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Theorizing the nexus of STEAM practice

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ABSTRACT

Recent advances in arts education policy, as outlined in the latest National Core Arts Standards, advocate for bringing digital media into the arts education classroom. The promise of such Science, Technology, Engineering, Arts, and Mathematics (STEAM)–based approaches is that, by coupling Science, Technology, Engineering, and Mathematics (STEM) and the arts, new understandings and artifacts emerge that transcend either discipline. Evidence of this can be seen through fundamental shifts in both fields; in the arts, artists are expanding the creative potential for design through computational flexibility, which affords artists the ability to exceed the limitations of their tools. The infusion of the arts into STEM has shown to be equally transformative, with the emergence of tools and communities that not only engender new content understandings but also invite participation from populations historically underrepresented in STEM fields. Drawing on over a decade of research at the intersection of the arts, creativity, and new technologies from the Creativity Labs at Indiana University, this article theorizes the learning that takes place at effective couplings of STEAM to assist today's educators in realizing the potential for transformative experiences for learners of all levels. This article provides a synthesis of this past work across two compelling cases of STEAM-based tools, materials, and activities (i.e., the media-rich programming environment Scratch as well as the work the LilyPad Arduino used to create electronic textiles), incorporating findings from more than 50 peer-reviewed papers and books, and conceptually outlines an approach to "gathering STEAM" in arts education classrooms today. Implications are explored for policy makers in teacher education to think about preservice curriculum and field experiences; policy makers in arts education to think about tools needed in classrooms today; as well as how art education can play a critical role in STEM disciplines and offer solutions to address STEM pipeline challenges. Such efforts extend current and prior discussions in the arts education landscape about the use of new technologies, and draw our attention to how new technologies can be leveraged for artistic expression.

KEYWORDS
Arts education; computer science; media arts; nexus theory; Scratch

Recent advances in arts education policy, as outlined in the latest National Core Arts Standards (National Coaltion for Core Arts Standards, 2014), advocate for bringing digital media into the arts education classroom. And, in many cases, the infusion of new technology into arts education is bringing about new explorations of interactivity (i.e., "the extent to which users can participate in modifying the form and content of a mediated environment in real time"; Steuer, 1995, p. 46), theory and form, from expressive digital stories to moving sculptures. Similarly, the increased focus on creative expression in Science, Technology, Engineering, and Mathematics (STEM) fields—the Science, Technology, Engineering, Arts, and Mathematics (STEAM) movement popularized by the Rhode Island School of Design (RISD)—seems poised to create shifts in what is possible in the fields of computer science, engineering, and other STEM areas. A concern for many educators at this intersection, however, is whether the resulting experiences of the "introduced" discipline (e.g., the art concepts infused into an engineering course, or a robotics concept incorporated into an art lesson) are pale versions of those explored in their original contexts. It's a question of how deep is the arts-based learning when infusing the arts into engineering, for example, if the learning focuses on a robot's color. Or, how internalized are STEM concepts when an arts student uses a digital program to create a painting? The failure of many such lessons is one of imagination—that they result in fundamentally unchanged understandings of, and approaches to, either discipline.

The promise of STEAM approaches is that, by coupling STEM and the arts, new understandings and artifacts emerge that transcend either discipline. Evidence of this can be seen through fundamental shifts in both fields; in the arts, artists are expanding the creative

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potential for design through computational flexibility (Smith, 2006), which affords artists the ability to exceed the limitations of their tools. The infusion of the arts into STEM has shown to be equally transformative, with the emergence of tools and communities that not only engender new content understandings but also invite participation from populations historically underrepresented in STEM fields. Drawing on over a decade of research at the intersection of the arts, creativity, and new technologies from the Creativity Labs at Indiana University (e.g., Peppler & Kafai, 2007; Peppler, 2013a, 2013c; Peppler, 2014), this article theorizes the learning that takes place at effective couplings of STEAM to assist today's educators in realizing the potential for transformative experiences for learners of all levels.

This article highlights lessons learned from the design and study of the visual computer programming environment, Scratch (Peppler, 2013a, 2013b), where youth came to see computer programming "like paper" because it allowed them to create whatever they wanted. In addition, this article highlights what it means to take computation beyond the screen into e-textiles (i.e., wearable electronics that can be sewn into clothing and other fabric artifacts using conductive thread) and robotics (Peppler, Sharpe, & Glosson, 2013). Such efforts align traditional fine arts traditions like sculpture and 3D construction with cutting-edge technologies. This article provides a synthesis of this past work, incorporating findings from more than 50 peer-reviewed papers and books, and conceptually outlines an approach to "gathering STEAM" in arts education classrooms today. Implications are explored for policy makers in teacher education to think about preservice curriculum and field experiences; policy makers in arts education to think about tools needed in classrooms today; as well as how art education can play a critical role in STEM disciplines and offer solutions to address STEM pipeline challenges. Such efforts extend current and prior discussions in the arts education landscape about the use of new technologies, and draws our attention to how new technologies can be leveraged for artistic expression.

