Solder and Wire or Needle and Thread: Examining the Effects of Electronic Textile Construction Kits on Girls' Attitudes Towards Computing and Arts

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Abstract: The gender gap in computing has persisted—and grown—over the past 40 years. Prior work has identified a number of contributing factors for the persistence of the divide, including environmental cues, software themes, and course content. More recently, the design of software and hardware tools have been investigated as potentially contributing to the gender gap, and a new class of tools designed with gender in mind have risen to prominence. This study compared one such tool—the Adafruit Flora, an electronic textiles platform—to a comparable platform that was not designed with gender in mind—the Arduino Leonardo. While there were some shifts in self-identification, the most notable result was that the participants' views of computing and arts became less stereotyped. However, there was no meaningful difference between workshops in this regard. Our results indicate that the relationship between e-textiles and gender may be more complicated than previously thought.

Introduction and background

According to the latest statistics released by the US Department of Education, 55,000 students received a degree in computer science in 2014. Of those students, only 10,000 were women. An article in Newsweek describes the situation: "The gender gap is real and takes many forms… Despite great strides by women in other formerly male fields, such as law and medicine, women are turning away from the computer industry. Men earning computer-science degrees outnumber women 3 to 1 and the gap is growing" (Kantrowitz, 1994).

There are two things that are alarming about this quote. First, the quote is from 1994. This means that the gender gap in computer science has been a problem recognized by popular media for over 20 years. But, even more worrying is the fact that the gender gap in computer science stood at 3 to 1 in 1994, but in 2014 it stood at 4.5 to 1. This means that not only has the gender gap in computing persisted for over 20 years, but it has gotten wider.

Although some argue that concern about the gender gap is blown out of proportion (Cummins, 2015), we are committed to the view that closing the gender gap is of highest priority. Prior research has demonstrated that the gender gap is not the result of girls simply choosing not to study computing, but rather is the result of systematic biases built into the learning environment that suppress women's participation (e.g., Alvarado & Dodds, 2010). For example, when software contains historically masculine themes like battle and war, girls' performance relative to boys drops. When the software is modified to be more gender-neutral, the gender difference disappears (J. Cooper, 2006; Joel Cooper, Hall, & Huff, 1990).

If themes are important to consider when designing educational software, it makes sense to consider them when designing other educational toolkits as well. The literature around hardware/electronics construction kits is not nearly as mature as the literature around software, but work in this area seems to indicate that the affordances and design features of construction kits can have similar impacts on youths' attitudes and behavior. For example, Buchholz et al. found that when using the Lilypad Arduino, a hardware construction kit designed for creating electronic textiles, girls in mixed-gender dyads spent more time engaged in key practices, and had more opportunities to take on leadership roles (Buchholz, Shively, Peppler, & Wohlwend, 2014). The authors argue that the affordances of the Lilypad Arduino are those that "have historically been valued in feminine communities of practice", and that these cultural affordances "expanded the ways [for girls] into complex electronics and computing content" (p. 18). There is a growing body of literature that both grounds the Lilypad design in theory (Buechley & Eisenberg, 2008; Kafai & Burke, 2014) and explores its impact on children in learning environments (Buchholz et al., 2014; Kafai et al., 2013; Peppler & Glosson, 2013; Qiu, Buechley, Baafi, & Dubow, 2013). This body of research is nearly unanimous in its declaration that the Lilypad opens up a new pathway for girls to become interested and engaged with computing and engineering.

The body of work that has arisen around the Lilypad Arduino provides evidence that providing affordances grounded in feminine communities of practice might be an effective way of increasing girls' interest in computing. However, most of the studies in this arena to date have been observational, and the underlying mechanism responsible for the shift in attitudes is unclear. What is still missing is a direct comparison of how kits with similar functionality but different affordances affect girls' attitudes. This study made such a comparison. We used an experimental design with two experimental groups—one using an e-textiles kit, and the other using the original Arduino interface of pins and wires—and a control group to better tease out the effects of the design of the construction kit on attitudes.

Methods

Participants

N=49 6th and 8th grade girls were recruited from an all-girls middle school in Silicon Valley (N=46 6th graders, N=3 8th graders). The school is notable in that computer science is one of the core subjects, so all of the students had some prior programming experience with Scratch.

