have, and it's all nonverbal, So this is the bilingual kids, this special ed kids, the kids with autism. They all, this is a common language that we use, so they can come in and press which color. And then in my head, probably most kids are gonna be green or some are sad because they're just at school. But if someone touches yellow or red, then I know I can check in with them. Like I don't have to say anything right now. Kind of keep an eye on him. (See Fig. 8).*
M	Challenge: Need more scaffolding for design projects	*T1: So, maybe, on the design card, even if it doesn't have anything else, making clear copper lines to where it would connect on the CPX... and then when they're creating, they only use the pins they need, but they have a straight line to the pin to start that project because that was the hardest part was lining things back up so that you weren't overlapping another pin or your copper tape wasn't going under and touching another pin when it should have been only touching one of the pins. They [students] will prefer having more technical guidelines for that.*

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