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With STEM (science, technology, engineering, mathematics) education at the forefront of national attention due to anticipated shortages in future STEM workforce, there is a need to create meaningful and integrated STEM learning experiences in middle and high school classrooms (PCAST, 2010). Research details the ways in which early exposure to personally engaging and meaningful STEM learning opportunities lead to a higher likelihood of STEM degree attainment (Tai, Fan, Lui, & Maltese, 2006). These experiences must provide the foundational knowledge that will prepare students to both become informed citizens and seed their interest in and awareness of professional opportunities in STEM. While computing (using computers) is an essential skill set for many STEM professions, computing in education tends to lack meaningful integration with solving authentic STEM problems (Barron, Martin, & Roberts, 2007). Although state and national standards addressing computing are becoming more prevalent, the skills they entail are often isolated from the rest of the curriculum. As such, the integrated scientific and computing skills and concepts necessary to ensure that students are well prepared for their future careers remain elusive (Hofstein & Lunetta, 2004).

A national epidemic of homogeneity of STEM participants in professional fields exists, with a majority of STEM jobs in the US being filled by White and Asian males (PCAST, 2009). The result is a diversity vacuum that leads to declining diversity of STEM research agendas (PCAST, 2014). Many wonder how we, as a nation, can further foster both access to and interest in STEM for traditionally underrepresented students. The *Maker Movement* (Peppler & Bender, 2013), in which students engage directly with STEM content and skills through the design, prototyping, and creation of objects (Vossoughi & Bevan, 2014), has created new opportunities for diversifying STEM learning activities and connecting to students' interests. Among the many tools and activities associated with the Maker Movement, electronic textiles (e-textiles) have shown particular promise for engaging underrepresented students.

E-textiles activities incorporate not only basic circuitry concepts but also elements of embedded computing for controlling the behavior of fabric artifacts, such as light up sweatshirts, pillows that play music, or stuffed animals that grunt when squeezed. In contrast to conventional wires and breadboards, these artifacts are created using novel materials such as a flat, sewable microcontroller, conductive fibers or conductive Velcro, sensors for light, sound, and pressure, and actuators such as LEDs and speakers, in addition to traditional aspects of fabric crafts. To create a functional e-textiles artifact, users must design, sew, and program a circuit that is embedded in a fabric artifact. Through the process of creating an e-textiles artifact, students have the opportunity to design and build solutions to personally relevant problems that entail application of core scientific knowledge from existing physical and life sciences curricula. E-textiles activities often result in the design and creation of artifacts that represent not only a significant academic accomplishment, but are also personally and culturally meaningful.

This paper seeks to explore the interactions between the known impacts of e-textiles on students as they grapple with issues of culture and identity while developing their identities as students of sciences (DiSalvo, Guzdial, Bruckman, & McKlin, 2014; Tan, Kang, Ockman, & McKlin, 2014; impacts of Thompson, 2014). We also explore the ways in which established impacts on students create a new opportunity for teachers to reconceive their notions of who succeeds at science. Through the lenses of third space theory and cultural reproduction theory we examine the mechanisms by which this can occur for students and teachers through the introduction of e-textiles projects. First, we present the case of Romana, a Native American girl who was thirteen years old at the time data was collected, and her experiences with electronic textiles. Our classroom observations and informal interviews are used as a springboard for exploring the ways in which her cultural identity interacted with the materials and assigned projects. With her experience illustrating the ways in which students commonly experience engaging in e-textiles, we shift to examine the changes in teacher notions of student ability and engagement through e-textiles. We explore shifts in one teacher's cultural conceptions of his students, particularly his English language learning (ELL) students, during the integration of e-textiles activities into his existing curriculum. His perceptions of what made best instruction--and why he considered this instruction best--are analyzed in the context of his work in examining the effectiveness of e-textiles in his own classes. We explore with him his changing perceptions of what students could do within a science classroom as a way to examine the potential power of e-textiles to act as a transformative experience for both teachers and students.

