Exploring the Influence of Equity-Oriented Pedagogy on Non-Dominant Youths’ Attitudes Toward Science Through Making

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Abstract

The purpose of this qualitative case study was to explore how equity-oriented pedagogy infused with Making activities promoted five non-dominant middle school youths’ attitudes toward science in an after-school program in the Midwestern United States. The researchers conducted pre- and post-interviews with five students from non-dominant backgrounds, and also administered attitudinal surveys to the five students at two time points (pre/post). Additionally, the researchers observed the level of student participation by video recording each after-school session, observed the level of student anxiety by using skin temperature biofeedback, and examined student artifacts. The findings revealed three themes. This study found that equity-oriented pedagogy infused with Making activities showed great potential in sustaining non-dominant youths’ positive attitudes toward science.

Keywords: after-school program, informal learning environments, maker education, non-dominant youth, physiological data, scientific argumentation

Introduction and Literature Review

Historically, engineering has not been a prominent component of K–12 education in the United States. The Next Generation Science Standards (NGSS Lead States, 2013) were intended to change this reality by integrating science and engineering practices into the curriculum and promoting engineering design as a critical element of K–12 education. When students start with engineering practices and design process thinking early, they develop important skills such as communication, collaboration, and inquiry that form a solid foundation for college and careers (NGSS Lead States, 2013). The Maker movement recently has burgeoned and shows great potential to integrate science and engineering practices in K–12 schools. Rapid adoption of Makerspaces has taken place in schools due to the technologically rich opportunities they provide and the hands-on nature of school activities. By definition, Makerspaces are physical locations in which students can work individually or in groups to
create a physical product through designing, prototyping, and manufacturing with tools and resources. Students who use Makerspaces benefit from the support of a larger community with a potentially diverse skillset (Blikstein et al., 2017; Chu et al., 2017).

**Makerspaces and STEAM**
The terms STEAM (science, technology, engineering, arts, and mathematics) and Makerspaces often are associated with each other because Makerspaces provide a space for hands-on STEAM learning and exploration. For example, the NASA STEAM Innovation Lab is a Makerspace approach to bringing NASA’s universe of knowledge into educational spaces around the country and to increase scientific literacy and interest in STEAM careers (Cline et al., 2020). Kumpulainen and Kajamaa (2020) studied the sociomaterial movements of student engagement in an elementary school’s Makerspace in Finland. They conducted a qualitative analysis of 85 hours of video recordings of 9–12-year-old students’ engagement in a Makerspace. The findings showed that the Makerspace engaged students and provided learning opportunities in STEAM.

Makerspaces take many forms. Some Makerspaces can be artistic in nature, with sewing, painting, and crafting projects, while other Makerspaces can be much more technical in nature and include tools such as 3D printers, electronics, robotics, and high-quality digital fabrication tools, which can afford students the opportunities to develop engineering practices. Sophisticated Makerspaces may include a collection of both high- and low-technology activities (Martin, 2015). Regardless of the activities taking place in Makerspaces, the philosophy of Makerspaces is to offer a place for students to learn through Making by providing an opportunity to create and share an artifact in a unique form that combines both self-directed learning and collaboration (Cohen et al., 2017).

**Makerspaces and Equity-Oriented Pedagogy**
Makerspaces commonly occur in after-school programs or summer camps and have the ability to enrich school curriculum and to bring equity-oriented pedagogy to informal learning contexts. In the current study, we define equity-oriented pedagogy as an approach to education in which teachers develop strategies and cultivate classroom environments that better support all students, particularly those who have been disadvantaged in school and in society in general (Banks & Banks, 1995). The strategies include careful examination of the power dynamics between adults and students in the space and ways to embrace students’ repertoires of knowledge and practice (Martin et al., 2018).

