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Crafting Paper Circuits: Gendered Materials for Circuitry Learning

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Abstract: Given the persistent issues of equity in technology-rich fields, this study argues that our choice of tools and materials significantly impacts both what is possible to be learned as well as who participates. This study examined students' learning of basic circuitry concepts through the use of paper circuitry toolkits in art-based activities. The data was collected in a 4-day workshop for middle school students (N=17). Findings showed that arts integration promoted the creation of paper circuits that leads to artistic exploration into STEM engagement. Pre- and post-tests results showed improvement for students by gender. Although the boys outperformed the girls on paper circuits, the girls outperformed the boys on e-textiles which is considered more "feminine" than others. The findings imply the nuances between material property and gendered practice to understand how we can better design tools and materials to rupture stagnant norms around educational practices.

The persistently lopsided gender makeup of the workforce in science, technology, engineering, and math (STEM) in the U.S. (e.g., only 28% of women work in STEM related occupations) suggests that the gender gap in STEM education is still obstinately wide (Corbett, & Hill, 2015). Yet, despite several national initiatives to diversify participation in STEM fields, the underlying culture of computing and engineering education remains relatively stagnant, with curriculum, tools, and materials that continue to emphasize areas historically aligned more closely with male interests than women's (Margolis & Fisher, 2003). Furthermore, these tools and materials seem to be failing today's youth, as they are arriving at college without an understanding of the big ideas important to electronics and computing (Peppler & Glosson, 2013).

Given the persistent issues of equity in technology-rich fields (Prey & Weaver, 2013), this study argues that our choice of tools and materials significantly impacts both what is possible to be learned as well as who participates. For instance, materials and tools such as sewing with textiles are often seen as the domain of females (Beaudry, 2006), whereas actions and materials such as building electronics are often seen as the domain of males. Recent studies focus on ways to resolve lopsided gender participation in STEM fields by addressing the tools we teach with (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) (Sullivan & Bers, 2016). However, little attention is paid to the role of tools and materials as the initial drivers of these outcomes, both in terms of who participates as well as what is learned. 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.

This study is part of a larger research project that aims to examine students' learning of basic circuitry concepts (i.e., current flow, connection, and polarity) using paper circuitry in art-based activities. From its inception, *Chibitronics™* provided a new way to learn and create circuits but with the affordances of paper crafting and possibilities for expressive art creations (Qi & Buechley, 2014). The purpose of this study is to explore how this circuitry toolkit impacts learning by gender, and simultaneously, how it presents multiple possibilities of artistic expression for youth. Therefore, in this study, we aim to address the following research questions: *(1) To what extent does the art-based workshop support students' learning of basic circuitry concepts via paper circuits? (2) To what extent do the learning gains vary by the types of toolkits and by gender?*

Social Constructionism: Designing Art-based Learning Activities

In this work, we draw on sociocultural understandings of constructionism in a way that seeks to understand both the social 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 (1980), who in his elaboration of Piaget's constructivist ideas posited that learners construct their own knowledge through their experiences with meaningful tools and artifacts with others.

Studies have shown that arts integration benefits student performance in STEM areas (e.g., Hardiman et al., 2014). Particularly, arts-based activities can serve as effective mediators for learning (e.g., Halverson & Sheridan, 2014) because of their focus on the creation of meaningful artifacts and social interactions with others. From the perspective of constructionism, the creation of art artifacts in a social context not only affords learning as it promotes an internalized mental structure of physical experience, but the learner and the artifact actively can create meaning as the learners make sense of their world (Peppler & Thompson, under review).

Through the lens of the constructionist approach, we examine art-based activities as cultural practices, along with the related tools and materials which carry historical expectations for what counts as expertise. These expectations evoke *social scripts* that may prompt gendered patterns of participation. According to our prior work (Peppler & Thompson, under review), we found that the intersection of practices created by the tools and materials also created space for the performance of gendered scripts. For example, e-textiles is a science and engineering activity (fields often dominated by men); however, the integration of the sewing materials invited girls to take leadership roles and have more "hands-on" access to the projects than is typically expected or allowed in classroom science activities. Building on our prior work, in this study, we are interested in exploring the performance by gender with the use of paper circuits and examining how the concepts which students learned through paper circuits can possibly be transferred to other types of circuitry toolkits.

