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Tools and materials as non-neutral actors in STEAM education

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ABSTRACT

Background: This study builds on posthumanist and new materialist orientations to examine the role of material properties and the gendered identity texts of educational tools as active agents in STEM learning.
Methods: Over 200 youth, ages 5–15, were randomly assigned to 90-minute introductions to one of five commercial circuitry toolkits. Youth took a pre- and post-assessment; we analyzed results using quantitative tests of significance. We used an established sorting task to gather youth perspectives of the tools as identity texts through design markers of gendered identities within the toolkits. We examined the relationship between learning outcomes and the gendered design components of the toolkits.
Findings: Toolkits that privilege feminine or artistic elements significantly impacted learning more than traditional toolkits used in schools, which showed little to no significant learning gains. We relate this to the inextricability of materiality and the gendered identities of these tools and materials.
Contribution: This study shows how arts-based or feminine-coded tools can be more effective for teaching and learning, serving as a counter to common resistance to adopting such tools and materials for STEM learning. We outline design implications for toolkits and educational experiences to disrupt stagnant social, cultural, and historical norms in STEM education.

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Introduction

Given the persistent issues of equity in technology-rich fields (e.g., Margolis & Fisher, 2003; Prey & Weaver, 2013), this article argues that our choice of

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tools and materials significantly impacts both what is possible to be learned as well as the active role that the tools' intersectional identities (e.g., Wohlwend, 2009) play in the learning process. A focus on the relationship between tools and technologies and the structuring of disciplinary subject matter is nothing new to those in the learning sciences; it is long understood that this relationship is central to our understanding of learning (Vygotsky, 1978). However, recent efforts to correct the persistently lopsided gender participation in technology-rich fields have approached this problem by addressing the way in which we teach with these tools (i.e., pedagogy), what is created with them (i.e., robots vs sculptural artifacts), and what audiences can be formed around their practice (i.e., girls-only robotics clubs). Less attention is paid, by contrast, to the role of tools and materials as the initial drivers of these outcomes, both in terms of the intersectional identities of the tools (e.g., Pahl & Rowsell, 2010; Wohlwend, 2009) as well as what is learned with them. The marginal gains in gender representation due to these prior efforts (e.g., Corbett & Hill, 2015) may start to explain a different root cause of this persistent problem.

Initial evidence to support this inquiry comes from the emergence of new tools and materials that have spurred many shifts in the ways we interact with technology by infusing the arts and traditionally feminine-coded practices into traditional STEM approaches (Peppler, 2014). Prominent examples include e-textiles (i.e., blending electronics with textile design) (e.g., Buechley & Eisenberg, 2008; Peppler & Glosson, 2013), Squishy Circuits (i.e., blending electronics with playdough) (e.g., Johnson & Thomas, 2010; Peppler et al., 2018), Tunepad (Gorson et al., 2017), and Ziro cardboard robotics kits (i.e., blending robotics, crafting, and puppetry play) (Seehra et al., 2015), which leverage arts practices into STEM principles. Research on these types of tools and materials suggests that the infusion of STEAM approaches may offer alternative opportunities for broadening participation in technology-rich endeavors and deepening learning across domains (Buechley et al., 2013; Mejias et al., 2021). Furthermore, STEAM toolkits designed by women, such as the LilyPad Arduino, have been shown to radically disrupt gendered participation in fields historically dominated by men (e.g., Buechley & Mako-Hill, 2010). This study seeks to illuminate the design elements that have a significant impact on learning by examining an area of STEM that has been shown to be consistently difficult to learn: circuitry, or building and arranging electronic components connected by conductive pathways such that an electric current can flow (Fredette & Lochhead, 1980; R. Osborne, 1981, 1983; J. Osborne et al., 1991). While several commercial toolkits are available for learning about circuitry, little research—with some exceptions (Blikstein, 2013; Davis & Blikstein, 2020)—exists on their efficacy or the design features that best support learning. To fill this gap, we seek to examine how electronic kits that integrate STEAM materials can be assessed along dimensions that prove productive for learning, particularly by focusing on the links between learning, material history, and the intersectional identities of STEM tools and materials. This work aims to contribute to a history of scholarship in the Learning Sciences around issues of equitable STE(A)M learning environments and the future design of STEM tools and activities for learning.

Background

Sociocultural constructionism

In this work, we draw on sociocultural understandings of constructionism in a way that seeks to understand both the sociocultural nature of learning and the power of designing and creating artifacts that can be shared and iterated upon. Much of this notion comes from Papert, who in his elaboration of Piaget's constructivist ideas, posited that learners can construct their own knowledge through their experiences with physical tools and artifacts (1980). In this, he also worked to showcase the importance of design in learning, describing design as a process of externalizing and iterating upon one's understanding (ibid.). Others have also discussed design as a learning process, particularly in cases where learners must refine their understanding of a concept to discover why a design has not worked as expected and make repairs accordingly (e.g., Y. B. Kafai, 2006; Kolodner et al., 2003; Papert, 1980). Papert argued that through design, tools and materials can become "objects-to-think-with" (1980), building a relationship between emergent internal and external models and creating possibilities for powerful learning.

A crucial part of constructionist learning environments is a space for learners to create artifacts that have meaning both to themselves and their peers or community (Resnick, 2002). This social view of constructionism is in line with theories that build on learning as socially constructed (e.g., Case, 1996), and focuses on both the individual's artifact design as well as community contribution and influence on the artifact (Peppler & Kafai, 2007). Thus, it is necessary to explore both the designs learners create as well as the common practices embedded in the surrounding communities, including how they are expressed through the selection of tools, materials, and activities in the learning environment.

Socio-material orientations to constructionism

While constructionists have long identified that tools and materials can vary in their efficacy for supporting the learning process, constructionists have done little to recognize that the tools and materials come with intersectional identities that inter- and intra-act with learners' own interests and identities. This is now being explored in new posthumanist and materialist orientations (e.g., Barad, 2003; Kuby et al., 2018) that we argue impacts learning in significant ways (Peppler et al., 2020).

Posthumanist and new materialist perspectives suggest that we must think beyond materials simply as mediators of activity and understand materials as actors when they come together with humans (e.g., Kuby, 2017; Taylor & Hughes, 2016). Not only do materials have histories that carry forward into the present, as is often discussed in literacy studies (e.g., Pahl & Rowsell, 2010), but materials also have agency of their own that come together with humans to form "intra-actions" (Barad, 2003) that are greater than the individual parts. These moments of coming together create possibilities for learning, and posthuman perspectives can help us better understand how the social, cultural, and historical messages put forth by the materials in these intra-actions impact the human actors, and vice versa (Barad, 2003).

This posthumanist turn converges with many lines of research within the constructionist tradition on the examination of material agency and its impact on learning outcomes that dates to diSessa's understanding of epistemic tools on the learning of physics (DiSessa, 1993), as well as Papert's (1980) notion of "body syntonicity" where the body's interaction with the material world plays a crucial role in the learning process. Additionally, more recent work has examined how the arts can shape the materiality of learning in STEM culture by producing new forms of engagement. Jeanne Bamberger's research on music as an introduction to mathematics (Bamberger & diSessa, 2003) reveals that creating music and musical representations uniquely highlights the usefulness of mathematics to learners and prompts them to enact new complex mathematical ideas. Horn (2018) discussed tangible interactions and cueing forms, arguing that educational designers need to think in particular ways about the types of interactions made possible through their designs, and that cueing forms can be invoked through physical artifacts, but also through other factors such as symbols, or situational cues. Additional studies take new material orientations toward STEM learning within the realm of maker education or crafting. DesPortes (DesPortes et al., 2016) examines the intersections between dance and computing, showing that dance supports learners in accessing more abstract thought, which in turn allows the computational objects they create together to take on more types of interpretations and meanings. These findings are echoed in the studies of Eisenberg (Eisenberg et al., 2015), who advocated for infusing STEM constructionist education with crafting cultures and including viewing stop motion animation and multiliteracies to reframe and expand making and computing (Wilkerson-Jerde et al., 2015). More generally within the constructionist literature, the work of Wilensky and colleagues on "restructurations" present a shift in perspective associated with everyday knowledge to make, for example, science concepts less "mathy" (Wilensky & Papert, 2010). This line of research purposefully inserts the arts into explorations of material agency in STEM learning.

For the purposes of disrupting persistent inequities in education, new materialist and posthuman perspectives help us scrutinize the often-overlooked ways that materials invite or discourage participation in educational settings (e.g., de Freitas & Sinclair, 2013; Ivinson & Renold, 2013; Kuntz & Presnall, 2012; Thiel & Jones, 2017). By questioning the mediational roles of materials, we surface a more constructive, and ultimately more equitable, flattening of hierarchies across people and matter (Peppler et al., 2020). In sum, a posthuman turn in constructionist research helps us to rethink and reemphasize the material basis of STEM culture, helping us to understand the role of materials in shaping learning outcomes, and the ways in which we can design technologies (and their interactions) to have more desirable learning outcomes. Furthermore, this shift helps to illuminate that much of the way we theorize learning is shaped by materials, as well; that materials influence the ways we "think and theorize about education" (Sørensen, 2009).