To date, little empirical research has been conducted on Makerspaces in K–12 informal learning settings (Papavlasopoulou et al., 2017). In their four-year critical ethnography study, Calabrese Barton and Tan (2018) studied how and why 48 youth from non-dominant groups engaged in Making during two making settings of an after-school, youth-focused, and community-based Makerspace program. The findings indicated that (a) framing youths’ experiences through the lens of equitably-consequential learning and (b) incorporating ways to develop youths’ identities as makers are critical in shaping the culture of the Makerspace for non-dominant youths. In particular, the practice of Making was principally shaped by youth’s values, desires, and community wisdom, which led to possible new opportunities for non-dominant youths’ science, technology, engineering, and mathematics (STEM) knowledge and practice. Community wisdom is an integrated base of knowledge, skills and assets that residents use to solve the community issues. The equity-oriented pedagogy included providing opportunities to draw on their home culture and knowledge coming from their families through discussion and reflection in the Making process, which further supported them in deepening and applying science and engineering knowledge and practice.

Vossoughi and Bevan (2014), in their ethnographic study involving 25 non-dominant youth (ages 15–20 years) in inquiry and meaning-making, also explored the role of equity-oriented pedagogy by blending STEM practices/concepts and artistic elements into a weekly Making after-school program that was delivered in urban communities. The findings revealed types of equity-oriented pedagogy involving co-making that can build intellectual safety and offer specific forms of guidance in the Making process for non-dominant youth. The equity-oriented pedagogy included encouraging related STEM practices (e.g., observing) and providing opportunities for reflecting and reaffirming value placed on iteration and experimentation in the Making process. As such, these youth developed new relationships with the act of learning in Making contexts, including the development of confidence in problem solving.
The above studies point out that Making in the context of after-school programs can provide an effective learning environment to support youths’ development of identities in science, promote active participation in science and engineering practices, and leverage cultural resources. Specifically, with equity-oriented pedagogy, the emergence of Makerspaces for creative engineering and science can potentially close gaps in opportunities for non-dominant youth to participate in STEM activities (Bevan, 2017; Cohen, 2018; Dawson, 2017; Oakes et al., 1990; Quinn & Cooc, 2015; Sheridan et al., 2014). In this study, we used Making activities to refer to a combination of engineering, art, and design practices that take place in Makerspaces (Wagh et al., 2017).

**Constructivism and Making**

In this study, we used constructivism (Piaget, 2013) as a guiding framework and focused on the features of play and experimentation to ground our design of equity-oriented Making activities in an after-school program (Vossoughi et al., 2013). Play and experimentation are valuable elements of constructivist learning (Reaney, 2019) that have been adopted into Maker education. Play involves the consideration of combinations of novel ideas and the hypothetical outcomes of imagined scenarios. It allows learners to engage in mental exploration in which they can create, reflect on, and enhance their understanding. Likewise, experimentation involves the manipulation and testing of ideas and provides learners with direct feedback about the accuracy of their ideas as they develop them. Play and experimentation are powerful forces in the cognitive development of learners. Typically, the features of play and experimentation are missing in formal science learning and could be promoted by an after-school program, a form of informal science learning (Fisher-Maltese et al., 2018). Studies on constructivist approaches to science education have shown potential in enhancing learners’ attitudes toward science (Semerci & Batdi, 2015; Toraman & Demir, 2016).

**Attitudes Toward Science**

Research indicates that positive attitudes toward science can lead to increases in science achievement (Osborne et al., 2003). Attitude toward science generally refers to the feelings, beliefs, and values held about an object that may involve the enterprise of science, the impact of science on society, school science, or scientists themselves (Klopfer, 1971). Over the past several decades, research has explored the construct of attitudes toward science and has been effective in validating interrelated sub-constructs (Hong & Lin, 2011).