Background

Constructionism as a mechanism for exploring problem solving through artifact construction and manipulation acts as the historic framework for today's Maker Movement (Harel & Papert, 1991). New tools and materials for construction (e.g., 3-D printers, laser cutters, micro-processors, computer numeric control (CNC) machines) create new opportunities for learner engagement (Halverson & Sheridan, 2014; Vossoughi & Bevan, 2014). New technological opportunities are coming at lower economic cost, making experiences more widely accessible to community groups and schools (Blikstein, 2013). While the technological options are ever-evolving, the emergence of the Maker Movement has led to increased interest by a wide range of stakeholders in hands-on, interest-driven STEM learning. While the majority of making activities tend to focus on more traditional robotics and electronics projects, there has also been increased interest in promoting equitable STEM learning opportunities through making (Brahms & Crowley, 2016; Calabrese Barton, Tan, & Greenberg, accepted; Vossoughi, Hooper, & Escudé, 2016). One approach has been to merge heritage craft practices with new, digital technologies (Searle & Kafai, 2015). E-textiles provides students the opportunity to construct objects of personal value while tackling meaningful problems important to them in ways that are educationally empowering with contemporary technologies (e.g. Blikstein, 2008; Blikstein, 2013).

One way to promote student interest in science learning is to engage students in interest-driven projects so that learning activities can be built on their existing interests and practices (Norris & Phillips, 2003). Embedding STEM learning, and science in particular, into the context of experiences builds on prior interests and knowledge (Petrich, Wilkinson, & Bevan, 2012). When students do not connect and identify with their science learning, they often retain negative feelings towards science as a discipline (Basu & Barton, 2007). Interest-driven learning contexts help students to engage in and perceive the value of STEM learning (Azevedo, 2013). Inquiry-based learning focused on hands-on projects provides a model for fostering students' science interest by engaging students in projects to understand the value and relevance of scientific thinking, processes, and experimentation have in their everyday lives. For example, cooking provides a daily relevant context for engaging students in investigating chemical and physical reactions within a personalized context (Clegg, Gardner, & Kolodner, 2010). By using students' personal interest and engaging their prior knowledge, the opportunity for promoting better science learning exists.

Maker activities that involve traditional crafting, for instance e-textiles, may also disrupt traditional barriers to STEM interest. One key to e-textiles potential in disrupting historically gendered boundaries to STEM participation is the authentic integration of crafting into more obviously STEM-related knowledge and skills with electronics and computing (Kafai, Fields, & Searle, 2012). E-textiles occupy a hidden, even disruptive corner of the Maker movement with their focus on handcrafts and sewing rather than their dependency on larger machines or on-screen digital designs (Searle, Fields, Lui, & Kafai, 2014). In one year of e-textiles workshops, Searle, et al. (2014), found that girls were less intimidated by crafting elements of e-textiles whether or not they had prior expertise compared with their male classmates. Crafting then provided a pathway into circuitry and computing for the girls in their study, with a majority of girls reporting that they were most proud of the "techie" elements of their projects at the conclusion of the workshops. While the girls did not necessarily embrace "techie" identities, they were proud of their newfound circuitry and coding knowledge. Weibert et al (2014) similarly found that e-textiles have the potential to encourage girls' interest in technology while at the same time not forcing them into conventional gender roles that favor masculine identities and obscure feminine ones. Beyond gender, integrating handcrafts and traditional knowledge into making has also shown some promise in bringing non-dominant groups into school-based STEM learning. For example, Kafai, Searle, Martinez, & Brayboy (2014) proposed a culturally responsive approach to making in one Native American community through the linkage of e-textiles artifact creation with community funds of knowledge around craft, circuits, and the natural world as a way of engaging Native American middle school students in STEM learning. Heritage craft practices have a long, if contentious, history in many Native American communities. By connecting these more familiar practices to less familiar programming and computational thinking skills, Native American youth began to see themselves as engaged participants in their own technology learning (Kafai, Searle, Martinez, & Brayboy, 2014). Across multiple studies, we find creating alternate paths for students to perceive themselves as students and makers of technology, e-textiles provides a powerful tool for high academic achievement and learning across ethnicities and genders (Gu, Tofel-Grehl, Fields, Sun, & Maahs-Fladung, 2016). These findings indicate that e-textiles acts a productively disruptive tool for learners to better envision themselves as students of science and technology.

With the goal of better understanding the possible interactions between personal and cultural identities and making activities, we posited the following research questions:

1. How did one student's conception of science and her place in it shift through her engagement with e-textiles?
2. How did one teachers' conception of student enthusiasm and ability shift through the course of teaching an e-textiles unit?

Methods

For this analysis we intentionally selected a student from one study site and a teacher from another study site. This choice was made not for lack of examples at both sites, but rather, because we seek to explore how e-textiles making activities create transformative opportunities regardless of the location. We seek to share multiple snapshots we observed of those transformations across power-structure dynamics and locations.