Background

Ushering in a new era through STEAM

In every era, the arts reflect the current historical moment. Artists make use of the tools, materials, and ideas at hand to heighten our awareness, to create aesthetically compelling work, and to transform our everyday experience (Brown, 1988; Dewey, 1934/1980; Greene, 1995; Hatano & Inagaki, 1987). Today, one of the most pervasive impacts on the world around is arguably the influx of new technologies, so it should come as no surprise that new technologies are being used ubiquitously as creative tools in the arts. This emergent domain of art involving new technologies is an expansive and somewhat amorphous area that is inclusive of several different artistic genres and artistic practices, which are commonly referred to as "media arts," "new media," "digital art," or "interactive art." Although the terms have a good deal of overlap, the term "media arts" is used in this article to "encompass all forms of creative practice involving or referring to art that makes use of electronic equipment, computation, and new communication technologies" (Peppler, 2010a, p. 2119). Beyond surface forays into technology (such as typing a letter, saving a file, capturing an image, or recording a sound file), media arts encourage designing, creating, and interacting with technology in new ways, which are being widely explored in contemporary art practice.

This mix of tools, materials, techniques, and concepts brings contemporary artists in touch with a number of traditional design and technology domains, including fashion design, product design, arts, crafts, textile design, game design, media design, interaction design, architecture and interior design as well as a number of traditional technology domains, including digital technology, wearable technology, material science, mechatronics, electrical engineering, wireless technology, and nanotechnology, among others (Seymour, 2010). In fact, many contemporary artworks are created by artists that have either cross-disciplinary training or by teams of collaborators that each specialize in different areas. For example, computer scientists at the German Research Center for Artificial Intelligence & Ludwig Maximillians University (LMU) Munich transformed the facade of an Austrian city building into a crowdsourced digital painting canvas for the 2010 Ars Electronica festival in Linz. Fueled by a "touch projector" and a multi-user collaborative mobile app, passersby could interact with the surface of the facade by aiming their smartphone at the building, observing it in live video, and freely "painting" using their touch screens. The phone app would identify and track the interactive area, transferring the user's brushstrokes in real-time to the surface of the building. Such technology—an amalgam of interaction design, computer science, and wireless technology—provides a rare opportunity for individuals to take design ownership of their public spaces, as well as facilitates spontaneous, multi-user collaboration on a grand scale.

Similarly, Cory Arcangel, a musician/digital-hacker-turned-multimedia-artist, transforms modified videogames from their original, YouTube video mash-ups, and outmoded electronics into meditations on the relationship between culture and its technology. With solo shows across the art world's most prominent museums—Hamburger Bahnhoff, Miami's Museum of Contemporary Art, the Barbican, the Whitney, and more—Arcangel is a leader in a growing movement in contemporary art that prizes explorations at the intersection of digital and physical worlds. In his interactive *Various Self Playing Bowling Games (aka Beat the Champ)* (2011), Arcangel projects 14 video bowling games from the 1970s to 2000 on museum walls and invites museum-goers to play each game using controllers (original to the console for each game) that he hacked in advance to throw only gutter balls. The Sisyphusian humiliation of the scenario causes viewers and participants to reexamine the extent to which their abilities are, and always have been, enhanced or constrained by the technologies in their lives.

As a third example, Hussein Chalayan is a founding figure of a movement that weds technology, fashion, and the body. Across a 20-year career of innovative techno-fashion, Hussein uses the interaction of programmed clothing, the wearer, and the viewer to subvert traditional notions of fashion, sexuality, and the power dynamics between human and machine. In this 2007 "One Hundred Eleven" show in Paris, Chalayan presented a series of six animatronic dresses that seamlessly morphed from one historic fashion trend to the next through a sophisticated network of motors invisibly stitched into the garments and activated by the wearer—necklines rise and fall, jackets open, hats dramatically change shape, skirts open and self-bustle, fabric reverses itself on its own accord (i.e., turning itself inside out through a set of embedded motors and pulleys), among many other technological feats. In this act, Chalayan manages to embrace vintage dressmaking as well as high technology in his account of the history of fashion.

Collectively, Arcangel, Chalayan, and LMU's work are exemplars of technology-infused art, not merely amplifying traditional arts concepts through the use of new tools, but seeking to transform and extend the possibilities of creative expression.

Using nexus theory to understand STEAM

"Art and science" has a long, entwined history dating back to Plato and Aristotle, through da Vinci and the later Enlightenment. However, beginning in the 20th century the idea of "two cultures" distinct in their epistemological orientations began to emerge that have been problematic ever since (Snow, 1961). In the 21st century, attention has turned once again to the intersections of art and science, at both theoretical and practical levels. Indeed in many ways interest has accelerated as artists have adopted the tools of science (e.g., large-scale data sets) and the questions of science (e.g., climate change), whereas many scientists have sought to collaborate with artists in order to achieve new scientific insights (e.g., through embodiments, performances, and visualizations). For example, recent studies have examined the ways in which training in the arts correlates with higher performance in the sciences (see Root-Bernstein & Pathak, 2016 for a review). Recent interdisciplinary initiatives have increasingly blurred boundaries between fields, in part due to the ubiquity and centrality of digital technologies, with renewed interest in the potential of art and science to advance STEM participation and knowledge (Malina, Mills, Cencic, & Pelletier, 2013; McDougall, Bevan, & Semper, 2011). In the United States, for example, the National Science Foundation, in partnership with the National Endowment for the Arts, has sponsored several projects that have explored the intersections of arts, sciences, and technology through a series of meetings, which led to the founding of SEAD (Sciences, Engineering, Arts, and Design), a network of artists and scientists exploring intersections.