In 2007, the Trends in International Mathematics and Science Study (TIMSS) developed and provided validity evidence for three scales to measure students’ attitudes toward science. These scales represent three aspects of students’ attitudes toward science: liking science, confidence in science, and valuing science. Validity evidence for the TIMSS scales has been sustained in subsequent versions of TIMSS (Martin & Preuschoff, 2008; Martin et al., 2016). In this study, we used three dimensions of students’ attitudes toward science (liking science, confidence in science, and valuing science) to guide the qualitative data analysis. Furthermore, this study aims at examining one of the critical sub-constructs of confidence in science—anxiety toward science (Osborne et al., 2003).

Attitude toward science primarily has been examined using self-reported survey data (Semerci & Batdi, 2015; Toraman & Demir, 2016). Obtaining physiological data can also offer insights into attitudes toward science. Research from the past several decades (e.g., Carlton et al., 2020; Sano & Picord, 2013; Vos et al., 2012) has indicated that a variety of physiological signals (e.g., skin temperature) have potential in identifying levels of anxiety. Herborn et al. (2015), for example, indicated that skin temperature temporarily drops under acute anxiety. Dyke (2016) investigated levels of stress experienced by neurosurgeons using biodot technology, which measures skin temperature and can be an indicator of physiological stress, to assess the levels of stress experienced by neurosurgeons before and after performing operations. Sahler and Zhao (2017) investigated the effect of incorporating biodot technology into the management plan on healthcare resource utilization among adolescents with anxiety issues. To date, the use of such physiological data has been adopted widely in the disciplines of medical, healthcare, and special education. The present study continues this trend by using biodot technology to collect physiological data to explore students’ attitudes toward science, specifically anxiety toward science.

**Purpose of the Study**

To provide nuanced insight into youths’ attitudes toward science, the present qualitative study explored how equity-oriented pedagogy infused...
with Making activities promoted five non-dominant middle school youth’s attitudes toward science in an after-school program in the Midwestern United States. To address the limitations of prior studies, which have relied exclusively on self-report survey data, this study employed video-taped observation of youths’ affective behaviors to assess their attitudes toward different Making activities and experiences and also employed the use of skin temperature biofeedback. Specifically, the following research question was posed: How does equity-oriented pedagogy infused with Making activities promote five non-dominant middle school youths’ attitudes toward science in an after-school program?

Methods
In this study, a qualitative multiple-case design (Yin, 2018) enabled us to explore and compare the similarities and differences of each case in which each case consists of a youth who participated in a year-long (fall and spring semesters) after-school program. In spring, the school closed early in early March due to the COVID-19 pandemic.

Site and Participant Selection
We selected a middle school located in a suburban area in northern Illinois in which about 76% of students came from low-income families. This school district aims to serve students from underrepresented populations and diverse ethnic student populations (i.e., African American 20%, Asian 3%, Caucasian 20%, Hispanic 52%). We used a purposeful, criterion sampling strategy (Patton, 1990) to select six 12-year-old youths (three male and three female) from non-dominant groups enrolled in a science teacher’s sixth grade science classes that consisted of a total of 150–160 students. In the present study, the terms “dominant” and “non-dominant” groups are used with reference to student diversity (Paris & Alim, 2014). The non-dominant group(s) refer to student groups that historically lack social prestige and institutionalized privilege and include economically disadvantaged students, students from underrepresented groups, and girls. The selection criteria included aspiration to learn science and interest in participating in Making activities. None of the students had attended a science after-school program or science summer programs in the past. One of the male students withdrew from the program in the middle of the year because he had to move to another school district due to his father’s new job, so the final data set included five participants: Sally, Gigi, Aala, Terry, and Neal (all pseudonyms).

Description of the Makerspace-Infused Activities
To align with the Next Generation Science Standards and Illinois Learning Standards in the United States, the development team designed an interdisciplinary curriculum that involved students in both science practices (e.g. observing) and engineering practices (e.g. design sketches) and promoted their ability to apply STEM practices in Making activities. There were five persons involved in the curriculum development and implementation. The team was composed of one male instructor with background in mechanical engineering, one female instructor with background in chemical engineering, one female instructor with background in general science, and two instructors with background in science education. We started the after-school program in October to give the teachers time to recruit students in the fall semester.