The Student: Romana

Romana, a thirteen year-old Native American girl, attended what we will call Eagle High School, a charter school located on tribal lands in the Southwestern US, serving primarily Native American students. Like many other schools serving predominantly Native American students, Romana's school faced a constant threat of school closure due to low performance on standardized tests (Brayboy & Maaka, 2016; McCarty & Lee, 2014). Because of this high-stakes climate, most classes were focused on getting students up to grade level in math and reading, often through the completion of seemingly endless worksheets. Although there were spaces within school where students could engage in interest-driven, hands-on learning, such as an elective robotics class, girls tended to frequent these spaces less than their male peers and often complained about how "boring" or "tedious" their other classes were. Prior exposure to computing was limited to general technology use. Like many of her peers, Romana struggled with finding school enjoyable.

The Teacher: Mr. Robotoe

A middle school teacher with 12 years of experience, ten of them at the school described in this article, Mr. Robotoe taught science in a rural town in the Western US that we will call Farmtown. Like many rural towns throughout the US, Farmtown has experienced a relatively recent influx of migrant workers and their families (Hamman, Wortham, & Murillo, 2015). As a result, Mr. Robotoe's student population is ethnically, linguistically, and socioeconomically diverse. While some of his students come from highly affluent homes with all the supports and expectations of higher education typical of affluent homes, nearly half of his students are ELLs from migrant families with significantly lower socioeconomic affordances.

Data Collection

Data collection for the student, Romana, was conducted as part of a larger study that combined design-based research with ethnography to understand the development and implementation of a culturally responsive computing curriculum in the context of a Native Studies class. During the three-week e-textiles unit, classroom sessions were video recorded as often as the students would allow, and fieldnotes documented students' progress on their projects and their thoughts on e-textiles more generally. Photographs also documented students' design processes. Informal interviews were conducted as part of these classroom sessions. Final reflective interviews were also conducted based on student availability during lunch, though Romana was not one of the students interviewed.

Mr. Robotoe's data was collected as part of a larger quasi-experimental study examining the impacts of e-textiles on learning outcomes within core science classrooms. Observations of Mr. Robotoe's teaching were conducted for four hours a day during the month long unit. Additionally, he was interviewed, formally and informally, before, during, and after teaching the unit.

Introduction to the Native Studies E-textiles Project

In December 2013, thirteen year-old Romana participated in a three-week e-textiles unit as part of her gender-segregated Native Studies class. Based on the results of prior work (Kafai, Searle, Martinez, & Brayboy, 2014), we constrained the design task both technically and aesthetically. Each student in the class was charged with making her own "human sensor" hoodie sweatshirt (Kafai, Fields, & Searle, 2014) using the LilyPad Arduino e-textiles construction kit (Buechley & Eisenberg, 2008). The activity drew on cultural content by having students make e-textile designs connected to plants that were of significance to local Indigenous communities. One goal was that making a light-up, wearable version of a traditional food source would reinforce what students had already learned about the significance of traditional food sources and perhaps spark larger community-level conversations when students took their projects home. Another goal was that students would learn something about computing and its connections to culture through the process of designing and making e-textiles.

Each "human sensor" hoodie included a felt e-textile patch based on a culturally relevant aesthetic design, a LilyPad Arduino, at least three LED lights, and two metal snaps attached to the negative ground and an analog port, respectively. These snaps connected to snaps on hooded sweatshirts that were pre-"wired" with conductive fabric patches on the cuffs that connected to metal snaps on the front of the sweatshirt. When a student's e-textile patch was connected to the snaps on the sweatshirt, it created a "human sensor" e-textile project (see Figure 1). In a "human sensor" project, the two conductive fabric patches on the cuffs of the sweatshirt function as a sensor to measure resistance from the human body when touched simultaneously. This means is that by touching two patches, students can light up LED lights using the natural conductivity of their own body.