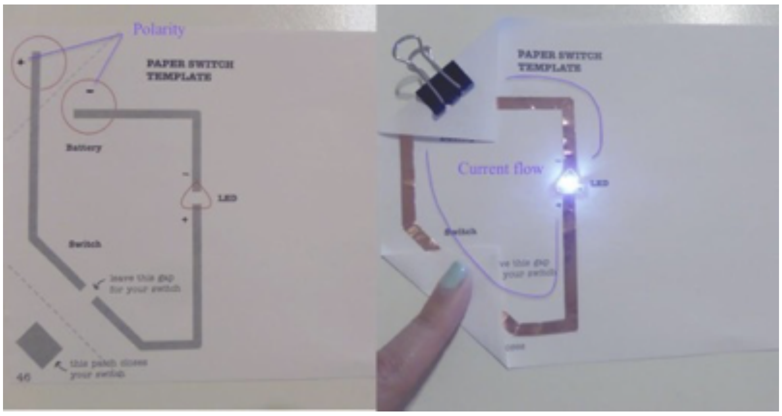
Methods

Setting, Participants, and Workshop

To answer the aforementioned research questions, we measured learning gains of middle school students after participating in a circuitry workshop with *Chibitronics™* paper circuit toolkits. Building on the previous studies (Peppler & Glosson, 2013), we modified and created a 4-day workshop (90 minutes a day) for a charter class located in Southern California, USA. A total of 17 students (F= 9, M = 7, unidentified = 1) between the ages of 11 and 13 participated in the workshop. Nine out of 17 participants self-identified as White, and the others identified as either Asian, Hispanic, multiracial Asian, or multiracial Hispanic. For each day, we introduced circuitry concepts, such as current flow and polarity using Chibitronics (see Figure 1). Simple daily activities led from learning how to light up one to three LEDs (lights) using a coin battery and finished with one final project by creating a greeting card and a microcontroller board to automatically light up the lights.

Figure 1

Examples of Basic Circuitry on a Paper Circuit



Data Sources and Analysis

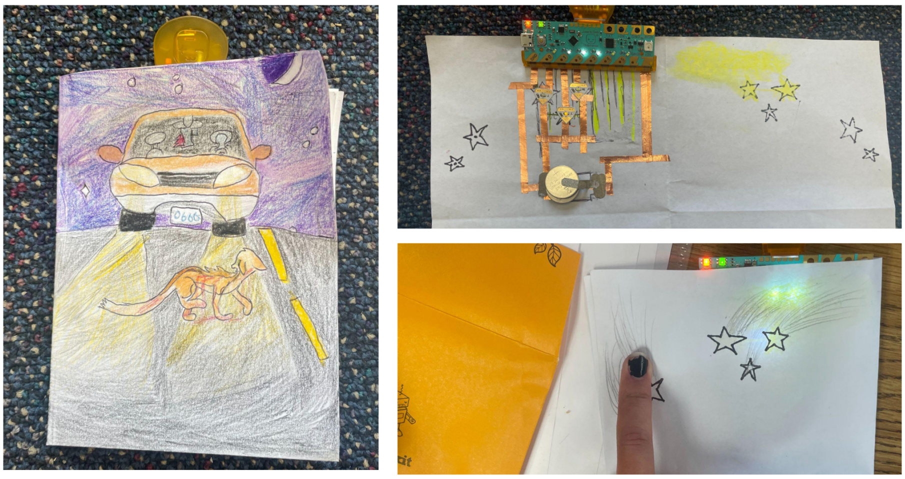
At the beginning and end of the workshop, we administered paper-based pre- and post-tests which included circuit diagram questions to assess the concepts of circuitry: current flow, connections, and polarity across three separate electronic toolkits, including e-textiles, breadboards, and paper circuitry. The content of the workshop and the measurement instrument have been refined and improved over previous study implementations. The pre- and post-tests had three sections, one section corresponding to one circuitry or computational toolkit: breadboard, e-textiles, and paper circuits. These sections compared how youth formed working circuits using materials familiar to them (i.e., Chibitronics) against less familiar materials (i.e., e-textile and breadboard). To understand how learning with paper circuits serves as indicators to prepare for future circuitry learning, we analyzed students' learning gains while youth were exposed with less familiar materials (i.e., other circuitry toolkits). These gains can serve as indicators of preparedness for future circuitry learning across settings.

In the pre- and post-tests, students were provided engineering components (e.g., LEDs, battery, microcontroller) as stickers to simulate the functions and draw lines across the components to accomplish the tests. We then developed coding schemes to examine students' competence of basic circuitry concepts from pre- to post-tests. The highest scores of pre- and post-test is 18. The inter-rater reliability of the coding scheme was calculated by Cohen's kappa with k =.82. Two researchers scored the pre- and post-tests based on the coding scheme. Building on the coding results, a paired sample t-test and one-way ANOVA were applied to examine the changes and differences between pre- and post-tests by gender and types of toolkits.