STEM toolkits as gendered identity texts, youth as consumers

To further theorize how objects can come to have tangible identities in the learning experience, we draw from posthumanist research in literacy and media studies that argue how commercially produced toolkits, toys, and youth-targeted cultural artifacts can carry imprints of the social customs that brought them into existence (Brougère, 2006; Gee, 1996; Holland et al., 1998; Rowsell & Pahl, 2007). Such text markers can be reflected in the designers' choices in modes and materials (Kress, 1997, 2003) as informed by the identity performances available within prevalent discourses within a culture (Butler, 1993) and upheld by families, schools, or communities (Bourdieu & Nice, 1977). Wohlwend (2009), expanding on Rowsell and Pahl's (2007) concept of artifacts as having *sedimented identities*, proposed that youth-targeted products represent predetermined identities projected for consumers and solidified through manufacturers' design methods and distribution processes. These identity markers in youth-targeted products and media interact in a dynamic interplay with the artifacts youth create with the tools and materials available to them. In the current study, we argue that the perceived identities (as communicated through design elements) of our tools and materials have gendered qualities, with ramifications that can support or hinder learning beyond their ability to signal invitations to participate.

Powerful tools and successfully disrupting stagnant norms in STEM

The case of e-textiles—fabrics and textiles that integrate electronic components, such as conductive threads or circuits, enabling them to perform electronic functions—presents a clear example of deeply entrenched gender historical practices (Beaudry, 2006) that can be disrupted through material changes that engage new types of practices not historically related to the field. In this instance, the infusion of sewing (and the socio-historical patterns of use surrounding those tools) into circuitry and coding productively disrupts what it means to participate in a high-tech field. This is done because the tools send signals (i.e., scripts) that are read by the learners to perform in specific ways. The implications of these disruptions are tangible: while online communities for sharing computing projects are typically overwhelmingly dominated by men, e-textiles communities showcase work that is 65% by women designers (Buechley & Mako-Hill, 2010). In this case, the addition of arts and crafting practices disrupt the historically stagnant aspects of coding and circuitry that have predominantly belonged to men in the latter half of the century, fundamentally shifting what it means to engage in computing.

This study additionally builds on research that recognizes the influence of culture and society in shaping individual gender identities (Connell, 1987; Connell & Messerschmidt, 2005; Paechter, 2003), and align with the idea that gender is not an inherent characteristic determined by biological sex, but rather a social construction that is learned and performed (Butler, 1990; Halberstam, 1998; Kessler & McKenna, 1978; Martin, 2006). While we do not view these markers as static or permanent, and fully acknowledge that gender as a binary is an inaccurate and incomplete social construction (e.g., Francis & Paechter, 2015), we also acknowledge that misconceptions and enactions of gender are entrenched and persistent, and still believed to hold truth by many adults and children. Our previous research has shown how traditional gendered expectations in STEM can tangibly affect youth's learning in several ways (e.g., Buchholz et al., 2014). While it is outside the scope of this study, future work should seek to disquiet these stagnant norms, particularly within K-8 learning communities, as well as create new ways to evoke this conversation among young people.

To aid in this effort, we resonate with Francis and Paechter's (2015) trifold approach to studying gender in education, one that triangulates the perception of researchers that learners being observed are girls, boys, women, men, etc. (i.e., a "spectator view"); how learners see their own gender expression (i.e., the "respondent's view"); and the semiotic analysis of how gender production is informed within the local context (i.e., "local discursive and material collage"). The present study invited youth to identify the gendered messages of a particular toolkit, which aligns youth as researchers in the Francis and Paechter's "spectator view." In this role, youth were asked to further unpack the discursive and material collage that informs their own perceptions of various toolkits as containing feminine or masculine qualities. While this is a starting point for further exploration of intersectional identity texts based on existing methodologies, this serves as the start of a conversation to see if there are consistent patterns that are perceived by the youth, as opposed to simply the researchers' analyses of the tools themselves. As such, we discuss boys and girls, and masculinities and femininities, in this work as an entry point to considering how the tools, materials, and practices we introduce in educational settings may enable or constrain equitable learning. By understanding how masculinities and femininities are constructed in our everyday tools and materials, we as designers can start to deconstruct these norms in productive ways.

Toolkits and circuitry learning

For this paper, we focus on how circuitry learning is transformed by a variety of ways to introduce the arts and crafts as made available by the prevalence of new kits on the commercial market. This focus is additionally salient because prior research shows us that misconceptions about circuits are common and persistent (e.g., Evans, 1978; Thiberghien & Delacote, 1976), and that within circuitry learning, students need in-depth understanding about the anatomy of each component in a circuit. Further, students also need to understand the fundamental concepts of how these components interact and connect. Prior work (e.g., R. Osborne, 1981, 1983; J. Osborne et al., 1991; Peppler & Glosson, 2013; Shepardson & Moje, 1994) shows that current flow, battery polarity, and circuit connections are three fundamental concepts that may be easily misunderstood but could potentially be explored with more clarity through new tools and materials.

Here, we use a constructionist and sociomaterial approach to design to consider closely what tools and materials we bring into a learning environment, what histories and practices those tools might bring with them, and how these may intersect in new or old ways. In this way, we can also explore the relationship between learning outcomes supported by circuitry toolkits and the identities of the tools themselves. Additionally important to learning is not just learning within one setting, but across settings and tools. In this work, we look at the constraints and affordances of training in circuitry with one toolkit for learning about circuits in another toolkit which we view as a type of transfer that signals potential for future successful engagement.

Methods

Research questions

The following research questions guided the current study:

(1) Which circuitry toolkits most effectively support the learning of circuitry and why? What are the design features (i.e., which materials, affordances and design choices) of the kits that seem to best support learning?
(2) Further, do youth recognize consistent design elements as gendered "identity texts" within circuitry learning, and, if so, how?

Overview of study design

We conducted this study in two parts: Aligning with research question 1, we used an experimental design to systematically compare five STEAM-based kits and the impacts on the use of these toolkits on circuitry learning outcomes. We targeted three key circuitry concepts (i.e., current flow, battery polarity, and circuit connections) across and between five groups of youth (total $N = 214$) that participated in a controlled circuitry learning workshop using one of the five STEAM-based circuitry kits (see Table 1). Before and after each workshop, youth took an assessment to gauge circuitry learning. We coded and analyzed the results using quantitative group comparison techniques. Each group's workshop followed a controlled schedule of activities (see Appendix A for workshop design).

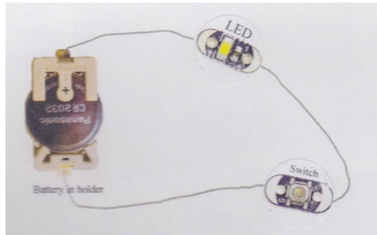
In a second phase, aligning with research question 2, we met with a subset of 49 youth individually and asked them to sort the five circuitry kits according to how they thought the kits would be perceived in terms of gender identity. In the process, we asked youth semi-structured interview questions regarding their reasons for their sorting choices. We analyzed these data using a mix of quantitative and qualitative techniques. Using quantitative methods allowed us to systematically compare the kits for their perceived differences in gender and further probe youth to identify specific identity markers within each of the kits. What was initially an effort to prepare recommendations for educators evolved as we uncovered patterns that, in light of prior literature, helped us retheorize challenges in building more equitable learning environments for more learners.

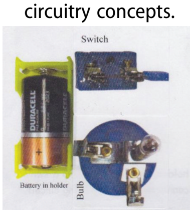
Setting and participants

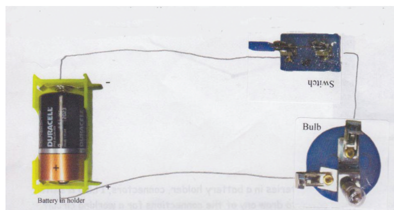
The circuitry workshops in the first phase of the study took place at a charter school in a midwestern college town centered on project-based learning. Currently, the school has 276 students with 78% of students identifying as

Table 1. Illustrative cases: pre and post-test results for selected children in the e-textiles group.