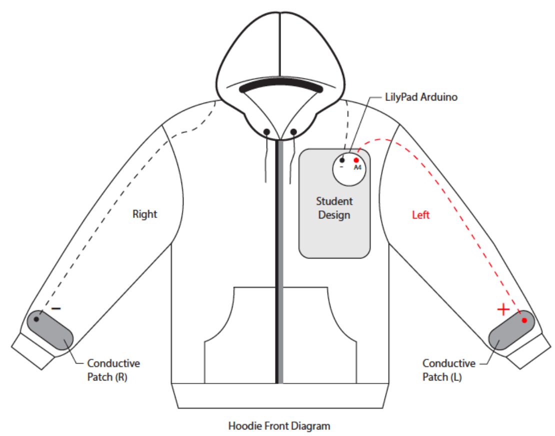

Figure 1. Human Sensor Hoodie

The Student Experience

For her project, Romana expanded upon a template for an Agave plant that the instructors provided. She chose to construct her project out of neon pink felt, leading to the project nickname "Radioactive Agave." Her first Agave plant included the required LilyPad Arduino and three LED lights. Later, Romana added a second Agave plant to her design so that she could incorporate a light sensor into her project.

Figure 2. Romana's initial circuitry blueprint, in-process project, and completed felt patch with light sensor.

In order to create this project, Romana first had to design the circuitry, developing a "blueprint" for her project (see Figure 2). She then had to construct the project using everyday craft supplies like felt, scissors, and a needle alongside hi-tech materials like conductive thread, a sewable micro controller, and sewable LED lights. After successfully constructing and programming her initial 3 LED project, Romana decided she wanted to add a light sensor. Because Romana's initial circuitry blueprint only covered how to connect three LED lights to the micro-controller on a single felt Agave plant, she faced additional circuitry challenges when she wanted to add a light sensor. Specifically, she had to cross negative and positive lines of uninsulated conductive thread without creating a short circuit. In fieldnotes, one of the instructors (Salomon) documented the experience, writing:

> Romana turned around from her seat in front of me to ask me what to do next – she had managed to carefully sew from the positive on the light sensor she is adding through the negative line without touching it, but she couldn't remember where to connect the line she was sewing on the LilyPad. I showed her how the positive went to the positive (the port right by the battery) and then reminded her about sewing from the sensor to A5 to avoid crossing wires. When I was done explaining, she said, "Oh yeah, I remember" and by the end of class she had finished the sewing.

With guidance from the instructors, Romana successfully integrated the circuitry for her light sensor. The following day, with instructor guidance, she observed the data from the light sensor, and, through multiple iterations, programmed her LEDs to be responsive to input from the light sensor.

Through the Native Studies e-textiles unit, Romana engaged in a number of valued computational thinking skills in addition to circuitry design and testing. She also collected and interpreted data from the light sensor she integrated into her project. Yet, prior to working on her electronic textiles project, Romana was a self-proclaimed "hater of school science." As we worked together on her project in class one day, she said, "I hate science." In response, we questioned whether she hated e-textiles and explained that they were a form of "doing science." Romana then elaborated, "It's not that science is boring. It's the way our teachers teach it." In other words, Romana struggled to see herself in school science.

Through the Native Studies e-textiles unit, Romana gained hands-on experience with designing, sewing, and programming functional circuitry through completion of a personally meaningful project, a neon pink Agave plant. Though this project was perhaps only tangentially related to her identity as an Indigenous person through the Agave design, Romana's project provided space to showcase other aspects of her identity, such as her affinity for the color pink or her "techie" skills. Eglash and Bennett (2009) refer to this space where identity work happens within the constraints of a particular technological tool as "design agency." For us, design agency is one of the most important and most challenging aspects of working with e-textiles in classroom spaces. Projects must be constrained enough so that they can be completed within a specified amount of class time, but also provide space for students to see themselves in and through the scientific concepts being taught.

In addition, several other things stand out about Romana's experiences with making an e-textiles design, particularly the way in which classroom space was organized as a kind of "third space" (Soja, 1996). Rather than rows of desks facing the front of the room, we rearranged the room to form collective sewing tables and, eventually, just gathered on the floor to sew together and help each other. Romana especially enjoyed when we sat on the floor and specifically requested that we sit on the floor during class time. We also worked outside of the classroom, taking over the school's parent center during lunch and eventually just gathering around two circular tables in the school cafeteria, because the girls wanted to show off their projects to their peers. At the same time, there were aspects of the project that were very school-like, including a knowledgeable instructor and a structured design task.