From the fall semester to early March in the spring semester, the topics included an introduction to science and engineering practices, exploration of STEM career choices, how to do 3D sketches, how to design in Tinkercad, how to use 3D printers, and printing a self-created design with a 3D printer. We encouraged the students to work together because the philosophy of the Makerspace is to promote collaboration. We found that, while the students worked independently, they also critiqued each other’s work and offered help when their peers had any questions.

Due to the COVID-19 pandemic, the school ceased the face-to-face instruction in early March. Due to the hands-on nature of the activities, we were not able to continue with three topics (introduction to alternative energies, building a solar car with a 3D printer, and conducting car testing/car race), which might be a limitation of this study. However, the topics covered from the fall semester to early March in the spring semester provided us an understanding of how the students were engaged in the STEM practices in engineering design process with 3D printing and the findings provided sufficient evidence to answer the research question.

Data Collection
We collected multiple sources of data to explore how equity-oriented pedagogy infused with Making activities promoted five non-dominant middle school youth’s attitudes toward science in an after-school program.
In-Depth Interviewing
We conducted pre- and post-interviews with five student participants. Each pre- and post-interview with each student took approximately 30 minutes. Interview prompts were geared toward exploring how the after-school program influenced the students’ attitudes toward science, and included questions such as, “Do you like science?” The pre-interviews were conducted face-to-face. The post-interviews were conducted via phone due to the COVID-19 pandemic.

Surveys
We administered the TIMSS (Trends in International Mathematics and Science Study; Martin et al., 2016) Student Attitudes Toward Science Survey to five students at two time points (pre/post). The survey measuring attitudes toward science has three scales, including Students Confident in Science, Students Like Learning Science, and Students Value Science. Each scale consisted of 5–9 Likert-type items—e.g. “Science is not one of my strengths” (Students Confident in Science), “I enjoy learning science” (Students Value Science), and “I would like a job that involves using science” (Students Value Science)—and administration of the three scales took approximately 20 minutes. Internal consistency (reliability) coefficients for these scales ranged from .81 to .88 (Martin et al., 2016).

Observation
We set up one video camcorder that recorded from the back of the classroom to best capture the level of each student’s participation in each activity at each session. The observation also included weekly conversations between the instructors and the students as well as among students. Each video clip lasted for 75 minutes.

Review of Artifacts
We collected each student’s weekly journal, their design on TinkerCAD, and their science notebook that had their design notes and design sketches. In the weekly journal, we provided prompts related to two essential components of scientific argumentation, the claim and the evidence, to guide participants to reflect on scientific phenomena and on engineering design processes (Sampson et al., 2012). A claim is a scientist’s position that they must justify with evidence. Evidence is a separate idea or example that supports a claim and comes from observation or experimentation. For example, in the journal, we prompted participants to answer whether a 3D printer runs in two or three dimensions and asked them to provide evidence after they observed how a 3D printer runs.

Physiological Data
We applied biodots to the back of each student’s hand to measure their level of anxiety at each session. When a student feels anxious, the capillaries constrict and the blood flow to the skin decreases, causing the skin temperature to drop. When the skin temperature drops, the biodots change color, turning black when a student is anxious and turning brown when a student is slightly anxious. Otherwise, the biodots remain green. One research assistant monitored the color of the biodots and recorded the color changes.