<table>
<tr><th>Kit Group</th><th>Pre-test/Score & Interpretation</th><th>Post-test/Score & Interpretation</th></tr>
<tr><td>e-Textiles</td><td>

Cf0, C0, P1
Le Shan - In this item, the negative side of the LED is attached to the negative side of the battery, but there is no evidence of engagement with the other circuitry concepts.</td><td>

Cf1, C0, P1
Le Shan - In this item, there seems to be a stronger understanding of all the concepts, however, every connection point is not addressed.</td></tr>
<tr><td>Traditional Kit</td><td>

Cf1, C0
Amy - This item received a score for current flow because the components were arranged in a general loop shape.
[There is no score for polarity because the bulb in the kit is unipolar]</td><td>

Cf1, C0
Amy - This item demonstrates stronger understanding of the loop structure, especially at the points of connection of per pencil lines. However, there is a gap in one connection point, leading toward a 0 score for connections.</td></tr>
</table>

Scores for Current Flow (Cf), Connections (C) and Polarity (P) are indicated.

white, and 27% of students eligible for free or reduced lunches (a metric often used as a proxy to describe economic need in the United States). We had a total of 214 participants ranging from 5 to 15 years old, split across five kit groups: e-textiles ($n = 44$), Traditional Kit ($n = 39$), littleBits ($n = 41$), Snap Circuits ($n = 43$), and Squishy Circuits ($n = 47$). The second phase of the study took place at a local after-school club that predominantly serviced the school. Youth at this club participated in pilot circuitry workshops, and thus had experience with the full range of circuitry kits at the time of the study. Participants ($N = 49$) ranged in age from 5 to 15 years old ($M = 9.14$), with nearly equal numbers of boys ($n = 25$) and girls ($n = 24$). We analyzed data from the workshops in the school, as this site provided the largest number of students in each kit group, creating a better sample size for between-group comparisons. The sorting task and interviews took place at the after-school club as these activities were extra-curricular and not possible to be done during class time. Note that except for the sorting task and interview results, we did not find differences between ages or genders, and so do not report on the breakout of these groups. When case examples are provided throughout, the names used are pseudonyms.

Tools and materials

We used the following five kits in our study: LilyPad Sewable Starter Kit for Arduino (e-textiles), a 9 V battery + lightbulb kit traditionally used in science classrooms, littleBits Base Inventor Kit, (e.g., Bdeir, 2009) Snap Circuits Classic SC-300, and Squishy Circuits Standard Kit. These tools represent a range of commercial STEAM-based toolkits, ranging from those we hypothesized would be interpreted by youth as being "completely STEM" (i.e., lacking any overt arts or craft connections) to kits that foreground their expressive/aesthetic associations. Additionally, we selected a spectrum of kits that variously present a range of design aesthetics in terms of color (e.g., primary vs pastels or rainbow), qualities of touch (e.g., hard plastics or soft fabrics), and mechanisms (e.g., building or snapping vs sculpting, weaving, or sewing). We determined that such an intentional range of materials would help us better identify and delineate the qualities that may impact learning and the perceived gender identity of the kit.

For the workshop, we controlled for the elements of each kit to be made available to constrain the learning opportunities of each kit to simple circuitry. In each case, the kit selections included the kit's (1) power source (i.e., the battery), (2) load (i.e., the LED or light), (3) connectors (e.g., alligator clips, snaps, wires, playdough, or needle & thread), and (4) on/off switch (typically a slide switch). In addition, a shared set of crafting supplies was supplied to all groups, including cardboard, fabric, recyclable materials, markers, paint, beads, etc. For the sorting task, parallel sets of materials from these kits were chosen, including (1) light or LED, (2) a switch, (3) a battery pack, (4) a buzzer or motor if available, and (5) connective pieces such as wires or conductive thread. Kit materials were placed in clear plastic baggies for the interview and sorting activity. See Appendix B for the five kits and the pieces and materials from each kit that we included in the workshop and sorting task.

Procedures and data sources

Below we describe and justify our design choices for the circuitry learning and participation phases of the data collection.

Circuitry learning

Data on circuitry learning outcomes come from the results of the pre- and post-assessments given to the youth. Prior efforts have focused on assessing circuitry learning by creating novel circuit diagrams as well as performing error detection analysis of circuit illustrations (Fredette & Lochhead, 1980; R. Osborne, 1983). The current work adapted this design and created an assessment that asked youth to create circuit diagrams with stickers from all five of the included toolkits. While these stickers do not exactly mirror the three-dimensional materiality of the actual components, our prior work (e.g., Peppler & Glosson, 2013) has shown that sticker assessments provide a unique way for youth to attend to the various components and parts of circuits in more authentic ways than traditional assessments, and that the activity creates a more inviting and low-stakes environment than traditional circuit assessments.

The assessment contained five items, prompting children to create a working circuit for each of the five kits. We developed pre- and posttests that had pictures of the battery holder (and other power components) for each kit on paper. Stickers of other components for each kit were made available to the children: the LED/bulb and switch. The pre- and posttests were the same and included directions for children to create a working circuit with the components, using a pencil if necessary (e-textiles and the Traditional Kit required the drawing of connections to form a working circuit). Table 1 shows examples of the test for two sample kits, with both the pre- and posttests, from selected students.

Investigating circuitry toolkits as identity texts

Data collection for the second phase of the study followed established procedures for sorting items based on gendered perceptions set forth by Campenni (1999), Pike and Jennings (2005), Sullivan (2016), and Raag and Rackliff (1998). These procedures mirror the ways in which society shapes how youth see certain toys and tools (and any overarching design elements shared across products) as being marketed to their gender identity. Based on the relative simplicity of the sorting task and lack of prior research on youth perceptions of the gendered identities of objects, we found this method to be a fruitful starting point for a conversation that wouldn't challenge youth's existing notions of normative perceptions of gender in school-based settings.

While initially designed as a task to uncover "who would play with" a particular toy, we leverage this task to uncover how youth would identify the gender of the kit, under the hypothesis that there would be correlation in learning outcomes concerning the gendered perceptions of the kit. In the original study, Campenni (1999) gave parents examples of toys and then asked them to rank each toy on a 1–9 Likert-type scale, with 1 being "only appropriate for girls" and 9 being "only appropriate for boys." Pike and Jennings (2005) showed pictures of toys to children and asked them to sort them as "for boys," "for girls," or "for both boys and girls." Similarly, in Sullivan (2016), researchers showed toys to children and asked them to sort each. Following each sort, researchers asked follow-up questions to elicit children's reasons for sorting that way, as well as their own experiences with the toy. In the Raag and Rackliff (1998) study, children were shown toys and asked a series of interview questions about whether they had seen the item and whether they liked or would play with the item. The task in the current study, which blended these approaches of sorting and follow-up questions, provided a systematic, transparent, and accessible way to assess youth's perceptions of these materials and their rationales.

The data collection took place in two parts, one immediately following the other. First was the gender-sorting task wherein youth were asked to place the kits into clear bins according to their perceptions of the kit's gendered identity. Immediately following, youth were asked to discuss the reasoning behind their choices. The gender-sorting task began with five clear plastic bins, identified with a labeled sticky note. The bin on the far left was labeled "boy," the bin on the far right was labeled "girl," and the bin in the middle was labeled "both boy and girl." The two in between had no words written on them. Participants were asked whether the materials in question seemed to be more boyish, girlish, both equally, neither, or somewhere in between. The participants placed the baggie in the bin of their choice, and the next baggie was then handed to them. Participants could place baggies in any bin, regardless of whether the bin had been selected previously. During the task, the researcher used a note-taking form to record each participant's choices and note any additional information.

Once the sorting was completed, interviews averaged 15 minutes and were audio-recorded. The interviewer asked participants about their familiarity with the kits. Participants were asked to share their rationale for their sorting choices, particularly those kits placed in the extreme left or right bins or in the center bin. This allowed us to focus on the genderedness of these perceptions and begin to examine the underlying reasons. The partial interview protocol is as follows:

- What about these kits [for kits placed on extreme ends] makes them boyish or girlish?
- What is it about these [for kits placed in the center] in the middle? Why did you place these here?

Analytical techniques

Circuitry learning

The pre- and posttests were scored based on the three crucial circuitry concepts: current, polarity and connections. Each of these items was independent of the other and seen as either absent or present (corresponding to a score of 0 or 1). The rubric for assessing the items was created and revised based on earlier work on designing new assessments to assess circuitry understanding using circuit diagrams as described above (Peppler & Glosson, 2013).

Twenty percent of the assessments were first scored, and the inter-rater reliability between the two scorers was 0.75. The scorers then met to achieve 100% agreement on these assessments, and the rubric was revised for clarity. The two scorers then scored the remaining assessments. To perform our statistical analysis, we calculated the Total-Pre and Total-Post scores, which is a sum of the current, polarity, and connections scores for the five kits in the pre- and posttests, respectively. Since the number of items for the Total-Pre and Total-Post was different for the Traditional Kit (12 items) compared to the other kits (11 items), the percentage (%) score was used in the calculations for accurate comparison. We then calculated Total scores for the concepts of current flow (5 points), connections (5 points), and polarity (4 points) for additional comparisons as well as scores using Totals from outside each group's own kit. For example, for youth in the e-textiles group, we excluded scores on e-textiles items, and so on. This gave us a measure of potential for future engagement, or how youth were prepared to make circuits using unfamiliar materials. In all cases, we ran statistical tests using percentages (ex: an individual receiving 9 of 12 possible points = 75%) and means of these percentages calculated for each group. In all cases, to compare pre- to posttest scores within groups, we used paired samples t-tests. To compare the differences between groups, we used one-way ANOVAs and Tukey post hoc analysis.