The promise of STEAM is that while there are particular sets of practices associated with STEM disciplines, that are distinct from the sets of practices in arts disciplines, some practices are common to both domains. Additionally, a unique set of practices emerges at the intersection or nexus of STEAM practice (see Figure 1). The notion of a "nexus of practice" (Scollon, 2001), an anthropological concept developed in language and literacy studies, explains how the typical practices in a cultural field make up a mesh of almost automatic routines and shared dispositions that members of that culture expect of one another. These sets of practices carry tacit

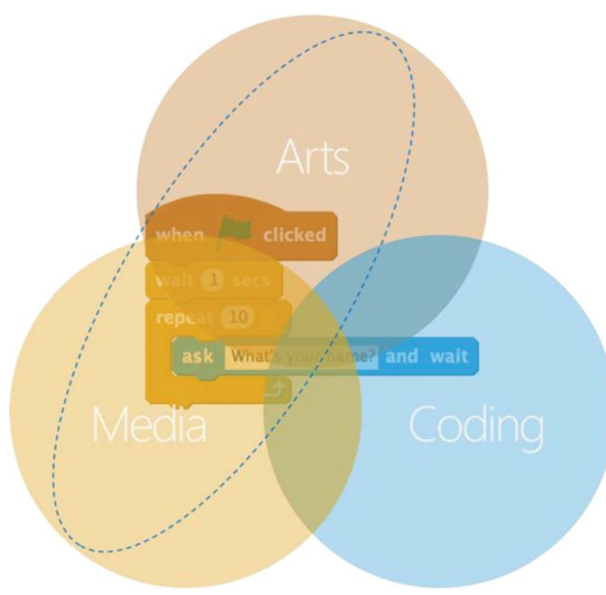

Figure 1. Scratch nexus, consisting of intersecting Arts, Media, and Coding.

expectations for particular kinds of knowledge, tools, materials, and tool users (Holland & Cole, 1995). Each cultural practice—with its related tools and materials—conveys distinct expectations for who and what constitutes experts and expertise. For example, skillful sewing with needles and fabric signals expertise in crafting or fashion cultures while successful construction of a working circuit signals expertise in electrical engineering or STEM learning communities. Additionally, these practices signal femininities and masculinities in gendered communities of practice (Connell & Messerschmidt, 2005; Paechter, 2003), frozen into tools and artifacts through histories of sewing for girls (Beaudry, 2006) and electronics for boys (Foster, 1995a, 1995b), along with their contemporary traces in expectations for female consumers of craft kits and fashion and for male consumers of video games and robotics.

Nexus theory (Wohlwend, 2014) posits that when different nexuses converge, conflicts and slippages among their disparate expectations have the potential to disrupt stagnant practices that have been at work in a field that might otherwise be impervious or slow to change (e.g., the under-representation of women and minorities in STEM fields as well as other contemporary challenges). The intersection of multiple nexuses is a site of convergence and emergence, as new practices overlap key valued practices espoused in prior work (Medina & Wohlwend, 2014). When new practices emerge in nexus, the results can be transformative, allowing greater access and broader participation. For example, the National Research Council's (2012) K12 Framework for Science Education identified eight practices related to science and engineering. These practices are meant to describe how scientists and engineers build knowledge about the natural and designed world. To help educators, researchers have organized them into three conceptually manageable clusters of activities: Investigating, Sense-making, and Critiquing practices (McNeill, Pimentel, & Strauss, 2013). Similarly in the arts, Kafai and Peppler (2011) identified 10 practices related to arts and technology, organized into four clusters of activities: Technical, Critical, Creative, and Ethical practices of production.

The nexus of these epistemic practices are central to many arts-and-sciences out-of-school programs. For example, programs involving activities such as e-textiles or kinetic sculptures, entail exploring materiality, producing tentative representations, collecting and responding to feedback, and revising plans and products (Peppler, 2013c; Vossoughi & Bevan, 2014). Other digital production programs, on the other hand, such as Scratch, integrate planning and design, deconstructing components, and responding to feedback, as well as critiquing and explaining within the Scratch community (Resnick & Rosenbaum, 2013). Media-related programs, such as Youth Radio, integrate noticing and questioning, collecting data, developing representations of understanding, responding to feedback and critique, and producing and communicating evidence-based explanations (Chávez & Soep, 2005). Each of these examples sit well at this intersection of STEAM but this article argues that it's more than a simple overlap that something unique happens at this nexus that transforms learning and participation in both domains.

Disruptive nexus of practice

The relationship between various tools and the structuring of subject matter is central to many examinations of disciplinary learning. Seymour Papert, for one, called attention to the impact of specific tools ("objects-to-think-with") (Papert, 1980) on the ways that individuals learn and perceive subject matter. Of potential interest to anyone infusing STEM learning into artistic endeavors is the impact that working with these tools has on our ontological understanding of robotics, computing, and engineering, particularly in the ways that it contrasts with learning outcomes that derive from the use of more traditional tools.