Data Analysis
We used cross-case synthesis (Yin, 2018) to analyze five cases. First, we began identifying the within-case patterns. We conducted the analysis using two coders with two cycles of coding. We followed the coding method outlined by Saldaña (2015) for qualitative inquiry, which prescribes a cyclical model that moves from codes to categories and eventually themes. In this method, the first-cycle coding involves a direct description of the data. The following explains how we developed the first theme. We began assigning data-driven descriptive codes to all data sources from a participant that reflected the same phenomenon. In the pre-interview, Sally indicated that she would like to be a “massager” (i.e. masseuse). We assigned a data-driven descriptive code, NSTEM-CC, to indicate a non-STEM career choice. In the post-interview, Sally changed her mind and stated that she wanted to be an environmental scientist. We assigned a data-driven descriptive code, STEM-CC, to indicate a STEM-related career choice. The observation data showed that Sally’s informal conversations in the classroom were consistent with what she shared in the interviews. We assigned the codes NSTEM-CC or STEM-CC to the excerpts of the conversations that involved her career choices. In the observation data, we also assigned a number of data-driven descriptive codes to the instructors’ equity-oriented pedagogy. For example, we assigned the code ED-PEDA to indicate that the instructors were engaged with the youths in discussion. We also assigned the code STORYT-PEDA to indicate that the instructors shared their personal stories about career choices. We repeated the same procedure to assign codes to all data sources of each participant in the first cycle. In the first cycle coding, 30 descriptive codes were generated.
The second cycle coding entailed classifying each of the descriptive codes to one of three category codes. We followed Martin’s et al. (2016) conceptualization of attitude toward science and focused our analysis using three category codes: their value of science, their confidence in science, and how they like science (Table 1). For example, for the first theme, we aggregated all data sources that were assigned the codes that indicate how much students value science, including career choices (e.g., NSTEM-CC vs. STEM-CC) and labeled them with the second-cycle category code, VS (Value Science), because STEM career choice is an important indicator of valuing science. Additionally, we examined each participant’s scores on the three scales of the TIMSS Student Attitudes Toward Science Survey (Students Like Learning Science, Students Confident in Science, and Students Value Science). For example, on the Students Value Science scale, Sally scored 10 on the pre-survey and 21 on the post-survey. Her scores increased from “Somewhat Value” to “Value” in the three levels ranging from “Value,” “Somewhat Value,” and “Do Not Value.” Table 2 presents each participant’s pre-survey and post-survey score on each of the three scales. In terms of within-case analysis, we analyzed how the attitudinal construct of valuing science was influenced by an after-school program that infused Maker education, and we also examined the relationships between the attitudinal construct of valuing science and other associated factors. For example, for the data that were assigned the category code VS (Value Science), we found that when Aala shared ideas for career choices in her pre-interview, she was not able to state what she wanted to be. But the discussion in the after-school program prompted her to have a conversation with her mother. She related her mother’s story about getting married at age 14 and stated that she wanted to have a STEM-related career such as a doctor, which reflected her increased value of science. When examining the associated factors for her changed value of science, we found that in the Making activities the instructors were able to afford her opportunities to engage in the

| Table 1 | Category codes | Definition | Examples/ Data Source |
|---------|----------------|------------|----------------------|
| Categories | Code | Definition | |
| Value Science | VS | How much students value science | Sally realized that being a scientist will be more fun to do./Post-Interview |
| Confidence in Science | CS | How well students can perform in science | Some students’ biodots appeared to be black in the design process./Biodots |
| Like Science | LS | How well students enjoy learning science | Terry was dedicated to his design in Tinkercad/Observation |