Toolkit gendered identification

For the sorting task, we calculated the data using a scale with "boy" as 1, "both boy and girl" as 3, and "girl" as 5 (these numbers were not used during the interviews or revealed to the participants to avoid the possibility that numbers could reflect some sort of value judgment). Means and standard deviations were calculated for each kit to determine an overall rank order, and for boys' and girls' perceptions separately. Using this scale allowed us to order the kits' rankings from most "boy"-seeming to most "girl"-seeming.

To analyze the interviews that accompanied the sorting task, the authors first transcribed and divided each one into segments corresponding to the five kits discussed, then focused on moments of explanation for why a kit was sorted in a particular way. To code the data, we utilized an iterative, ground-up analytic technique to allow themes and relationships to emerge organically from the data (Glaser & Strauss, 1967). Interview segments pertaining to each kit were coded separately, and then code counts were combined in the final analysis. Not every child explained every choice. As seen above, the interview prompted facilitators to ask for explanations for kits placed on the extreme ends and in the middle. Then, comments were grouped based on a few expected categories; additional categories were added as patterns emerged. We counted comments by individuals, so that if an individual repeated an idea in relation to a single kit, that code would not be counted twice. Ultimately, 110 comments were coded—this number reflects individuals' comments across each of the five kits combined. Two coders coded 20% of the data and reached 90% agreement ($K = .62$). They discussed the divergent cases and came to a consensus. The codebook was refined based on this data, and the first coder coded the rest of the sample. The final categories discussed here are as follows: (1) practice + material property; (2) personal experience; (3) aesthetic descriptors; (4) fairness/equality; and (5) gut feeling/I don't know. For example, the comment "It's colorful" was coded as an aesthetic descriptor. After these codes were established, the authors calculated the percentage of respondents who mentioned each one to illuminate the more common reasons behind any perceived genderedness.

Learning and kit identification

Finally, to explore whether there was a relationship between the results of the circuitry assessments and the results of the sorting task, we performed a Pearson product-moment correlation. We correlated the mean percentage gain scores per kit group with the mean sorting score per kit. Given the small sample size ($n = 5$ kit groups), we only looked at the general strength of the correlation and did not test the correlation for significance.

Findings

STEAM-based toolkits, which invite the integration of atypical STEM materials (i.e., rooted more in children's play, the arts, and crafting culture), shaped the learning process by infusing divergent aesthetic possibilities into the realizing of circuitry concepts. During the craft-construction portion of the intervention, youth developed design goals and explored the potential intersections of their circuit materials with the provided crafting supplies. Projects ranged from light-up socks to neat rows of playdough (Figure 1). In

Figure 1. Youth STEAM projects with kits (from L to R) e-textiles, traditional kit, littleBits, snap circuits, and squishy circuits.

their designs, youth had to find ways to interweave aesthetic goals with the engineered aspects of their circuit, which surfaced unforeseen constraints. With each unplanned discovery, youth would modify or add elements to their crafts, engaging the epistemic practices of both art (e.g., looking closely, augmenting meaning through aesthetics, and evaluating the success of the project (Y. Kafai & Peppler, 2011)) and science (e.g., designing solutions, testing and optimizing solutions, and communicating results (National Research Council, 2012)). In this way, the broader design possibilities of the kits that invite integration with outside materials (e.g., combining play-dough, cardboard, or clothing) allows users to engage circuitry concepts in a wide range of contexts.

Which circuitry toolkits most effectively support the learning of circuitry and why?

Here, we present the results of the impacts of the STEAM-based toolkits on circuitry learning outcomes as measured by the pre- and posttest circuit diagram assessments. In this work, we searched for overall gains in youths' ability to create working circuit diagrams (both within their kit and across novel kit applications in which they had not been trained) that revealed what they knew about the three targeted core concepts: current flow, connections, and polarity. In addition, we were also interested in whether training within the targeted kit prepared learners to engage in new learning opportunities (i.e., potential for future engagement tasks that youth were not directly trained to answer). This included putting questions on the pre-/post-assessment where youth had to draw functioning circuits across all five kits in which four of those kits they would have had no prior experience.

Overall, the e-textiles group presented the highest percentage gain from pre- to post- at 18.7% (e.g., a little over 2.6 points gained from pre- to posttest). By contrast, the Traditional Kit group presented the lowest gain scores from pre- to post- at 9.0% (e.g., less than a 1.3-point gain). In between these two extremes were the littleBits (14.6%, or just over 2 points) Snap Circuits (11.5%, or slightly over 1.6 points) and Squishy Circuits (9.1%, or slightly less than 1.3

Table 2. Pre- and posttest results of circuit diagram assessment using paired sample t-tests.

% Scores	Overall			Current Flow			Connections			Polarity		
Group	*M*	*N*	SD	*M*	*N*	SD	*M*	*N*	SD	*M*	*N*	SD
E-textiles												
Pre-test	27.3%	44	0.17%	29.6%	44	0.27%	7.7%	44	0.13%	48.9%	44	0.29%
Post-test	45.9%	44	0.24%	57.7%	44	0.36%	15.0%	44	0.22%	69.9%	44	0.28%
Traditional												
Pre-test	33.7%	39	0.19%	38.0%	39	0.33%	9.7%	39	0.16%	58.3%	39	0.29%
Post-test	42.7%	39	0.19%	63.1%	39	0.35%	11.3%	39	0.16%	56.4%	39	0.29%
littleBits												
Pre-test	30.7%	41	0.18%	36.1%	41	0.33%	7.8%	41	0.13%	52.4%	41	0.23%
Post-test	45.3%	41	0.23%	53.2%	41	0.32%	24.4%	41	0.22%	61.6%	41	0.29%
Snap Circuits												
Pre-test	27.7%	43	0.16%	29.%	43	0.30%	6.5%	43	0.12%	51.7%	43	0.25%
Post-test	39.2%	43	0.18%	45.6%	43	0.28%	16.7%	43	0.19%	59.3%	43	0.24%
Squishy Circuits												
Pre-test	31.6%	47	0.20%	42.6%	47	0.37%	7.7%	47	0.12%	47.9%	47	0.27%
Post-test	40.7%	47	0.21%	51.5%	47	0.35%	13.6%	47	0.20%	61.2%	47	0.23%

points) groups. These percentage scores for the overall test, broken down by concept (current flow, connections, polarity), can be found in Table 2.

We next sought to understand whether all groups significantly improved in their ability to draw a working circuit diagram from the start to the end of the study. That each group had an opportunity to learn the afforded content was important to establish upfront, knowing that these core concepts are historically difficult for learners to grasp. Looking at the percentage score on the pre- and posttests, paired samples t-tests showed that the participants' ability to diagram a working circuit was significantly higher in the post-assessment than in the pre-assessment for all groups (see Table 2). Paired sample t-tests showed the e-textiles group gained significantly (t[43] = 6.180, $p = .000$), as did the Traditional Kit (t[38] = 3.126, $p = .003$), littleBits (t[40] = 5.810, $p = .000$), Snap Circuits (t[42] = 5.386, $p = .000$) and the Squishy Circuits (t[46] = 3.836, $p = .000$) groups. This establishes that the controlled approach to teaching circuits was successful across kits. However, as learning scientists, we are primarily interested in the material affordances of each kit and the conditions that promote learning. This led to examining subscales and the extent to which the kits variously prepare youth for future learning tasks. To further test for significant differences between learning outcomes of each kit group, we performed a one-way ANOVA to uncover the relative magnitude of the gains per kit. Here, there was a statistically significant difference between kit groups ($F(4,209) = 2.538$, $p = .041$). A Tukey post-hoc test revealed that gain scores were significantly different between e-textiles ($M = .1867$; SD = .2003) and Traditional kit groups ($M = .0897$, SD = .1793); $p = .075$; as well as between e-textiles ($M = .1867$; SD = .2003) and Squishy Circuits kit groups ($M = .0912$, SD = .1630); $p = .060$ (both significant at $p < .10$), implicating that the youth trained in the e-textiles kit demonstrated an advantage in learning over the Traditional and Squishy Circuits groups. This suggests that some kits have material advantages for teaching circuitry learning over other kits, which should factor into our decision-making process as we select tools and materials for classroom learning.

Current flow, connections, and polarity

To investigate the relative strengths and weaknesses of each of the toolkits, we looked at the average gains and tested for significance using a paired samples t-test between pre- to posttests for the three targeted concepts: connections, current flow, and polarity. Across the groups, the e-textiles, littleBits, and Squishy Circuits groups demonstrated significant gains ($p < .05$) across all three targeted concepts (see Table 2). By contrast, the Traditional Kit group only demonstrated significant gains ($p < .05$) in their understanding of current flow. The Snap Circuits group also only demonstrated significant gains ($p < .05$) in their understanding of current flow and connections. This suggests that all kits don't equally teach the three core concepts important to circuitry learning.