Design

The study took place in a Silicon Valley all-girls middle school during a week-long intersession. During this intersession all classes were suspended and the 6th and 8th grade girls chose from a number of different week-long workshop opportunities. We offered two different workshops during the intersession. In the first workshop, called Electric Fashion, we introduced the students to programming microcontrollers with electronic textiles. The students in this workshop worked exclusively with the Adafruit Flora—a sewable Arduino microcontroller—and a variety of sewable LEDs and sensors. This group of girls is referred to as the SEW group (Sewing and Electronics Workshop) in this paper. The second workshop, called Light Up Your Life, covered the same conceptual content as the first workshop, but used a different programmable microcontroller. Instead of a microcontroller designed for e-textiles, this group used a microcontroller called the Arduino Leonardo. And instead of using conductive thread to connect the sensors and LEDs, the students in Light Up Your Life used wires, solder, and breadboards. This group of girls is referred to as the WIRE group (Workshop Involving leonaRdo and Electronics) in this paper. The third group—the control group—was composed of girls who took part in other workshops offered by the school (Table 1). Choices included workshops in stop animation, outdoor survival, learning about and drinking tea, set design, quilting, sailing, and others. Ours were the only workshops where students worked with electronics and computer programming.

Table 1: Full study design

Participants	Pre-Surveys (30 min)	Treatment	Post-Surveys (30 min)
SEW Group (N=10)	Implicit and Explicit Attitudes	Electric Fashion: create fashion projects with electronic textiles	Implicit and Explicit Attitudes
WIRE Group (N=10)	Implicit and Explicit Attitudes	Light Up Your Life: Make everyday objects interactive	Implicit and Explicit Attitudes
Control Group (N=29)	Implicit and Explicit Attitudes	None	Implicit and Explicit Attitudes

Out of the 49 students who took part in our study, N=20 were selected by the school administration to take part in our workshops and N=29 were selected to be in the control group. The administration stated that the assignments were random, however we were not part of the randomization or selection process. Students in the control group took part in a variety of different workshops unrelated to electronics and programming, but still took the pre- and post-surveys. N=10 (9 6th graders) students were assigned to the Electric Fashion workshop, and the other N=10 (8 6th graders) were assigned to the Light Up Your Life workshop.

The girls in the SEW and WIRE groups used the same software to program their projects and were taught using the same materials (with slight changes to account for the differences in the hardware). The girls in both workshops had access to the same crafting and construction materials, and we did not make suggestions about the kinds of projects they might choose to make. Every attempt was made to control the software and instructional content between the two workshops so that the effects of the hardware design on the girls' attitudes could be isolated. The surveys were administered once at the start of the week and once at the end of the week.

Hardware and software

Students in the SEW group learned to program the Adafruit Flora, a microcontroller that can be sewn into fabric and other soft materials (Figure 1, left). The Flora is compatible with a number of sewable sensors (e.g., a light sensor, a motion sensor) and actuators (e.g., sewable LEDs). These components can be connected by sewing them together using stainless steel conductive thread to complete a complete, responsive, programmable system.

Students in the WIRE group learned to program the Arduino Leonardo (Figure 1, right). Both the Flora and Micro use the same microcontroller, the ATmega 32u4. This means that a program written for the Flora can be downloaded to the Micro and the functionality will be identical. However, the Arduino Leonardo is not designed to be sewn into soft materials using conductive thread. Instead, the Leonardo is the latest in a long line of hobbyist microcontrollers (stretching back to the BASIC Stamp, released in 1992) to use wire, breadboards, and soldering as the primary connection method. The full list of sensors and actuators provided for each group is reported in Table 2 below.

Figure 1. On the left are materials that were used in the SEW group, and on the right are materials that were used in the WIRE group.

Table 2: Comparison of microcontrollers and electronics used in each workshop

	SEW Group	WIRE Group
Microcontroller	Adafruit Flora	Arduino Leonardo
Sensors (Inputs)	Color Sensor, Accelerometer, Compass, Light Sensor	Accelerometer, Compass, Light Sensor, Pressure Sensor, Temperature Sensor
Actuators (Outputs)	Sewable LEDs, LED Strip	LED Strip
Miscellaneous Items	Conductive Fabric, Conductive Thread, Alligator Clips	Breadboard, Wires, Solder and Soldering Iron, Wire Strippers