| Table 2 | Participant’s scores on the TIMSS student attitudes toward science Pre-Survey and Post-Survey |
|---------|---------------------------------------------------------------------------------------------------------------------------------|
| Scale   | Students Like Learning Science | Students Value Science | Students Confident in Science |
| Sally   | Pre: 14 (Like) Post: 14 (Like) | Pre: 10 (Somewhat Value) Post: 21 (Value) | Pre: 19 (Confident) Post: 20 (Confident) |
| Gigi    | Pre: 14 (Like) Post: 14 (Like) | Pre: 15 (Value) Post: 16 (Value) | Pre: 12 (Confident) Post: 14 (Confident) |
| Aala    | Pre: 15 (Like) Post: 15 (Like) | Pre: 18 (Value) Post: 18 (Value) | Pre: 16 (Confident) Post: 25 (Confident) |
| Terry   | Pre: 18 (Like) Post: 15 (Like) | Pre: 17 (Value) Post: 17 (Value) | Pre: 25 (Confident) Post: 25 (Confident) |
| Neal    | Pre: 15 (Like) Post: 7 (Do Not Like) | Pre: 8 (Don’t Value) Post: 12 (Somewhat Value) | Pre: 16 (Confident) Post: 14 (Confident) |
discussion of STEM career choices and adopt storytelling to help her contextualize STEM career choices, thus promoting her value of science. After drawing some tentative conclusions from these within-case patterns, we examined the relationships across the cases and developed the first theme. Then we continued to develop the second and third themes. The inter-rater reliability for the two levels of coding was about 87%. This study adopted triangulation, peer debriefing, and thick description to ensure trustworthiness had been met (Lincoln & Guba, 1985).

Findings and Discussion

In this section, we present the three emergent themes together with discussion. The three themes we identified were:

- **Theme One**: In the Making activities, the instructors were able to afford the youths opportunities to engage in the discussion of STEM career choices and adopt storytelling to help them contextualize STEM career choices, thus promoting their value of science.
- **Theme Two**: In the Making activities, the instructors afforded the students opportunities for experimenting with their design ideas, which helped them to sustain confidence in science.
- **Theme Three**: In the Making activities, the instructors adopted prompts in journaling to hone the youths’ science and engineering practice that provided fun and challenging elements distinct from formal science learning, which sustained their liking of science.

**Theme One: In the Making Activities, the Instructors were Able to Afford the Youths Opportunities to Engage in the Discussion of STEM Career Choices and Adopt Storytelling to Help Them Contextualize STEM Career Choices, Thus Promoting Their Value of Science**

Based on the data from the TIMSS “Students Value Science” scale (Table 2), Gigi’s score increased slightly from the pre-survey to the post-survey. Aala’s and Terry’s scores remained the same. These three students’ scores fell into the “Value Science” level in the three levels ranging from “Value,” “Somewhat Value,” and “Do Not Value” science. In contrast, Neal’s and Sally’s scores increased notably. Neal’s level of valuing science changed from “Don’t value” to “Somewhat Value,” and Sally’s level of valuing science changed from “Somewhat value” to “Value.”

In the first interview at the beginning of the program, Sally indicated a career choice that was not STEM-related. Specifically, she said, “I would like to be a massager. My dad is a lawn maintainer. His feet always hurt when he gets home.” Gigi, Aala, and Neal had no idea about what they would like to be. Terry stated that he would like to be an engineer, saying, “I found it’s interesting to build things.” In the post-interview in the spring, we asked Sally if she still wanted to be a massager. She said, “Not really because now I realize that being an environmental scientist will be more fun to do and I like that kind of stuff. I like to work with people.” Neal, Gigi, and Aala each shared that they would like to be a doctor. Terry again stated that he would like to be an engineer.

When we probed Sally, Neal, Gigi, and Aala for their career choices, they referred to an earlier discussion that took place with their instructors and their peers during the fall after-school program about STEM career choices and about the application of 3D printing. For example, when we introduced 3D printing in the fall, the instructors shared a story in which a college mechanical engineering major designed and printed prosthetics for an aspiring violinist born with one hand, using a laboratory-scale 3D printer. The observation data showed that all students were fascinated by this story and asked many questions such as, “Can the 3D printer we are going to use print prosthetics?” Additionally, the students asked about the applications of 3D printing in science, engineering, and medical fields and brainstormed their design ideas for 3D printing. Specifically, Neal, Gigi and Aala shared how the discussion in the after-school program inspired them to have a conversation with their parents or other family members about career choices. Gigi said, “I talked to my mom and dad. They encouraged me to be a doctor. That is my goal.” Neal said, “My mom is a nurse. I guess I want to be a doctor and I want to do research in medicine.” Aala said, “I talked to my mom. She got married at 14. She told me no one in the world will take care of me. I have to go to college and learn something useful.” She further commented, “My friends and my cousins want to do that [becoming a doctor]. I get to help people survive.”