To further test for significant differences between the learning outcomes of each kit group, we used a one-way ANOVA for each measure to examine whether youth increased their understanding of current flow ($F(4,209) = 2.497$, $p = .021$), connections ($F(4,209) = 4.313$, $p = .002$), and polarity ($F(4,209) = 3.062$, $p = .018$)] in addition to their abilities to draw accurate circuit diagrams. There was a statistically significant difference between kit groups for each measure, revealing that kits had differential affordances for teaching the three targeted concepts (see Table 2 as well as Figure 2). In the following sections, we look closely at each of these core concepts, the relative average gains for each of the kit groups, as well as the material affordances of each kit and their alignment (or misalignment) with each of the targeted concepts.

What are the design features of the kits that seem to best support learning?

Design feature 1: Malleable loops to communicate Current flow

E-Textiles and the Traditional Kits both demonstrated the highest average gains for the learning of *current flow* (28.2% [or 1.4 points gained from pre- to post-] and 25.1% [1.3 points] respectively). This may be in part because both kits promote the creation of a malleable loop (one with conductive thread and one with alligator clips and insulated wires) that visually accentuates how electricity flows in a loop-based configuration through a circuit. The littleBits (17.1% [.86 points]), Snap Circuits (15.8% [.79 points]), and Squishy Circuits (8.9% [.45 points]), all had lower average gains but still significantly supported the learning

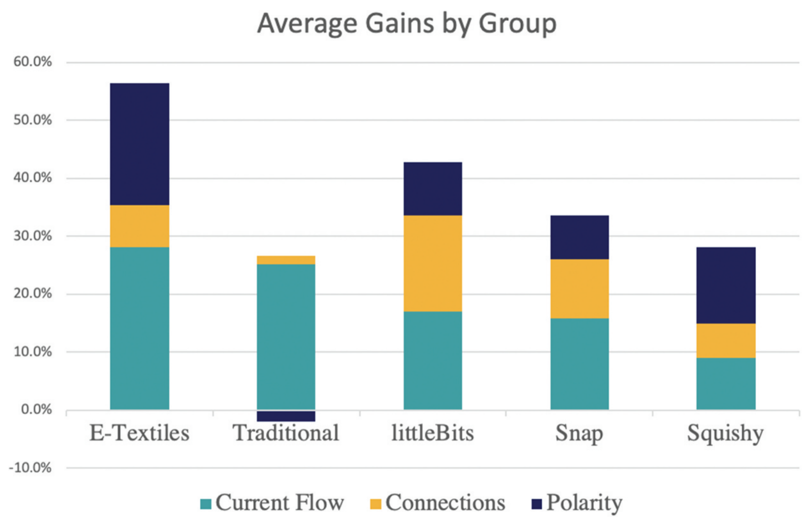


Figure 2. Average gains in current flow, connections and polarity by group, creating a unique learning profile for each kit.

of current flow from pre- to posttest. This demonstrates that there is a variety of ways that current flow can be successfully materialized, though it appears that sewing circuits—which has an additional affordance of an alignment between the conceptual idea of a current traveling a path and the embodied action of a needle and thread traversing that same path—may convey this with clarity.

Design feature 2: Magnetic fields to teach the importance of connections

By contrast, only four of the five kits significantly improved youths' learning of the role that *connections* play in a circuit. The two kits groups that demonstrated the highest average gains for the learning of connections were LittleBits and Snap Circuits (16.6% [or .83 points gained from pre- to post-] and 10.2% [.51 points] respective average gains). The littleBits group significantly outperformed the Traditional Kit (1.5% [.08 points]) as well as the Squishy Circuits kit groups (6.0% [.3 points]). These findings suggest that magnets are highly productive for conveying the importance of solid connections between component parts in a circuit. The relative power of the magnetic field, with components repelling each other when their poles are incorrectly aligned, as well as the strength of the magnets satisfyingly snapping together when a proper connection is made, indicates the importance of that action and emphasizes to the learner when connections are correctly performed. Similarly, snaps seem to convey an alignment with the idea of making a solid connection at various junctures in the circuit. Meanwhile, the act of careful sewing of conductive thread around an LED or switch, like securely stitching a button onto a garment (e-textiles = 7.1% average gains [.36 points]), or squishing playdough around a component to make a tight connection, both seem to promote significant learning but to a lesser degree. The Traditional Kit's use of alligator clips to secure connections, by contrast, didn't lead to significant gains in youths' learning of connections ($p > .05$). This finding suggests that designers should rethink how these parts fasten together to promote learning.

Design feature 3: Unidirectional vs bidirectional loads to convey polarity

A starker disparity arises in terms of each kit's ability to promote *polarity* learning, with only three out of the five groups demonstrating significant gains ($p < .05$): e-textiles (21% average gains [.84 points gained from pre- to post-]), Squishy Circuits (13.3% [.53 points]), and littleBits (9.2% [.37 points]). Of note, the Traditional Kit far underperformed the other kits in terms of average gains between pre- and posttests (−1.9% [.08-point loss from pre- to post-]), leading to a decline in posttest scores in this area. This finding suggests that kits that included LEDs led to greater understanding of polarity over time given that an LED is unidirectional while a traditional lightbulb contains a bidirectional load in which the polarity of the light is of no consequence to the performance of the circuit. In other words, it may be important that the kit actively promotes ways to get the solution wrong, having the learner engage in a period of debugging. As in the case of Snap Circuits (7.6% average gains [.3 points] that were not significant from pre- to posttest), it may be that this repair can happen too quickly, or the part indicates the solution (i.e., with an arrow painted on it), depriving the learner of a period of inquiry in this concept.

Design conclusions: Potential for future engagement

Choosing a kit for classroom learning in many ways is about preparing learners for future learning experiences, primarily because most of these toolkits do not closely resemble the real-life contexts in which these techniques would be applied (Bransford & Schwartz, 1999). This is a tall order, given what the prior literature demonstrates about the persistent difficulty for teaching and learning these targeted concepts (e.g., Evans, 1978; Thiberghien & Delacote, 1976).

To create a nuanced picture of performance, we present the scores for each group *outside* their own kit, testing the ability for youth to apply the conceptual understanding learned within a singular kit to other novel contexts. This meant removing the scores on the e-textiles items for the e-textiles group scores, the Traditional Kit items from the Traditional Kit group scores, and so on. We performed statistical analyses using these "outside kit" scores and present these below (Table 3).

To determine whether there was a significant difference between the pre- and posttest scores (using the "outside kit" data), we ran a paired

Table 3. Comparisons of pre- and posttest results for only those "outside kit" circuit diagram items using paired samples t-tests.

		Outside Kit		
Group	Time	*M*	*N*	SD
E-Textiles	Pre-test	29.6%	44	0.18%
	Post-test	46.3%	44	0.23%
Traditional	Pre-test	35.9%	39	0.19%
	Post-test	40.0%	39	0.20%
littleBits	Pre-test	30.8%	41	0.21%
	Post-test	39.3%	41	0.24%
Snap Circuits	Pre-test	28.1%	43	0.18%
	Post-test	33.4%	43	0.17%
Squishy Circuits	Pre-test	28.1%	47	0.20%
	Post-test	35.0%	47	0.24%

samples t-test for each of the kit groups. There were significant gains in youths' ability to broadly apply conceptual understanding gained within a single kit to new and novel problems for four of the five groups: e-textiles, $t(43) = 5.751$, $p = .000$, littleBits, $t(40) = 3.415$, $p = .001$; Snap Circuits, and $t(42) = 2.197$, $p = .034$; Squishy Circuits, $t(46) = 3.072$, $p = .004$. Importantly, the only group that failed to demonstrate significant gains between the pre- and posttest was the one trained using the Traditional circuit kit, $t(38) = 1.314$ ($p = .197$), suggesting that training with the Traditional Kit has limited application within other contexts. Given that this posttest was immediately issued, future studies should also look at how long students retain their conceptual knowledge using these kits, as our posttests were issued without any time lapse between instruction and test taking.

To look for significant differences in percentage gain scores between the different kits, we ran a one-way ANOVA with the kit groups as the independent variable, and the percentage gain scores as the dependent variable. There was a statistically significant difference between kit groups ($F(4,209) = 3.647$, $p = .007$). A Tukey post-hoc test revealed that gain scores were significantly different between the following groups: e-textiles (M=.1675, SD = .1931) and the Traditional Kit (M = .0405, SD = .1930), $p = .008$; and e-textiles and Snap Circuits (M = .0529, SD = .1579), $p = .018$. The gain score difference between the e-textile and the Squishy Circuits group (M = 0.0697; SD = 0.1556), $p = .056$, was approaching significance. These results suggest that, while there are several kits that may support learning in different ways, the e-textiles kit best prepares learners for future circuitry learning, followed closely by the littleBits kit and Squishy Circuits.