While the Arduino programming environment does simplify many of the difficult parts of physical computing, it may not be the ideal environment for middle-school students' first exposure to physical computing (Sadler, Shluzas, & Blikstein, 2016). Because the participants were all learning the Scratch programming language (Resnick et al., 2009) as part of their core curriculum, a member of our research team (Proctor) created a set of tools that allowed the girls to use the Scratch programming language to program their microcontrollers. Using a Scratch extension and a connected helper application, we created a hardware simulator that provided a way to light up virtual LEDs, read input from virtual sensors, and connect the virtual sensors and virtual LEDs using block-based code. Both workshops used the same simulator, whose graphic interface consisted of a row of circles to represent LEDs and several bars to represent sensor values. The helper application translated participants' code to the Arduino language and logged versions of participants' programs. More details on the software and an analysis of this code will be published in future work.

Instruments

In order to understand the girls' changes in self-identification and their shifts in gender perception a set of instruments was administered before and after the workshop. We analyzed these data to understand the girls' attitudes before the workshops and to measure how their attitudes changed as a result of being in either the SEW, WIRE, or control groups. We included instruments to measure both explicit and implicit attitudes.

We were interested in the following attitudes: personal identification with computer science, personal identification with arts, gender perceptions of computer science, and gender perceptions of arts. Our hope was to gain a more nuanced understanding of how gender perceptions and personal identity were related, and how gender perceptions and personal identity might change as a result of being in the different workshops.

Traditionally, self-report measures have been used to assess students' attitudes towards computing and gender. However, explicit responses can be influenced by social or personal pressure (self-presentation) (Greenwald & Breckler, 1986). For this reason, implicit measures of attitudes were included in the study. The implicit tests measured the subset of explicit attitudes that were most vulnerable to self-presentation bias: gender perceptions and self-identification with computing and arts.

Explicit attitudes: Identity and gender semantic differentials

We designed two 36-item, 11-point semantic differentials (Osgood, 1952), one for measuring identity and the other for measuring gender perceptions of computer science and the arts. The surveys were created on the Qualtrics platform and administered online. The Gender Semantic Differential was designed to measure the girls' explicit gender perceptions on computing and arts, while the Identity Semantic Differential Scale was designed to measure the girls' explicit self-identification on those same categories. In a semantic differential scale, participants are presented with a set of attitude objects and asked to rate each of them along a bipolar adjective scale. On the Gender Semantic Differential Scale, participants rated words from 0 (masculine) to 10 (feminine) (Figure 2). On the Identity Semantic Differential Scale, they rated the same words from 0 (Not My Kind of Thing) to 10 (My Kind of Thing or Could Be My Kind of Thing). The same 36 items were presented in both scales. The order of the questions was randomized at the participant level.

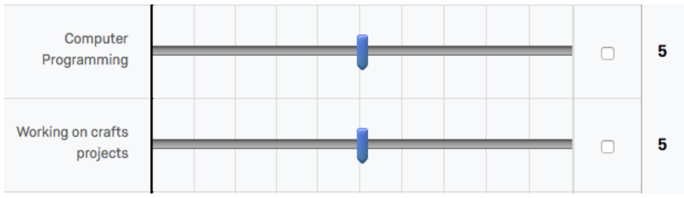

Figure 2. Two example items from the semantic differential measure of explicit attitudes.

We originally designed each scale to measure the following categories: computing, electronics, arts, crafts, and stereotypically feminine. We evaluated each of the categories using Cronbach's alpha and found that they were not consistent. To remedy this, we broke the original categories into sub-categories (a priori) and recomputed Cronbach's alpha for each new category. These new groupings proved to be more consistent (alpha > 0.7). The final list of categories, along with the individual items in each category and Cronbach's alpha, can be found in Table 3.

Table 3: Categories and corresponding individual items for the explicit attitudes semantic differential

Category	Individual Items	Cronbach's Alpha (Gender)	Cronbach's alpha (Identity)
CS Actions	Debugging a broken program, Programming robots, Computer hacking, Computer programming, Making projects with computers, Writing code, Solving problems with software	0.85	0.92
Electronics Actions	Troubleshooting electronics, Building electronics projects	0.84	0.74
Arts	Drawing, Sketching, Painting, Making art, Art class	0.89	0.92
Stereotypically Feminine	Me, Makeup, Nail polish, Fashion, Working on fashion projects, Sewing	0.80	0.88

In addition to analyzing these categories, we also hand-picked a subset of questions to analyze individually. These items were chosen because of their theoretical importance to answering our research questions. We chose these items before analysis to reduce the risk of Type 1 error. The following items were chosen for individual analysis: Conductive thread, Arduino, Troubleshooting electronics, Building electronics projects, Scratch, Working on crafts projects, Me, Sewing, Working on fashion projects, Soldering, and Computer programming.