A salient, although often unrecognized factor at play at the STEAM intersection, is how tools and materials bear traces of their histories of cultural use and access, communicating gendered scripts that invite participants to read and perform masculinities and femininities in socially recognized ways (Butler, 1990). Sharing, sewing, or constructing practices sediment into tools through years of everyday routines (Pahl & Rowsell, 2010), creating dense nexus of unspoken yet naturalized ways of "doing and being" that contribute to differential participation for girls and boys. This theorization contrasts sharply with explanations of gender disparities in STEM as inherent "lack" in girls (i.e., girls lack the skills, interest, or confidence necessary to participate equitably with male counterparts). Instead, the action orientation to cultural tools in nexus theory reconceptualizes this disparity by uncovering tacit expectations for cultural practices and social actors that are concretized through historical uses of tools, materials, and gendered communities of practice (Paechter, 2003).

Rather than viewing gender as a static identity marker that defines participation in electronics and computing projects, we examined histories of materials, tools, and practices that influence whether girls or boys working in mixed gender pairs were implicitly granted hands-on access. In the case of e-textiles, we found that replacing traditional circuitry toolkits with novel circuitry materials and tools like needles, fabric, and conductive thread ruptured traditional gender scripts around electronics and computing. In turn, girls take on leadership roles in completing highly complex electronics projects by engaging in practices historically embedded within communities of practice with gendered histories (Buchholz, Shively, Peppler, & Wohlwend, 2014). Moreover, these cumulative hands-on opportunities are critical to building working knowledge and understanding of electronics and computing concepts over time.

A closer examination of these tacit understandings are particularly timely, given that the persistently lopsided gender makeup of computer and information science programs in U.S. universities and colleges (e.g., only 18% of engineering undergraduates in 2009 were women) suggests that the gender gap in computing education is still obstinately wide (Prey & Weaver, 2013). Yet despite several national initiatives to diversify participation in STEM fields, the underlying culture of computing 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). Fortunately, contemporary electronics and computing is rife with new tools and materials that are spurring shifts in the ways individuals interact with technology, presenting opportunities for us to reshape learning and participation. As Scollon (2001) theorized, a small change in a mediated action—such as handling sewing and crafting tools and materials—results in meaningful differences in access, participation, and leadership.

Practices at the intersection: Programming, physical computing, and harnessing digital media

A central practice in contemporary art (as highlighted in the Arcangel, Chalayan, and LMU's work cited above) is the leveraging of software and hardware to sense and control the physical world, whether it be a garment, a video game experience, or the lighting of a building's exterior—what many would call physical computing. The use of the phrase *physical computing* for artists and designers warrants further clarification: physical computing, in the broadest sense, means building physical systems that are interactive through the use of hardware and software that can communicate with people by using sensors and actuators controlled by small computers, called "microcontrollers." Generally, physical computing can be viewed as a way of describing the relationship individuals have with the digital world. The term is widely used by designers, artists, and those in higher education to describe the electronics used in handmade art, design or do it yourself (DIY) hobby projects that use sensors and microcontrollers to control motors, lights, sound, other hardware, or on-screen displays.

In his prior work, Smith has advanced an understanding of "computational flexibility" (2006), which builds on practices involving knowing how to use computationally rich software (e.g., word processors, spreadsheets, and presentation tools) as well as develop fluency (i.e., knowing how and why existing tools do not meet current needs), but extends this to include the ability to create the tools that one can otherwise only imagine. It's precisely for these reasons that artists need to learn how to computer program—to be able to leverage the new medium of the computer and to create new tools and materials that are not otherwise possible.

STEM practitioners have simultaneously emphasized that learning to code can be characterized as a set of practices that are often referred to as "computational thinking." Computational thinking (CT) refers to the human ability to formulate problems so that their solutions can be represented as computational steps or algorithms to be carried out by a computer. The term was coined by Jeannette Wing (2006) to describe a set of thinking skills, habits, and approaches that are integral to solving complex problems using a computer and widely applicable in today's technology-rich society. Thinking computationally draws on the concepts that are fundamental to computer science, and involves systematically and efficiently processing information and tasks.

Of all media arts concepts, learning to code has been met with the most trepidation from arts educators, many of whom do not embrace it as an expressive medium. STEM domains, similarly, have struggled to attract new populations who see computer programming as a barrier to participation. However, coding and creative expression is a juncture where there is substantial transformative potential for each discipline. There are several notable tools that successfully blend and entangle STEAM practices in ways that disrupt historical challenges in STEM fields and invite a full range of aesthetic expression, which are further theorized here to help us better understand how to design, analyze, and explain the transformative potential of STEAM. The first example comes from the early research studies on the Scratch visual programming language that engages youth computational media artmaking. The second example comes from the body of research around the LilyPad Arduino technology used to embed wearable computers and other electronics into clothing or other textiles using conductive thread and fabrics to create interactive electronic textiles (or e-textiles) designs.