Do youth recognize consistent design elements as gendered "identity texts" within circuitry learning, and, if so, how?

If the findings above show that material property can be linked to conceptual learning, youths' gendered identification of kits as being "boy" or "girl" further warrants interrogation into the inextricability of material property from gendered practice, particularly since questions frequently surface from administrators about fears of whether a "girlie" kit can benefit boys' learning. In this section, we further unpack the gendered identities of the toolkits investigated, and the extent to which youth perceive or read these materials and their sedimented histories of use. While this sorting task was adapted from prior literature, one could imagine a provocative array of ways to elicit information from youth on how they read the kits, externalizing assumptions that factor into their learning.

A total of 49 youth in the afterschool club participated in this activity, with approximately an equal distribution of girls and boys. On average, findings indicated that the Traditional Kit was placed closest to the "boy" category, while e-textiles were seen as being closest to the "girl" category (see Table 4). Snap Circuits was positioned on average closer to the boy side of the spectrum, while littleBits was positioned on average closer to the girl side of the spectrum. Squishy Circuits was the kit most positioned in the both/neither position (i.e., at 3).

The self-identified gender of the respondent played a role in terms of the rank ordering of the kits; the youth that self-identified as boys ranked Snap Circuits closest to the "boy" category, followed by the Traditional Kit, while girls ranked the Traditional Kit as more toward the "boy" category, followed by littleBits. Both genders claimed Squishy Circuits as being of their gender, with girls giving the kit a mean of 3.25, SD = 0.74 and boys giving it a mean of 2.48, SD = 1.01. Furthermore, girls were more likely to use the extremes of the Likert scale in their sorting, with the range of average scores per kit spanning a larger range for girls (1.46)

Table 4. Means and standard deviations of the genderedness rankings.

Ranking	Overall Mean (*sd*)		Boys Mean (*sd*)		Girls Mean (*sd*)	
1	Traditional Kit	2.40 (SD = 1.03)	Snap Circuits	2.29 (SD = 0.86)	Traditional Kit	2.33 (SD = 1.09)
2	Snap Circuits	2.54 (SD = 0.94)	Traditional Kit	2.46 (SD = 0.98)	littleBits	2.67 (SD = 1.01)
3	littleBits	2.69 (SD = 0.98)	Squishy Circuits	2.48 (SD = 1.01)	Snap Circuits	2.79 (SD = 0.98)
4	Squishy Circuits	2.86 (SD = 0.96)	littleBits	2.72 (SD = 0.98)	Squishy Circuits	3.25 (SD = 0.74)
5	E-textiles	3.51 (SD = 1.14)	E-textiles	3.24 (SD = 1.17)	E-textiles	3.79 (SD = 1.06)

than boys (.95), suggesting that the gendered nature of each kit was more intense for girls.

Table 4 displays the rank order and means for all youth. Further, Figure 3 provides a visual representation of the average rank position for each kit. This ordering provides insight into the second research question by not only showing that there are differences between how the kits are perceived, but also by beginning to demonstrate that boys and girls had different reactions to the kits.

As students sorted the kits into the designated boxes, they were also asked to explain why they made their decisions. This was easier for some youth than others; answers like "I don't know" and "I just feel that way" were not uncommon. In some ways, this demonstrates how deeply ingrained socially gendered archetypes may be for many youths, existing at the intuitive level rather than easily articulated. However, of those that responded, five main themes emerged. Table 5 provides a summary table of the definitions and examples of each of these themes, which are further explored in the sections below.

Somewhat surprisingly, while adults may assume that color or other aesthetic descriptors would be among the most common reasons cited by the youth, participants were most likely to talk about what practices were involved when playing with the kits, such as sewing and snapping, and various material properties of the kit elements, such as flexible or hard, as a rationale for sorting the kits into gendered categories (48.2% of individual respondents). This aligns with how we observed youth dividing labor in mixed gender dyads, as well; while girls felt pressured to lead on sewing materials, boys felt pressured to lead on technical aspects of an activity (i.e., using a multimeter to debug a circuit), despite levels of prior experience (Buchholz et al., 2014). The following is one example of how this came up in gendered ways; as one girl, Faith,[1] was talking about e-textiles, she cited how sewing was a skill girls were more likely to have.

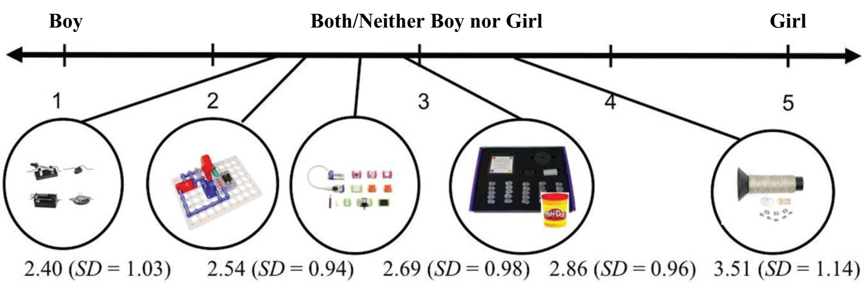


Figure 3. Kits in rank order for average overall mean.

[1]All names a pseudonyms.

Table 5. Themes by percentage of individual respondent occurrences.

Code	Description	Example	% Individual Respondents/Total Comments Coded
Practice + Material Property	What one can do with a kit, or how it can act	"More girls sew."	48.2%/110
Personal Experiences	A child's own experiences with a kit or related activities and practices	"I saw mostly boys playing with it."	23.6%/110
Aesthetic Descriptors	What a kit looks like	"It's colorful."	10%/110
Fairness/Equality	Expression that anyone could or should be able to use a kit	"I personally think that boys and girls can do the same thing."	8.2%/110
Gut Feeling/I don't know	Explicit lack of explanation	"I don't know"	10%/110

Interviewer: The one thing that you put on the extreme end is the e-textiles, and you put it in the "Girl" [bin]. So, what makes it [this way]?

Faith (identified as girl): Because girls, because *most* girls, know how to sew but not many boys do.

In a similar vein, Squishy Circuits, where the playdough lends itself to artistic endeavors, was occasionally also seen as a girl-ish kit.

Ace (identified as boy): I kind of think girls would like to make pretty shapes out of that clay.

By contrast, the snapping and connecting practices present in Snap Circuits and littleBits were also often described as activities that boys were more likely to participate in or enjoy, as described by one of the girls:

Interviewer: The two kits that you put on the boys' side . . . what makes it [that way]?

Leonna (identified as girl): Because they [boys] like stuff that's cool and snap. The Snap ones, I think they look cool for the boys.

Another child mentioned that the Snap Circuits reminded her of LEGOs, which have often been categorized as toys appealing mostly to boys (Campenni, 1999; Sullivan, 2016). Across the interviews there surfaced an explicit connection for the youth in terms of who they felt the kit was designed *for* and how they perceived the identity of the kit. This suggests that when considering biases, stereotypes, and preferences associated with toolkits, designers and researchers should focus on the practices engaged by the kit rather than solely on the aesthetics.

Other rationales

The other themes mentioned here are personal experience, aesthetic descriptors, fairness/equality, and gut feeling/I don't know. While these align more with how adults may have expected genderedness to come across, these expectations contrast with the students' most common reasonings that the practices were driving the gendered perceptions. See Table 5 for brief examples of these codes.

Personal experiences were frequently cited and came up in 23.6% of individual respondents' coded responses. These responses indicated that about one out of four youth used their own experiences and the experiences of those around them to interpret the gendered identity of a particular circuitry kit. In these instances, regardless of the features of the kit, decisions were made based on the kinds of people they could concretely visualize using the materials. This suggests that who does something with a kit holds as much weight, or perhaps more, than what the kit looks like, and that the history of ownership of kits and previous purchasing of kits plays a part in the social construction of the gender of these toolkits.

Aesthetic descriptors were less frequently cited than expected at the onset of the study but came up in 10% of individual respondents' coded responses. In a previous large study of gender stereotypes around youth's toys, makeup kits, Barbies, jewelry boxes, bracelets, and doll clothes were listed as the toys most stereotypically associated with girls (Campenni, 1999; Sullivan, 2016). Those items are traditionally labeled as for girls through bright colors such as pink and purple, and pictures of girls on the boxes. However, this work suggests that factors other than this appearance-based marketing toward girls play a role in how youth perceive the gender of a kit. While this aspect was mentioned occasionally, it was much less important than the other themes discussed here. For example, the issue of "boy colors" or "girl colors" was only mentioned once among the 49 participants.

Fairness/equality was cited in 8.2% of individual respondents' coded responses. It is important to note that some youth did not agree with sorting the kits in this manner, often citing reasons of fairness or individual differences. In the gender sorting task, eight youths sorted all five kits as for "both/neither boy or girl," and many others put the majority of kits in this category. This suggests that while youth may believe that boys or girls might feel drawn to use a certain item, many seem to think that it should be up to individuals rather than stereotypes or social pressure to decide their own activities. This suggests that the intra-actional space between the identity of the kit and the learner is a complex one, warranting further examination.