Implicit attitudes: Identity and Gender Go/No-Go Association tasks

The Go/No-Go Association Test (GNAT) assesses the strength of an association between a target category (e.g., computing) and two poles of an attribute dimension (e.g., male-female) (Nosek & Banaji, 2001). During the GNAT procedure, stimuli from the target category and from one pole of the attribute dimension are the signal or go items, while stimuli that do not match the target category or the target pole of the attribute dimension serve as noise or no-go items. A correct response on a go trial requires pressing the space bar on a computer keyboard to correctly identify the stimulus as belonging to the target attribute or attribute dimension.

For example, a participant might be asked to correctly identify stimuli that are either related to computing (the target category) or feminine (the attribute dimension). On the first trial, the word "Internet" appears on the screen and the participant hits the space button—a correct response—and sees a green circle. On the next trial, the word "Boy" appears on the screen and the participant hits the space bar—an incorrect response—and sees a red check mark. Finally, the word "Sewing" appears on the screen and the participant does not hit the space bar. After 833 milliseconds, a green check mark appears on the screen (see Figure 3 for an example trial).

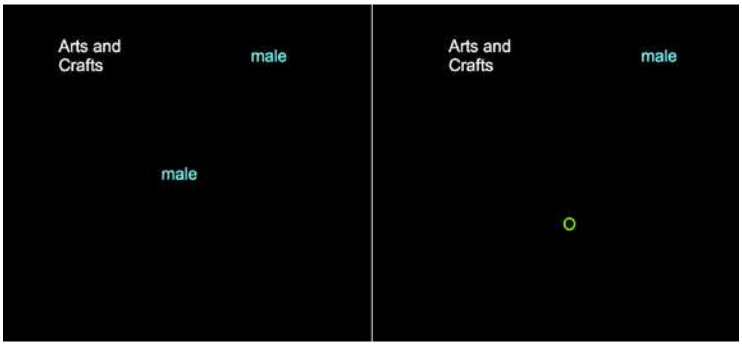

Figure 3. Example GNAT. On the top-left is the target concept (Arts) and on the top-right is the target attribute (masculine). When stimuli that match either of these signal categories are presented, a correct response is to hit the spacebar before the deadline.

We designed two GNATs to measure the strengths of eight different associations. The Gender GNAT measured the associations between female and computing, male and computing, female and arts, and male and arts (Table 4). The Identity GNAT measured the associations between self and computing, other and computing, self and arts, and other and arts (Table 4). Both GNATs were created on the Inquisit Millisecond platform and administered online using the Inquisit Millisecond Web Player (Draine, 1998). As recommended by the creators of the GNAT, d-prime was used as a measure of the strength of the participants' association between the two target concepts (Nosek & Banaji, 2001). The higher the d-prime, the easier it was for the participant to associate the target concept and attribute. d-prime values of zero indicate that the participant was unable to identify the signal at all. d-prime values below zero indicate that the participant was better at selecting the noise than the signal in that trial and most likely confused. In accordance with the advice of the GNAT designers, all values of d-prime below zero were removed before analysis. Due to low test-retest reliability, we were not able to compare pre-workshop scores to post-workshop scores. However, we were able to combine and analyze all of the pre-workshop data from the students to compare explicit and implicit attitudes.

Table 4: Gender GNAT targets, attributes, and stimuli

	Category	Gender Stimuli	Identity Stimuli
Target A	Computing	Artificial intelligence, programming, computers, robotics, coding, Arduino, algorithms, debugging, electronics, Scratch	Artificial intelligence, programming, computers, robotics, coding, Arduino, algorithms, debugging, electronics, Scratch
Target B	Arts	Pottery, sewing, drawing, sketching, arts, stencils, quilting, painting, crafts, knitting, jewelry	Pottery, sewing, drawing, sketching, arts, stencils, quilting, painting, crafts, knitting, jewelry
Attribute A	Female	Female, feminine, girl, woman, her, she, hers	Myself, me, mine, I, self, my
Attribute B	Male	Male, masculine, boy, man, him, he, his	Someone else, them, other, not me, they