Transformative cases

Interactive media artmaking with Scratch

In the early 2000s, Mitchel Resnick and Yasmin Kafai proposed a new approach to computer programming

(Resnick et al., 2009). This grew out of their observations at the Computer Clubhouse network, an international community of over 100 centers across 19 countries (Kafai, Peppler, & Chapman, 2009). While the network was designed as a studio to get youth interested in robotics and programming, as well as other types of digital creation, what emerged was an emphasis on media creation. In fact, most of the software aimed at teaching computer programming that was purchased for the clubhouse was unwrapped due to a lack of interest in the applications. This lack of interest in learning how to code was not just endemic to the clubhouse network, but was reflective of the larger social interest among youth in coding and robotics at the time.

What resulted from Resnick and Kafai's collaboration was the drag-and-drop visual programming environment, Scratch (Maloney et al., 2008; Resnick et al., 2009), a program that uses colorful text-based blocks that snap together to control on-screen objects called "sprites." In Scratch, users can create strings of commands by combining blocks of code in semantically meaningful ways. The relationships between the commands are made visually clear in the program by allowing some (but not all) of the blocks to snap together in what can be seen as "grammatical" combinations. These building blocks scaffold the novice programmer by facilitating easy debugging and enable learning through tinkering, avoiding the initial hurdles of debugging semantic errors in line code.

The initial conception of Scratch was meant to think about and merge practices of coding around practices of visual culture, blending youth's everyday media practices and controlling it through the language of computer programming. Toward this end, Scratch allows users to import and program any imported graphic image, whether one downloaded from the Web or a photo from a personal archive. Designers can draw their own objects using a paint editor in the program, frequently designing custom characters or backdrops that would relate to their imported media in expressive ways. What results from this exercise are richly personal, multimodal texts (Kress, 1997), incorporating a wealth of material from their everyday lives (e.g., their mothers' drawings and pictures of low-rider cars that they had downloaded) as well as from their interests in popular culture (Peppler & Kafai, 2007). The earliest Scratch projects emerging from the Computer Clubhouse frequently engaged images and songs from youths' favorite pop and rap stars, television shows, movies, video games, and toys, with youth deriving new meanings by remixing this media in novel ways by adding their own audio files and animations. In this regard, youth who engaged in Scratch developed technological fluency alongside an array of new literacies as they created their products.

After Scratch was introduced at a Computer Clubhouse in South Los Angeles among predominantly among Black and Latino youth, a programming culture took root over time within the community, and local practices emerged around the use of the tool (Kafai, Peppler, & Chui, 2007; Peppler & Kafai, 2007, 2008). In the beta version, Scratch quickly became the top program used at the Clubhouse, a testimony to the undergirding hypothesis guiding the design of scratch. As it gained in popularity, it also increasingly served to define what was considered central participation in the Clubhouse and who were considered central participants.

Nexus theory can offer an explanation of what makes Scratch so impactful as a transformative example of STEAM. The three central practices in which one engages when working with Scratch in the out-of-school hours, of many other possible practices, can be summarized as a blending of coding, media, and arts, working together to transform what it means to engage in each of these disciplines (see Figure 1) (Kafai & Peppler, 2011; Peppler & Kafai, 2007). Particularly, Scratch takes art-making and media-making and places computer programming at its core, which allows designers to create new tools and to treat the canvas "like paper" in order to create virtually anything they want (Peppler, 2010a). In vice versa, coding takes on new relevance–instead of doing an exercise or applied activity, Scratch offers a way to connect to youth's existing passions in digital media, including games, interactive art, animations, and other Web-based media. Taken together, the nexus of arts, media, and coding brings together multiple practices that provide alternate entry points into activity and multiple ways to be recognized as expert (e.g., as a knowledgeable media fan, a math whiz in coding, a creative artist with a distinct aesthetic). In this way STEAM disrupts the dominance of expertise in computer programming practices and surrounding coder culture by blending in visual culture (i.e., both arts and media).

When nexus converge, transformative impacts can be seen in multiple areas, including impacts on learning outcomes. Within the learning sciences, for example, one may ask what kind of learning outcomes are engendered in each of the depicted domains. Early observations of the beta versions of Scratch at the Computer Clubhouses in South LA revealed that youth were making significant learning gains in the arts, media, and computer science. Moreover, this work was among the first to assert that learning in media arts and computer science can occur in informal learning communities in absence of direct instruction (Maloney, Peppler, Kafai, Resnick, & Rusk, 2008; Peppler & Kafai, 2007), alerting us to the possibilities of how well designed tools can be shaped to promote the kinds of interest-driven learning that is valued in and out of schools (Peppler, 2013a, 2013b, 2014).

An external panel of media artists was commissioned to review the complete archive of work coming out of the Computer Clubhouse at the time in order to assess the artistic merit of youths' work in Scratch. Throughout this process, the panel discussed each aspect of the archive, creating wide consensus about the work, and developing metrics with which to evaluate the art. A systematic assessment of the archive revealed that individual youth significantly gained in their artistic and creative capacity over time. Measurements included youth's criticality in the work, technique, and use of interactivity. Moreover, the group as a whole gained significantly in all areas over the course of the initial 2-year period in which Scratch was first adopted (Peppler, 2010a).