Uncovering the relationship between learning and gendered identity texts

Finally, we look at the results around circuitry learning in relationship with the results around gendered perceptions of the kits. We performed a Pearson product-moment correlation to determine the relationship between average circuitry learning gains from pre- to posttest and the results of the sorting task. There was a positive linear relationship between learning gains and a kit being seen as "girl" (see Figure 4). This suggests that the kits perceived as more feminine or artsy also supported youth toward more effective circuitry learning. This is important for at least two reasons: First, toys, tools, and materials that are perceived as feminine are often dismissed as less academically or intellectually rigorous. Second, a potential concern of educators is frequently that time spent on artistic endeavors, such as making, sewing and designing, takes away from time needed to learn STEM content. The relationships here suggest that neither of these concerns are founded. We are seeing here that a kit with greater design and artistic flexibility, such as e-textiles, is both seen as more feminine and produces larger learning gains. In this sense, youth intuition about the gender of the kits also seem to predict the kit with stronger affordances for science learning. This serves as a reminder to reconsider tools and practices that may be undervalued due to their historic associations with "women's work" as potentially productive and rigorous for all learners.

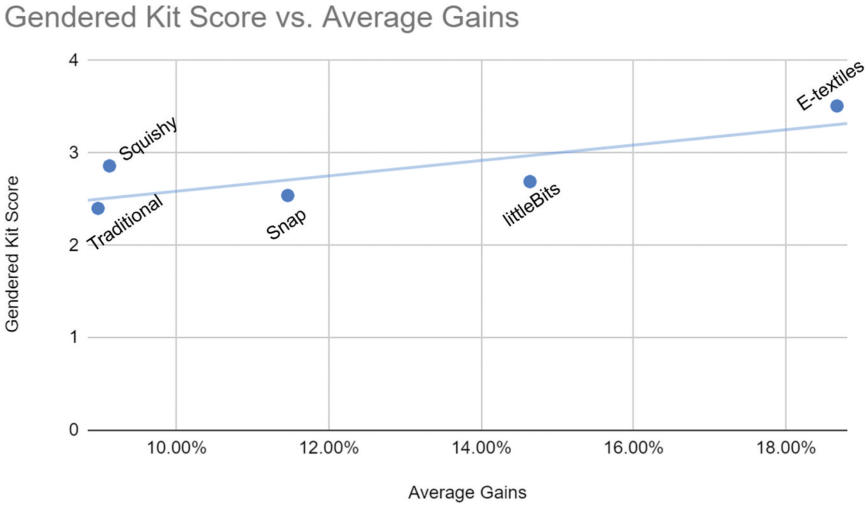


Figure 4. Correlation between average gain scores and kit ranking.

Discussion

The inextricable links between learning, material history, and gendered perceptions

Gendered perceptions invade teaching and learning environments and are commonly the basis of parental decisions when buying toys, what tools and materials school districts teach with, and what the learning possibilities are for the materials they use. While there is a need to dismantle these paradigms, this study serves a separate but related basic need: to disrupt the preconception that tools and materials that display traditional masculinities are better for learning, while those displaying femininities are primarily decorative, emotional, or side ventures to STEM learning. Another misconception that is dismantled here is the perception that feminine-perceived tools and materials are only valuable for inviting participation from girls but are not best for everyone. This study seeks to disrupt those associations by elevating design principles as the drivers of learning; in this case, tools and materials that embrace femininities correlate with STEM learning.

This work demonstrated that the kit most often seen as feminine and most closely aligned with artistic and expressive practices also supported the most significant circuitry learning outcomes for youth. We see this as not a coincidence but as a message that neutrality should not be positioned as a goal of educational design. When a tool, environment, or experience is coded as "neutral," it creates space for those with power to fill and overtake. Alternatively, we seek to design high-quality educational experiences that invite participation and learning, particularly for learners who often do not see themselves reflected in mainstream educational spaces. This aligns with recent strands of thought in feminist work (e.g., Paechter, 2003) acknowledging that highlighting the femininity present in culture and identity allows for fuller expressions of self and fuller participation in society.

That the e-textiles kit was so strongly associated with feminine practices in this study may suggest to readers that boys would be disinterested in this toolkit. However, throughout many experiences with e-textiles and youth over the years, the authors have taught numerous girls and boys how to sew throughout the process. These activities have been largely enjoyed by youth from a range of genders, ages, and backgrounds. It is also shown that when using e-textiles in classroom circuitry implementations, there is something present in the practice of sewing that allows girls to hold leadership roles during e-textile activities that, when using other types of electronics kits, are more generally led by boys (Buchholz et al., 2014). This is further evidence that a) incorporating a range of materials into science activities may provide youth with traditionally marginalized identity markers with more space to take up leadership roles in science and thus see themselves as potential scientists and b) youth with differing backgrounds and identity markers can benefit from learning with diverse and non-traditional materials in science (see Peppler & Glosson, 2013).

Highlighting this femininity also allows for discoveries such as those found in the current work: sewing a circuit—as opposed to snapping or clipping together a circuit—is better for learning about the mechanics of simple circuitry. While older tools may be sufficient for illustrating and demonstrating how electricity flows through a circuit (Fredette & Lochhead, 1980; R. Osborne, 1983), our work here calls for a diversification of not just the tools used in science learning, but of who has opportunities to design such tools and materials.

The fact remains that fewer cisgender women and girls, and non-binary individuals, are involved in STEM fields and activities than cisgender boys and men. During the study, one girl looked at everything she had sorted and stated, "Nothing really for girls … " The purpose of this work is to think about how wider ranges of people can feel invited into STEM spaces as new designers join the fold. And, in fact, the gender of the designers of each kit maps onto their kits' perceived gendered-ness in this study. As we see more female designers like Leah Buechley (e-textiles), Anne-Marie Thomas (Squishy Circuits), and Ayah Bdeir (littleBits) gaining prominence and specifically seeking to create STEAM-based experiences that appeal to a wide range of learners, we see how their design sensibilities and insights increasingly shape the next generation of STEM professionals. This type of work also lays the groundwork for future studies and new design work that explores how tools and materials are perceived by today's youth and the gendered nature of design features. Additionally, while this paper looks solely at gender, it is inevitable that race, ethnicity, and other cultural factors influence the tools used in STEM fields and education. Future research should critically investigate racialized, queer, and/or class-based construction of tools and materials as well.

The youth feel it: Tools are not neutral

The findings presented here suggest that the materials used to teach circuitry are not neutral and that the reasons these materials are perceived as gendered are more likely to be based on practices and experiences associated with the materials rather than solely based on the appearance of the kit. It is important to note again that when we discuss gender, we are referring to the performance of masculinities and femininities as they have been socially constructed. These practices and experiences are tightly tied to contemporary histories of work, such as the histories of mostly men practicing building and architecture, and of mostly women practicing sewing. This suggests that designers need to build new construction kits that hybridize STEM and other more diverse practices and not just tinker with instructional practices or aesthetics to engage broader audiences. Beyond the toolkits cited here, new paper circuitry construction kits like those created by Qi et al. (2018.) offer prominent examples of new approaches that also question the material properties and practices of circuitry.

In making sense of these gender ratings, it is not the ratings of the kits that are pertinent, but rather the variation among youth. If educators focus on the fact that girls most often attribute "girl" identifiers to e-textile kits, a logical, yet harmful conclusion might be that there should be "girl kits" for girls and "boy kits" for boys. This would inevitably lead to even greater instances of gender stereotyping and deterministic designs. One could imagine the extreme case of splitting a classroom into girls and boys for science class so that each could use more "gender appropriate" materials. Not only does this ignore the spectrum of gender identities that may be present in a classroom, but it also limits the possibilities of ways youth could see themselves as working with science in the future. Instead, there might be affordances generally for what is traditionally considered "girlie"– practices that entail art, design, and expressivity—for what may be important for learning more broadly.

Notably, there was a fair amount of variation within the boys and within the girls as well. This suggests that although the clusters seen around the ratings of each kit are useful and meaningful, there is no singular "boy opinion" or "girl opinion." Thus, it is not possible to design a kit "just for girls" or "just for boys" as differences between individuals are wide and important. This also illuminates the fact that "boy" and "girl" are social constructs used to categorize information, but do not fully represent individuals and their preferences.

Rather, the takeaway is that these materials used in classrooms are not read as neutral, despite efforts to design for neutrality. Youth with different backgrounds, experiences, preferences, and latent stereotypes will read and identify with materials in different ways. In fact, the most dangerous scenario of all is quite close to what we currently have in classrooms: that our chemistry, biology, and physics classrooms often rely on single, commonly hyper-masculine, manipulatives with the expectation that all students should engage equally with these materials. Instead, by diversifying the tools and materials we teach with, we have new ways to concretize challenging concepts, as well as invite participation and signal the diversity, variation, and complexity of STEM content. Thus, it is important to present science through a range of materials and activities, providing multiple opportunities for students to see themselves as represented and imagine future possibilities for themselves as potential scientists. It may be true that several girls could be more drawn to design-based science activities, but this gendered association should not be the sole basis for the design of science activities “for girls.”