In the Making activities, the instructors did not put strict time limitations on each activity. Given the playful nature of the Making activities, from the beginning of the program the instructors were able to cultivate the youths’ STEM career choices by engaging them in thinking about what they would like
to become and in sharing their thoughts with their peers and the instructors. While they listened to their peers’ career choices and struggled with what they themselves would like to become, the discussion early in the program provided a catalyst for the youths to talk to their parents about the potential career choices and examine their family members’ career choices. Because the instructors provided information about STEM career choices associated with the 3D printing, the youths developed about a better sense of potential STEM career choices over time, which explains why they chose STEM careers at the end of the program.

This study showed that some of non-dominant youths’ career choices could be influenced by both their peers’ and their community and family members’ occupations or living experience, which can be considered as family-based funds of knowledge (Hedges et al., 2011; Smith & Lucena, 2015). Research also indicates that career decisions are being made by students as early as the middle grades (Tai et al., 2006). However, very little STEM career exploration occurs before high school. In this study, the exposure to STEM career options through the Making activities means that non-dominant youths are likely to make decisions about career choices with sufficient information (Cheng et al., 2020). They can choose a path before knowing about all the options.

The findings also show that the playful quality of the student experience infused with Making activities was effective in sustaining or increasing students’ value of science by contextualizing their STEM career choices by sharing the instructors’ personal stories. In this after-school program, the instructors introduced the various college STEM major fields of study and STEM-related careers associated with STEM practices (e.g., observation) and the engineering design process (e.g., sketches) in the Making activities. The instructors introduced various college majors related to science (e.g., environmental science), engineering (e.g., mechanical engineering) and medical fields as potential career choices and connected the discussion to their personal stories. For example, one of the instructors shared his story of becoming a mechanical engineer. He enjoyed taking apart different devices such as a weight calculator or a bicycle when he was a child but didn’t know how to put them back together. On several occasions, his father blamed him for this. When he grew up, he realized that he liked to observe what was inside each device and liked to build objects, which led him to choose mechanical engineering as his college major and become a mechanical engineer. While leading the youths in the design of their own object with Tinkercad, he showed them both his sketch for a 3D printing of gears for a model car as well as the gears that he actually printed. The other two instructors similarly shared their own stories of becoming a scientist.

Research (Moitra, 2014; Muindi et al., 2020) indicates that stories can be appealing educational tools because they engage students, are believable and entertaining, and enable students to easily recall facts from the story. Students have eagerly responded to the storytelling pedagogy, suggesting that it can be leveraged to help them grasp complicated theories, engage them, and help improve their retention in STEM fields. In this study, the storytelling provided an opportunity for the youths to contextualize STEM concepts and practices (e.g., observation, design) in the context of STEM major choices, which could create positive trajectories for their future careers and enable them to value science as means to achieve career goals (Schlegel et al., 2019; Vossoughi & Bevan, 2014).

**Theme Two: In the Making Activities, the Instructors Afforded the Students Opportunities for Experimenting with Their Design Ideas, which Helped Them to Sustain Confidence in Science**

Based on the data obtained from the TIMSS “Students Confident in Science” scale (Table 2), all students sustained their confidence in science. Sally’s and Gigi’s scores increased slightly and Aala’s scores increased notably from the pre-survey to the post-survey. Terry maintained the same score. Nolan’s score decreased slightly. Among the three levels of confidence (“Confident,” “Somewhat Confident,” and “Not Confident” in science), scores for all the students fell into the “Confident in Science” level. In the pre-interviews, Sally, Aala, and Gigi shared that they were not confident in science while Terry and Neal said they were confident in science.