Throughout this process, the panel was drawn to the work that used coding but was divergent from familiar forms (such as highly realistic recreations of MPG games), gravitating instead toward work that was highly original and impactful in their own right. One of the focal cases that became a focus of discussions was the work of a young African-American fourth-grade student named Brandy. Her pieces were a mix of various types of media, including an interactive card (a present for a clubhouse mentor) that included a voice recording of her singing a rendition of Happy Birthday and several spinning objects, including a clip-art baby and a hand-drawn cookie. In another, she created a dialogue between treacherous-looking spiders in a high school gym using a recording of her voice and coordinated animations. While she had not yet gained recognition for her work at the clubhouse, the artist panel time and again came back to her work, not realizing that it was from the same author, recognizing the extraordinary potential of the artist, citing its similarly to "outsider art" pieces that were well regarded in the canon of contemporary art. Most notably, this young girl was able to program with Scratch before she was able to read and write in the English language. When asked, she described the Scratch experience as "like a map" because it helped her to learn (Peppler & Warschauer, 2012).

As further evidence of the impact of the transformative impact of Scratch, of the 17 million projects in the worldwide online Scratch community (scratch.mit.edu), more than 40% were created by female designers. This is an unprecedented ratio of female programmers in computer science learning communities. Furthermore, new programming languages targeted at novices and educational audiences either build on the open source Scratch code and/or make similar kinds of design decisions (e.g., see Ardublock, ModKit, BYOB), which is another sign of the success of the earlier Scratch language. Taken together, this body of work around Scratch suggests that these STEAM experiences are transformative in a number of ways, particularly in the ways that it has been demonstrated to improve learning outcomes and broaden participation.

Blending high and low tech with e-textiles

Similarly transformative STEAM experiences can be seen in youths' design and production of e-textiles, electronically enhanced garments and crafts that make use of electronic components, such as conductive thread, microprocessors, Light Emitting Diode (LEDs), and sensors. From AT&T's bio-tracking clothing to Chalayan's permutating dresses, e-textiles infuse fashion with electronics to produce unique and aesthetic effects using new conductive materials (Buechley, Peppler, Eisenberg, & Kafai, 2013). The use of e-textiles, as well as related forms of digital creativity that extends beyond the screen and into the physical world, have engendered new forms of creative production that are taking educational and professional fields in new directions.

Computer coding plays a central role in the design of e-textiles (Peppler, 2010a), facilitating interactions between the textile's movements or appearance, the wearer, and/or the outside world. To create an e-textile design, users engage in three intersecting domains of coding, crafting, and circuitry (Kafai, Fields, & Searle, 2014; Peppler, 2013a). However, despite sharing many common roots with robotic constructions (whose appearance is often secondary—if considered at all—to their ability to execute a task), e-textile artifacts are frequently conceived of as aesthetically compelling designs with electronically enhanced capabilities.

Coding can be realized in e-textile projects using a variety of methods, ranging from text-based coding environments, like Arduino (Banzi, 2008) to novice-friendly graphical programming block environments that extend Scratch-like functionality toward the programming of physical objects. One such environment is Modkit (Baafi & Millner, 2011), which enables users to drag and drop object blocks (such as "LED," "Button," "Knob," or "Speaker") into semantically functional combinations and assign them to outputs of a microcontroller. Once the program is uploaded to the physical microcontroller, the microcontroller can be stitched into a textile and connected to lights, motors and sensors via circuits stitched from conductive thread. Creating an e-textile, thus, provides opportunities to engage in not only computer science (for the programming of the microcontroller) but also circuitry (for the creation of a functioning circuit), crafting techniques (for the successful threading of conductive fibers between circuit components), and design (for the shape the stitched circuit creates in the e-textile, as well as the overall aesthetic vision for the piece in which the circuitry resides).

By merging sewing and electronics practices, e-textiles meaningfully combine two sets of gendered practices and expectations associated with craft and electronic materials. When examined through mediated discourse analysis, each cultural practice—with related tools and materials—carries distinct expectations for whom and what constitutes experts and expertise. For example, skillful sewing with needles and fabric signals expertise in crafting or fashion cultures, while successful construction of a working circuit signals expertise in electrical engineering or STEM learning communities. Additionally, these practices signal femininities and masculinities in gendered communities of practice (Connell & Messerschmidt, 2005; Paechter, 2003) through histories of sewing (Beaudry, 2006) for girls and electronics for boys (Foster, 1995a, 1995b) along with their contemporary traces in expectations for female consumers of craft kits and fashion and for male consumers of video games and robotics.

This nexus of e-textiles practice has sizeable implications for both participation and learning over time. The capacity for e-textiles to diversify participation was first documented by Buechley and Mako-Hill (2010), who discovered that e-textiles were arguably becoming the first-ever female-dominated computing community. While males created the majority of traditional Arduino projects posted on Vimeo, YouTube, Flickr, and other sites (85% vs. about 1% by women designers), women created most of the LilyPad Arduino projects (65%).

What is striking about this comparison is that both types of projects share the same microprocessor and are programmed in the same language (see Figures 2 and 3). Researchers posit that the resulting gender discrepancy could be due to some combination of the tools and materials used, the construction practices employed, and the nature of the products. From the perspective of nexus theory, the insertion of the arts (in this case, crafting) subtly shifts the typically masculine dominated practices typically found in STEM culture and traditional robotics. While some might argue that there is craftsmanship at play in most robotics, the focus on craftsmanship in traditionally robotics fundamentally differs from the more feminized crafting forms that teach about color, quality of craftsmanship and other aspects of design.