Potential for future engagement

The promise of e-textiles and other STEAM-based kits can be seen in other details of the learning outcomes shared in this study. Particularly, STEAM-based kits that supported the learning of the core circuitry concepts—current flow, connections, and polarity—seemed to involve a combination of elements that also supported future learning with new toolkits. That is, kits that combined elements of flexibility, feedback, and authentic materials seemed to best prepare youth to work with a range of electronic materials. Table 6 outlines these factors that we hypothesize played a role in the learning outcomes and translates these into takeaways for designers. These factors seem strongest in kits that combine STEM and the Arts practices in ways that create something new.

Rethinking the materials used for STEM learning in schools and makerspaces based on these findings could have massive impacts on what STEM education looks like, who joins STEM professions, and what drives their work. New generations of STEM professionals who learned with more equitable tools and materials will push the

Table 6. Circuitry kit design principles: summary of material findings and future design takeaways.

	Findings	Design Takeaway
Current Flow	Learning about current flow was particularly pronounced in kits that promoted the creation of a malleable loop (such as with conductive thread or alligator clips/insulated wires) that visually accentuated how electricity flows in a loop-based configuration through a circuit.	Create space for flexibility and malleability, particularly in the conductive materials that connect components, so youth can build loop configurations in many sizes, styles, etc.
Connections	Learning about connections was particularly pronounced through engagement with kits that use magnets, snaps, or other elements that required concentration on the connection points.	Build in the necessity to focus on the connection points, focusing on materials that provide some kind of feedback (e.g., tactile and/or auditory) so youth know they have made a strong connection.
Polarity	Learning about polarity was particularly pronounced through engagement with kits that used LEDs as the light source.	Use LEDs and other unidirectional components.
Potential for Future Engagement	Youth who participated in the e-textiles group seemed best prepared to work with other kit materials, although all kit groups except the Traditional Kit group learned significantly outside their own kit.	Kits that combine elements of flexibility, feedback, and authentic materials seem to best prepare youth to work with a range of electronic materials.

boundaries of science and technology in the future. Thus, this current research lays the groundwork for future studies and new design work that will make important shifts in the who and what of STEM education.

Limitations of the study

Gender matters

This paper acknowledges that the sorting task used here could potentially reinforce stereotypes by having youth artificially think of gender in a binary fashion, with little room for the fluid concept of gender that is more accepted today. As noted above, there was certainly variation between how youth responded to our questions regarding gender, indicating that their thinking continued to remain expansive and questioning. Future iterations of this task should consider modifications to alleviate this or incorporate a debrief that allows youth to consider the reality of gender as a spectrum. One exercise might involve allowing youth to tag materials in various ways, including multiple tags that collectively illustrate how tools and materials can convey femininity, masculinity, neither, both, and combinations along a spectrum in multiple ways simultaneously. While there is no evidence here to suggest that the task introduced new stereotypes or opinions about gender, it is certainly necessary to recognize this limitation and consider the possible implications.

Population and sample size

While the sample size for the circuitry learning portion of the study was substantial, the sorting task and interviews took place with 49 youth who all attended the same after-school club. For future work, it would be useful to look at a broader population of youth in case there were any inherent similarities or ideas shared by the youth in this space.

Simple circuitry concepts and kit materials

In terms of STEM learning, this study looked only at three concepts of simple circuitry. There are more complex concepts that are important for leveling up circuitry and robotics learning, and future work should look at other concepts as well. Additional, new commercially available circuitry and robotics learning kits come on the market frequently, and future work should continue to look at new kits as they come into circulation.

Conclusion

This article explored how the investigated materials and tools, in the way they are perceived and used, affect learning; and what the gendered perceptions and interpretations of the participants mean for learning. We sought to address two research questions: (1) Which circuitry toolkits most effectively support the learning of circuitry and why? What are the design features (i.e., which materials, affordances and design choices) of the kits that seem to best support learning? (2) Furthermore, do youth recognize consistent design elements as gendered "identity texts" within circuitry learning, and, if so, how?

To address the first research question, we conducted an experimental study of learning comparing youth outcomes after using one of five kits designed to support circuitry learning. The results of this study demonstrated that the e-textiles kit provided the strongest support for learning three simple circuitry concepts: polarity, connections, and current flow. Further, the results of this study also suggested that the design features most associated with arts and crafting practices, such as sewing down the conductive areas of the components or designing the layout of the circuit, are the features that best support learning.

To address the second research question, we conducted a posthumanist adaptation of a simple sorting task and interview study that asked youth to describe their perceptions of each circuitry kit as possessing a gender identity. The results of this study demonstrated that youth overall saw e-textiles as the kit most associated with femininity, and that their reasons for perceiving kits as gendered most often related to the practices associated with the kits. In other words, youth associated art and craft practices such as sewing and designing with feminine gender identifiers.

This is but the start of a longer research agenda to unravel the complex inter-and intra-actions between the sedimented identities of our tools and teaching environments over time, and their overall impact on learning. Taken together, these outcomes suggest that embracing designs in STEM education that center art and design practices may provide better learning outcomes for all youth through often minimized (and feminized) practices.

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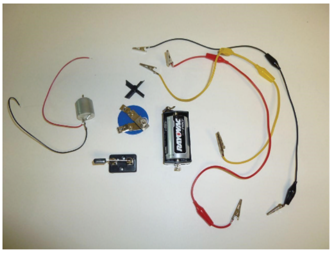
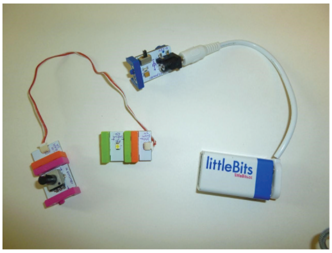
Appendices

Appendix A. Circuitry workshop design

Activity	Length
Goal 1: Measure and control for the understanding of circuits at the start of the workshop. ● All youth completed a circuitry pretest with items from all five STEAM-based toolkits.	20 minutes
Goal 2: Expose youth to the targeted vocabulary and conceptual concepts as experienced within their kit.	5 minutes
Goal 3: Allow youth to experience creating a model working circuit with their assigned kit, controlling for some kits that allow for immediate lighting vs. those that take longer to construct. ● Youth were randomly assigned to 1 of 5 workshop groups. During this time, they did not have access to the other kits or instructional materials. ● Youth were presented with the tools needed to light one LED with their assigned toolkit, in addition to an assortment of crafting supplies (e.g., cardboard, fabric, tape, recyclable materials, markers, paint, beads, etc.). ● The instructor for each group had a scripted introduction that presented the three core circuitry learning concepts and how they were instantiated in their given kit. ● All participants had a circuitry diagram specific to their kit, with key vocabulary and concepts labeled. ● Youth were each asked to individually create a working circuit with the provided materials.	
Goal 4: Create a STEAM-based project that combines both the circuitry with crafts, controlling for kits that emphasize crafting applications as opposed to those that don't. ● Youth were asked to individually create a craft that combined a functioning circuit with the provided crafting supplies. ● If youth were done early, they were allowed to partner with others for further exploration of the same materials.	85 minutes
Goal 5: Measure and control for the understanding of circuits at the end of the workshop. ● All youth completed a circuitry diagram posttest with items from all five toolkits	20 minutes

Appendix B. A range of five STEAM-based circuitry kits

Title & Description	Image
LilyPad Arduino e-Textiles. Sewing together small, specially designed electronic pieces with conductive thread. Includes battery holders and coin cell batteries, LEDs (light-emitting diodes), switches. Softer appearance than many other circuitry kits (Buechley & Eisenberg, 2008).	
Traditional Kit. Traditional circuit kits used widely in school settings. Includes non-polar light bulbs, insulated alligator clips, and a large battery in addition to motors, buzzers, and switches. Most pieces in primary colors, or black.	
littleBits. Several square-shaped "bits" connect to one another via small magnets on either side of each piece. Able to perform several actions at once (e.g. turn on a light and emit a buzzing sound). Includes power piece, LEDs, switches, motor, buzzers. Vibrant purple, pink, green, orange, and blue, playful fonts (Bdeir, 2009).	
Snap Circuits. Popular electronics kit by Elenco. Plastic pieces that snap together at conductive points. Includes LEDs, motors, a speaker that emits a sound when connected to sound chips, plus a book of projects for children to recreate. Large box, "retro" feel, with primary colors (Reisslein et al., 2013).	
Squishy Circuits. Electrical components joined together by malleable conductive dough instead of wires. Includes battery pack, several LEDs shaped like gumdrops, two different buzzers, a small DC motor. Children can help make their own conductive and insulating doughs or use commercial Play-Doh (Johnson & Thomas, 2010).