Results
Two distinct types of analysis were performed in the study. The first analysis is a comparison of implicit and explicit attitudes measured before the workshops, and the second is an analysis of changes in identity and gender perceptions as a result of taking part in the workshops. The first analysis was performed on the pooled pre-survey data collected from all of the experimental groups (N=49). The two goals of this analysis were to gain a better understanding of the girls' attitudes before the intervention and to compare their implicit and explicit attitudes. The second analysis was performed to better understand how taking part in either the SEW, WIRE, or control group changed the participants' identities and gender perceptions.

A comparison of implicit and explicit attitudes
An analysis of the pooled data from the pre-survey responses on the Gender GNAT (Figure 4, left), the girls were more likely to associate computing with male (mean=1.41, sd=0.88) than with female (mean =1.08,

sd=0.86); t(42) = 2.28, $p < 0.03$. The girls were also more likely to associate arts with female (mean=1.49, sd=0.82) than with male (mean=0.78, sd=0.70); t(43) = -6.15, $p < 10^{-6}$. In other words, the girls' automatic associations were in line with common stereotypes about computing, arts, and gender.

An analysis of the Identity GNAT (Figure 4, right) showed that the girls were more likely to associate arts with self (mean=1.00, sd=0.97) than with other (mean=0.73, sd=0.77); t(43) = 2.26, $p < 0.03$. However, no significant difference was detected between the mean d-prime values for self and computing (mean=0.86, sd=0.76) and other and computing (mean=0.86, sd=0.76); t(43) = 0.98, $p < 0.34$.

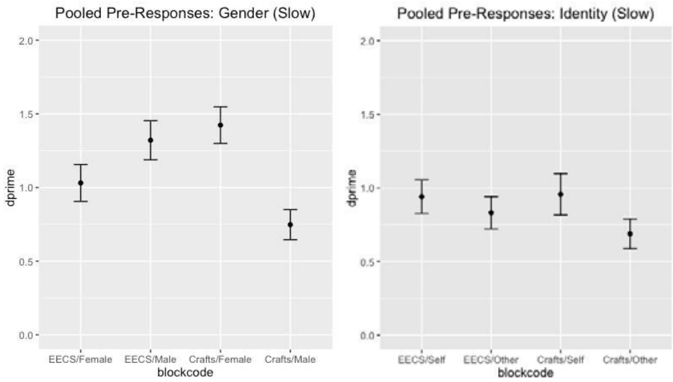

Figure 4. Implicit attitudes of the entire sample (N=49) before the workshop. Higher d-prime values indicate a stronger association between the two items. Error bars show standard error.

In order to compare the girls' explicit attitudes to their implicit attitudes, we matched items from the Semantic Differential to items presented in the GNAT and created two categories: Computing and Arts. On the gender semantic differential, a paired t-test showed that the girls were more likely to rate the computing items as more masculine (mean=6.23, sd=1.06) than the arts items (mean=4.79, sd=0.46); t(31)=-6.434, $p < 10^{-5}$. On the identity semantic differential, a paired t-test showed that the girls were more likely to rate the arts questions as more "My Kind of Thing" (mean=7.06, sd=1.80) than the computing questions (mean=5.97, sd=1.99); t(21)=-2.53, $p < 0.02$.

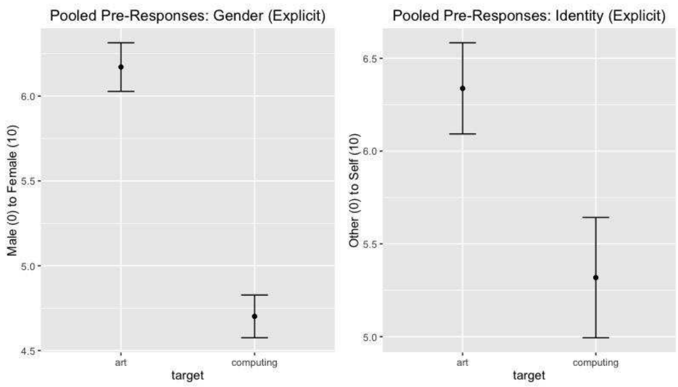

Figure 5. Explicit attitudes for the entire sample (N=49) before the workshop. Error bars show standard error.