The Teacher Experience

In the spring of 2013, Mr. Robotoe's school district provided a Science Engineering Technology and Math (STEM) professional development conference for interested teachers. During this professional development workshop, Mr. Robotoe was introduced to the concepts surrounding e-textiles. E-textiles allow teachers to provide students with the opportunity to explore electricity and circuitry in conjunction with computer programing while experimenting with activities and materials not commonly encountered in schools (i.e., sewing, thread, and fabric). Seeing applicability to his own middle school science classroom, Mr. Robotoe collaborated with researchers to develop a set of projects and lessons designed to meet the needs he perceived of his diverse students. Mr. Robotoe described his students as "two groups that live worlds apart on the same streets." He went on to explain:

> My normal kids do just fine in science. They do the work, they pay attention. I think the e-textiles projects will be great for them because they will really enjoy it. My other kids, the ELL kids, need this stuff. They need something that is fun and will work for them. The sewing projects will be great for them. I would expect them to do even better than the regular kids.

When pressed about his word choices, like "normal" and " regular" to describe his first-language English-speaking Caucasian students, Mr. Robotoe clarified. He said that because his second language students were tracked into remedial level classes his wording was accurate and not driven by issues of race or class.

During the process of developing the e-textiles making activities for use in his classroom, Mr. Robotoe was asked to predict which students would do best with sewable circuits. He quickly stated that he believed his Latino students would do best because hands-on learning was more accessible to them. When pressed to explain further, he stated "those kids don't speak the language so working with their hands is better. Their parents work in auto shops and probably sew a lot so I would guess they will be better prepared to do it." We followed up discussing the science content embedded in the e-textile projects and the conversation came back to his ELL students. When asked how he expected them to perform in learning the science content, he seemed more cautious. He wondered aloud if they would learn the projects or the science, yet articulated no similar concern for his non-ELL students.

The eighth grade science students at the school were divided into eight groups (class meeting periods), and were taught using a quasi-experimental design with half the groups learning the content via e-textiles and half via traditional curriculum. Grouping into class meeting periods was based on ability. Students in two class meeting periods were identified as gifted, four as "normal track," and two as remedial. It was in the remedial sections that nearly all of Mr. Robotoe's ELL students were placed.

Students were introduced to e-textiles through a three-project sequence. First students made a paper circuit (see figure 3), followed by a bracelet circuit (see figure 4) and finally with a preprogrammed microprocessor project.

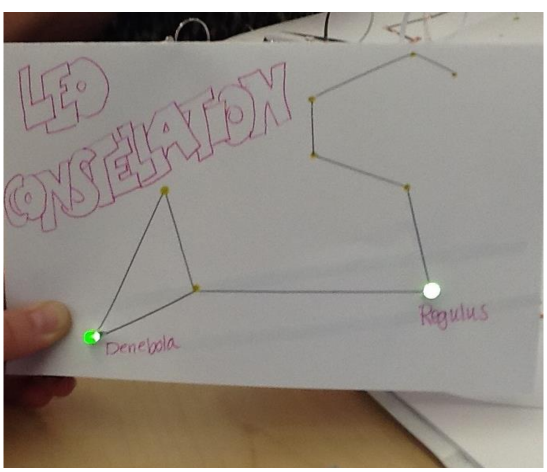

Figure3. Example Paper Circuit.

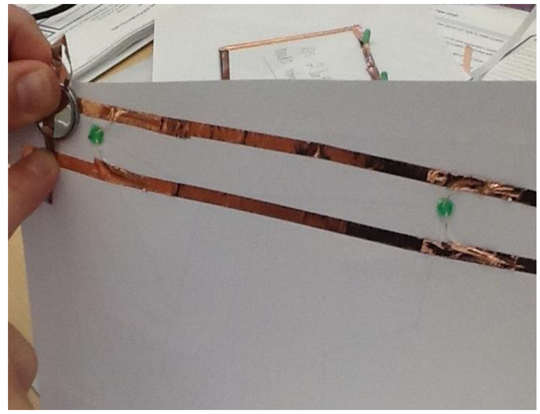

Figure 4. Example Bracelet Circuit.