The resonance of advanced electronics and computing among women around this unique nexus demonstrates a great deal of promise for transforming classroom practice in similar ways. In a series of e-textile design experiments in middle school settings, gender dynamics and

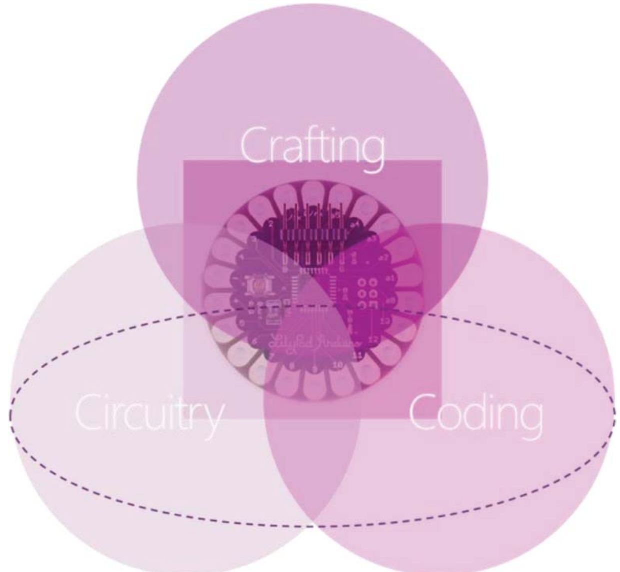

Figure 2. E-textiles (LilyPad Arduino) nexus, consisting of intersecting Crafting, Circuitry, and Coding.

participation patterns of girls and boys were observed as youth worked on e-textile projects in mixed-gender pairs (Peppler, 2013a; Buchholz et al., 2014). These studies reveal that, while boys and girls equally engage in e-textile creation—as evidenced by body language, gaze, talk-on-task, and other indicators—girls tend to play a greater leadership role. In the studies, projects were positioned in front of the girls 81% of the time; girls spent 58% of the time directing activity, troubleshooting, and deciding next steps; and girls made only 39% of the overall requests for help from teachers and peers.

Early leadership of female students was predictive of having more sophisticated command of the technology in subsequent projects, requiring less troubleshooting, time, and assistance from others. Upon further analyses, the authors also found that pairs determined who would take the lead on the activity based on the practice (and its gendered history) that they were to engage, with girls

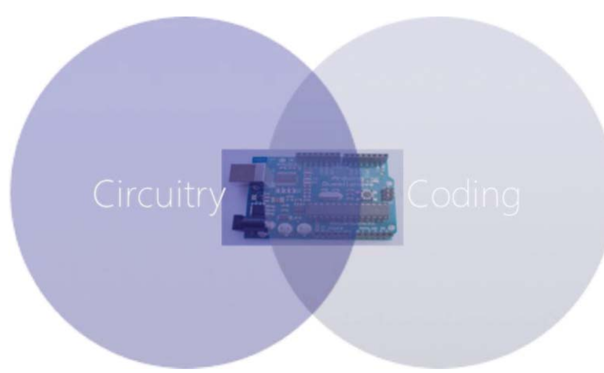

Figure 3. Arduino robotics nexus, consisting of intersecting Crafting, Circuitry, and Coding.

placed in the leadership role when it was time to sew or craft and boys placed in a leadership role when it was time to test or solder the connections (Peppler, 2013a; Buchholz et al., 2014). This division of labor was consistent but not negotiated within the groups, even when the boys had more prior experience and were more proficient in sewing than the girls.

Within this landscape, current research also suggests that e-textiles are not only effective tools for engaging women in computer programming and engineering, but might also lead to improved learning outcomes of STEM disciplinary content versus traditional approaches to these subjects (Kafai & Peppler, 2014). Over the past few decades, traditional circuitry construction kits have been failing young learners, as they are arriving at college without an understanding of the big ideas important to electronics and computing (for a review see Peppler & Glosson, 2013 as well as Maloney et al., 2008). Research over the years has consistently shown how students have misconceptions about circuitry concepts and procedural knowledge stemming from the tools and materials used in classroom learning experiences (Andersson & Karrqvist, 1979). In further probing for misconceptions among undergraduates enrolled in introductory physics and engineering courses, Fredette and Lockhead (1980) concluded that schools needed to be more explicit in helping students understand how all elements of a circuit require voltage to pass through an IN and an OUT terminal in early physics education.

In a 20-hour intervention study of conceptual understanding of circuitry after e-textile experiences, middle school youth were asked to use a set of LilyPad part stickers marked with clear positive and negative terminals to create a functioning circuit by drawing lines between the appropriate terminals (Peppler & Glosson, 2013). This assessment tested their knowledge of basic circuitry, specifically whether youth could create an overall working circuit, but more specifically, whether they understood three core concepts: current flow (i.e., completed circular paths with no redundancy or shorts), connections (i.e., completed lines successfully connecting one component to another and attention paid to the particular points of conductivity), and polarity (i.e., being mindful that the battery and LED have a positive side and a negative side). In this work, even students with prior experience constructing simple circuits could not translate this understanding to the new materials. However, after creating with e-textile materials, the authors found that students significantly increased their understanding of key circuitry concepts (Peppler & Glosson, 2013). Results demonstrated that students were able to diagram a working circuit considerably better in post-assessments than in pre-assessments. In addition, the students significantly increased their knowledge of current flow ($p < .05$), circuit polarity or directionality ($p < .05$), and connection ($p < .05$).