In summary, the girls' implicit and explicit attitudes were in agreement. Both implicitly and explicitly, they held stereotypical views of computing and arts: they were more likely to view computing as masculine and arts as feminine. In addition, the girls identified with arts both implicitly and explicitly, but were more indifferent towards computing.

Changes in identity and gender perceptions

We used a regression analysis to measure the changes in attitudes for participants in each workshop. We compared the SEW group to the control group, the WIRE group to the control group, and the SEW group to the WIRE group. In this analysis, the independent variable, workshop, involved three levels: SEW, WIRE, or

Control. The dependent variable was the mean of all the post-workshop questions in the category or item of interest, and the covariate was the mean of the pre-workshop questions from the same category or question. In other words, this analysis allowed us to compare post-workshop scores for participants in each workshop while controlling for pre-workshop scores.

Changes in identity

The participants' attitudes shifted in two out of four categories on the self-identification semantic differential: Electronics Actions and Arts. There was a significant positive shift in self-identification with Electronics Actions for the SEW group ($p=0.03$), and there was a marginal difference between the experimental groups ($p=0.11$) with the SEW group showing a more positive change than the WIRE group. In addition, there was a marginally significant negative shift in self-identification with Arts for the SEW group ($p=0.10$) when compared to control. On this category, there was no significant difference between the experimental groups.

On the individual items, there were two significant changes. First, there was a significant shift in self-identification with Arduino for each experimental group when compared to control ($p=0.009$ for WIRE, $p=0.04$ for SEW). There was no difference between the experimental groups. Second, there was a significant increase in self-identification with troubleshooting electronics for the SEW group when compared to control ($p=0.03$). There was a marginally significant difference between experimental groups ($p=0.10$), with the SEW group showing a more positive change than the WIRE group.

Changes in gender perceptions

The participants' attitudes did not shift in any of the four categories on the gender semantic differential. However, there were a number of notable shifts on individual items. There were significant or marginally significant increases in the perceived femininity of the following items: Conductive Thread ($p=0.08$ for SEW, $p=0.11$ for WIRE), Arduino ($p=0.10$ for SEW, $p=0.01$ for WIRE), and Scratch ($p=0.07$ for WIRE). There were significant increases in the perceived masculinity of the following items: Working on Crafts Projects ($p=0.08$ for WIRE, $p=0.10$ for SEW), and Working on Fashion Projects ($p=0.09$ for SEW). There were no significant differences between the SEW and WIRE groups for any of these items.

Discussion

In this paper we dug deeper into the claim that e-textiles may appeal to girls because of the alignment between the affordances of the kit (e.g., sewing) and historically feminine practices. Operating under this assumption, we expected to see differences between the two workshops. In particular, we expected that the SEW group would show more positive changes in self-identification with computing practices and a stronger reduction in gender stereotypes about computing when compared to both the WIRE group and the control group.

However, instead of seeing larger changes for the SEW group when compared to the WIRE group, we found that in nearly all cases, the two groups moved together. The girls in both groups experienced strong positive shifts in their self-identification with the Arduino. Their gender perceptions of a number of items became less stereotyped as well. Working with the traditional electronics kit appeared to be as effective at shifting girls' gender perceptions and identity as working with the e-textiles kit.

We see two possible ways of reconciling our findings with prior work. First, no prior work that we are aware of has directly compared an e-textiles kit like the Adafruit Flora to a functionally identical, but more traditional kit like the Arduino. The results of the present study indicate that in some cases, the results reported in those studies might have also been obtained with a more traditional Arduino. Second, it is possible that the effects previously reported only emerge in mixed-gender environments. If this is the case, then the explanation for why we did not see any differences could be that the participants' identities as girls were never activated, or that barriers to girls' participation are more likely to emerge in mixed-gender learning environments.

Conclusion

There is still much left to learn about how the design and affordances of the tools we use interact with our perceptions of gender, our attitudes, and our identities. Future work would include repeating this study with mixed-gender dyads and looking for activation of gender identities and corresponding changes in attitudes, replicating earlier work with a comparison group using an Arduino Leonardo to see if the same effects can be achieved with the more traditional platform, and exploring how historically-gendered tools might give rise to or disarm stereotype threat. Although our study shows that the picture is less simple than we thought, we hope our work has identified promising future pathways that may lead to closing the gender gap for good.

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