The students in all eight groups completed content knowledge pre and post tests, which indicated that learning outcomes for all students were statistically insignificant regardless of original grouping differences. However, survey data of all groups showed that e-textile groups, regardless of section, demonstrated higher affective and self-concept shifts than students in the traditional teaching sections. While changes in affect were uniform across all groups, Mr. Robotoe felt the changes for his ELL students were different. For the first time in his ten years teaching at the school, Mr. Robotoe felt that his ELL students "kept pace" with their classmates. Much to his surprise, he reported getting all the work, project and worksheet based, back from all groups at the same rate. He shared with us that one of his ELL students said "If you would have taught this way the whole year, I would have been way more interested in science." Mr Robotoe explained:

> Like many of my other Latino ELL students, Francisco did extremely well on their light-up bracelet and their Lily Tiny [pre-programmed microprocessor]. However, I would have never predicted why they would be so engaged in this project…. Many of my Latino students have parents and relatives that are expert sewers and expert sewing teachers. For the first time in their academic careers

> many of my Latino students received instruction and help with their homework from their parents or family members. Many Latino parents in our town do not speak English and often express their frustrations of not understanding their children's homework, not being able to help their children, and not knowing what homework is due. E-textiles helped generate interest in my students' schoolwork through something as simple as sewing.

Mr. Robotoe cared deeply for his students and felt positively about creating a way to allow both students and parents greater access to learning and engagement around schooling.

Mr. Robotoe correctly realized that hands-on learning opportunities like e-textiles afforded non-native speakers of English greater access to the content he sought to teach. While Mr. Robotoe still classified his students differently based on their cultural and linguistic identities, his conception of who would and could engage in science learning started to shift through the integration of e-textiles into his core content science class. In reflecting about his practice as an educator and the value of culturally relevant curricula such as e-textiles he stated:

> Why do I push myself to constantly change? The main reason is student engagement. We have many ELL students that have received nothing higher than a "C" at school. Many of our ELL students' grades consist of D's and F's. I can't emphasize enough how important it is for low SES, ELL, and achievement gap students to experience success in some realm of school. E-textiles is an excellent vehicle to reach and awaken students who have been dormant in science.

While Mr. Robotoe's continued thinking around culturally responsive teaching still presents areas of potential growth, his reflections and insights into how e-textiles influenced his students and his own practice demonstrates movement towards a more culturally aware vision of his students and of science as a discipline. He articulated a new belief after teaching e-textiles that the accessibility of school work to families might lead to better student engagement. He no longer felt that ELL student success was related to potential parental sewing or circuitry skills; instead he stated that because e-textiles was physically accessible, it opened a new dialogue between parents and students around school work.

Discussion

In this article, we explored making activities with e-textiles in two contexts and from two distinct perspectives. First, we examined thirteen year-old Romana's experiences making with e-textiles in a tribally-controlled charter school in the Southwestern US. Then, we examined Mr. Robotoe's experiences teaching e-textiles to a diverse group of eighth grade students, including a number of ELLs. Taken together, the cases highlight some of the tensions and possibilities around making activities as a platform for diversifying participation in STEM learning opportunities and the STEM workforce.

Recent scholarship has highlighted that making activities in and of themselves are not equity oriented (Vossoughi, Hooper, & Escudé, 2016). Many of the most popular activities like electronics and robotics projects simply reinforce existing inequities. While projects like e-textiles have the potential to provide transformative learning experiences for students and teachers alike, they also have the potential to reinforce stereotypes about students from non-dominant backgrounds as being kinesthetic learners who require "hands-on" experiences. Similarly, in the space of culturally responsive e-textiles, the potential exists for such project to reinforce simplistic ideas about what it means to be Native American rather than embracing the complicated, overlapping aspects of an individual's identity.

Our cases highlight two ways in which e-textiles can provide potentially transformative learning experiences. First, e-textiles making activities have the potential to reframe science for students as a space where their lived personal and cultural experiences are valued. Through the process of making e-textiles artifacts and sharing knowledge of craft and circuitry from out-of-school spaces, classrooms are physically reorganized, students become experts in some aspects of the projects, collaboration among peers is valued, and students and teacher work together to engage in cultural production. Further, e-textiles artifacts provide a way of making visible the contributions of culturally and linguistically diverse students. Additionally, e-textiles making activities have the potential to reframe science teaching. Rather than viewing his ELLs as deficient in some way, Mr. Robotoe began to see his students as resourceful individuals with knowledge to contribute to the classroom space. Through engaging with his students in e-textiles making activities, Mr. Robote made changes to his pedagogical repertoire that then caused him to rethink his taken-for-granted assumptions about race, class, and ethnicity. As we continue to work to provide equitable STEM learning opportunities, it is clear that we need to focus not just on the opportunities we are providing for students but also on educating teachers and making biases visible.

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