Findings

In the workshop, we found that arts integration promoted the creation of paper circuits that leads to artistic exploration into STEM engagement. Figure 2 shows examples of how creating a circuit using copper-colored tape and paper provides additional flexibility and possibility for exploration with aesthetics, color, shape, unexpected uses of circuits, and more. This is a similar pattern found in other toolkits that promote artistic engagement such as e-textiles or playdough circuits (Peppler & Glosson, 2013). In addition to a more artistic output, the process of crafting these types of circuits seem to deepen opportunities for applications of STEM concepts for greater learning. Further, arts integration seems to demonstrate a broader applicability for transfer of circuitry concepts from one set of context and materials to another. With flexible materials that require deep embodied actions, such as pressing down copper tape along its entire trace, circuitry kits like paper circuits create a unique relationship between the materials and the elements that are necessary to build a working circuit. This leaves space for learners to apply parts of that close relationship to other toolkits and potentially learn the new materials more easily.

Figure 2
Examples of Students' Work



The results from pre-test (M = 3.5, SD =6.5) and post-tests (M = 21.4, SD = 11.9) showed significant improvement for both girls and boys on basic circuitry concepts (M =17.94, SD = 11.77), $t(15) = 6.1$, $p < .001$ with a large effect size (d=1.58). The results indicate that all students improved on the circuitry concepts (i.e., current flow, connection, and polarity) from pre- to post-tests. To answer the second research question, we then further examined the differences between gender and types of toolkits.

Building on the findings from the first research question, we examined the differences among three types of toolkits by gender. The results showed that both girls and boys improved significantly on e-textile and paper circuitry (see Table 1 for details). Particularly, girls performed better on the e-textile than breadboard and paper circuitry from pre- to post-tests, whereas boys performed better on the paper circuitry than the other two toolkits. The results of descriptive statistics on gains indicated that boys outperformed the girls on all items except for e-textiles, which are arguably more feminine than the other two toolkits. Interestingly, girls scored the highest on e-textiles among the three toolkits, whereas e-textiles were not introduced in this workshop, and all students did not have prior experience on the toolkits. Paper circuits are considered as gender neutral based on our prior work (Peppler & Thompson, under review). Breadboard was not intuitive for either group based on the results.

Table 1
Paired Sample T-test Results of Learning Gains by Toolkits for Girls and Boys

	Girls				Boys				Girls & Boys Comparison
	Gains (Post-Pre)	SD	*t*	*p*	Gains (Post- Pre)	SD	*t*	*p*	Differences between Gains by Points (pts)
E-textiles	9.14	7.08	3.42*	.014	5.44	4.85	3.37*	.010	Girls 3.7pts > Boys
Breadboard	0.43	1.13	1.00	.356	1.33	4.56	0.88	.405	Boys 0.9pts > Girls
Paper circuitry	8.43	7.72	2.89*	.028	11.11	5.67	5.89**	.000	Boys 2.7pts > Girls

Highest scores = 18pts; *$p < .05$ **$p < .001$

Discussion and implications

The findings suggest that all students' competence of circuitry concepts improved from the paper circuits workshop, which indicates that paper circuits are a sufficient toolkit for meeting the relevant standards in basic circuitry/physics. The results showed significant differences by the types of toolkits. Students showed significant improvement on both e-textile and paper circuitry toolkits, indicating that learning circuitry in the context of paper circuits allows individuals to transfer this understanding to similar contexts, like e-textiles but not to breadboards or other more distal contexts. This may also be an artifact of the way that the workshop was taught to emphasize learnings that would easily transfer to e-textiles kits and conditions. Particularly, the findings supported our prior work that there are gendered patterns of practices and materials which may impact the performance of the circuit.

Moreover, the power of the more arts-based toolkits is echoed in studies where learners who used such kits outperformed their peers. Maker toolkits and the integration of new materials bring promising new ways to rethink how concepts are taught, and help educators and designers imagine new approaches for electrical engineering to advance societal needs unmet by our current uses of electrical energy. For future work, we will examine the qualitative aspect of the data to understand how these toolkits are perceived by gender and how these differences impact the ways they approach learning in specific domains. Building on the results of the study, we will investigate the inextricability of material property and gendered practice in an effort to understand how we can better design tools and materials to rupture stagnant norms around educational practices.

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