There is reason to believe that this understanding emerges through the embodied experience of designing e-textiles. Most novices to e-textiles do not fully understand the energy-transfer capabilities of physical objects and have difficulty distinguishing conductive from insulating materials. For example, even adult designers will incorrectly hypothesize that oil-based clay will be conductive (as they consider it to be "wet"; Peppler, Sharpe, & Glosson, 2013). Designers also often have to envision novel uses for existing materials (e.g., glass beads to insulate the conductive thread, a zipper on a hoodie to act as a switch in the circuit, or a patch of conductive fabric as a capacitor) or turn to new materials such as conductive yarn, paint, or thread. Coming up with new uses for mundane materials, or understanding the physical properties of unfamiliar materials, can take considerable trial and error.

Creating e-textiles requires a firm understanding of electronic circuitry, yet even simple circuits can pose a challenge to novice designers. For example, balancing the number of LEDs that can be lit by a 3V battery, accounting for Ohm's law, and wiring components in series and in parallel are all considerations that affect even the most basic e-textile construction (Peppler, Salen-Tekinbaş Gresalfi, & Santo, 2014). New materials also offer unique possibilities in electronic designs—for example, the natural resistance of conductive thread can be used instead of a traditional resistor or in place of a commercially available dimmer switch (i.e., the longer the thread, the greater the resistance in the circuit, and the shorter the thread, the less resistance in the circuit, which will cause the light to grow brighter). Much innovation in e-textile designs comes from creating textile analogs of traditional electronic components: soft speakers from magnets and conductive thread, switches from conductive beads, and so on (Perner-Wilson & Buechley, 2013).

Gathering STEAM: Discussion and conclusion

Comparing lessons learned across these two cases, there are key similarities and distinct differences in the ways that they combine STEAM. While both cases exemplify high quality STEAM practices, tools, and materials, they have different approaches to creating a transformative nexus of practice that rupture traditional norms and existing stagnant practices. It's important to note that both cases incorporate some ecology of creative production that integrates art with a lowercase "a" (such as making a traditional female crafts) and Art with a capital

"A" (such as fine arts subjects typically offered in schools and higher education institutions). In the case of Scratch, this is done through the combination of both visual and performing arts with traditional media production practices that frequently reference pop culture. In the case of the LilyPad Arduino, this is done through an emphasis on design and traditional female crafts.

As the field begins to move forward to design new tools and experiences for today's youth that have a similar power to disrupt, this may be a common design principle worth applying. It may be that this helps to create both relevance and accessibility (i.e., the everyday art forms may stress an ease and accessibility that contrasts with the culture and perceptions around traditional STEM practices, calling our traditional conceptions of the fields into question). Perhaps this hints at the larger synergy of a STEAM approach, making STEM fields more accessible and art fields more culturally valued.

The work presented above contains implications for policy makers in teacher education as well. When the important impact that these experiences can have on youth's learning and participation can be seen, it stands to reason that we should be more mindful of our preservice curriculum and field experiences to better engage early career teachers in transformative STEAM opportunities. There are also implications here about the potential benefit of more cross-disciplinary training as opposed to the popular preservice teaching model where students major in one discipline or electively emphasize one discipline over others. Thinking about recrafting higher education to bring STEAM into closer conversation may assist us in conserving what is unique about each disciplinary perspective while encouraging stronger connections across youth's learning experiences and bringing these increasingly integrated disciplines into closer conversation during the school years.

This work also provides implications for administrators and policy makers in arts education to think about tools needed in classrooms today as well as how to construct K–12 environments that allow for this type of teaching and learning. While art education can play a critical role in STEM disciplines and offer solutions to address STEM pipeline challenges, they are often relegated to the sidelines and underfunded in today's schools. Considering the open-platform or low-cost options available for creating the project types included here can help K–12 arts educators and administrators envision a sustainable 21st-century STEAM studio. It is important, of course, to consider the conversations that still need to take place in order for these experiences to occur: What kinds of staffing are needed and what kind of inservice professional development needs to be in place? Which tools and materials should be purchased and stocked in the classroom? How do we as a society evaluate the existing commercial tools and materials to make high quality and efficacious financial decisions? Taken together, there is a distinct need for future evaluation and research on the ever-increasing proliferation of new tools and environments to determine their efficacy for teaching and learning, as well as a need to develop new tools and materials that are equally expressive as the tools currently used in the arts classroom. These are but a few of the questions and challenges facing our administrators and policy makers today in the emerging STEAM landscape.

Such STEAM efforts extend current and prior discussions in the arts education landscape about the use of new technologies, and draw our attention to how new technologies can be leveraged for artistic expression. Further, the emphasis on computational approaches to new technologies broadens existing conversations around the new national Media Arts Standards that have focused to date on more production types of work, including animation and film-making, over the kinds of STEAM work showcased here.

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