A number of students’ biotos turned brown or black (slightly anxious to anxious) and, among these students, most of them were female students (Table 3). When they began learning how to operate a 3D printer during the fourth week, Sally’s and Aala’s bioto turned black (anxious) and Gigi’s bioto turned brown (slightly anxious). All boys’ biotos remained green (calm). During the seventh week when they first learned how to use Tinkercad
Table 3

| Week (and topic)                  | Sally | Gigi | Aala | Terry | Neal |
|---------------------------------|-------|------|------|-------|------|
| Week 1 (STEM majors and careers)| Green | Green | Green| Green | Green|
| Week 2 (STEM majors and careers)| Green | Green | Green| Green | Green|
| Week 3 (observing 3D printer)   | Green | Green | Green| Green | Green|
| Week 4 (Practice 3D printer)    | Black | Brown| Black| Green | Green|
| Week 5 (sketching)              | Green | Green| Green| Green | Green|
| Week 6 (Learn Tinkercad)        | Green | Green| Green| Green | Green|
| Week 7 (Tinkercad Design I)     | Black | Brown| Black| Green | Green|
| Week 8 (Tinkercad Design II)    | Black | Green| Black| Green | Green|
| Week 9 (3D printing)            | Green | Green| Green| Absent| Green|
| Week 10 (another Tinkercad design challenge) | Black | Black| Black| Black | Black|
| Week 11 (another Tinkercad design challenge) | Brown | Absent| Brown| Green | Green|
| Week 12 (3D printing)           | Green | Green| Green| Green | Absent|

Green = Calm, Brown = Slightly Anxious, Black = Anxious.

for their design, Sally’s and Aala’s biodot turned black and Gigi’s biodot turned brown. All boys’ biodots remained green. During the following (eighth) week of Tinkercad design practice, Sally’s and Aala’s biodots remained black and Gigi’s biodot remained green. All boys’ biodots remained green.

Figures 1 and 2 show Sally’s design and Terry’s design when they practiced the basic features of Tinkercad. During the tenth week when they began engaging in Tinkercad design challenge, the biodots of all students, regardless of gender, turned black. In the Tinkercad design challenge, they were asked to apply the advanced features (e.g., combining sections, carving out sections) to design a complex object. During the following (eleventh) week of Tinkercad design challenge, Sally’s and Aala’s biodots turned brown. All the boys’ biodots remained green.

Figures 3 and 4 show Sally’s design and Terry’s design when they applied the advanced features of Tinkercad in the Tinkercad design challenge. In particular, the female students indicated that learning a new topic or a new tool “made them more nervous.” The observation data also indicated that Sally, Aala, and Gigi tended to ask for the instructors’ help in the design process during the seventh week, the eighth week, the tenth week, and the eleventh week. In contrast, Terry and Neal seemed a bit anxious and asked a few questions during the tenth week when they began the Tinkercad challenge activity.

Numerous studies (e.g., Mallow et al., 2010; Quinn & Cooc, 2015) have suggested that girls tend to start losing confidence in science and engineering in the middle grades, and the difference between boys’ and girls’ level of anxiety toward science and engineering
appears to widen as they grow older. However, the current study showed mixed findings. Although the physiological data and the interview data suggested that the female students tended to show more anxiety in learning new science and engineering activities than the male students and the female students didn’t seem as confident as their male peers, the female students’ confidence scores increased and remained at the level of “Confident in Science” throughout the program. We provided each student two or more weeks to learn a new Making topic or learn a new Making tool so they had sufficient time to experiment with their ideas. Further, in the Making activities, the instructors offered students opportunities for experimenting ideas. As (lack of) anxiety is one sub-construct of confidence, experimenting with ideas has great potential to reduce non-dominant students’ anxiety in science and engineering and sustain their confidence in science and engineering, particularly for female students. As Aala said, “I was so glad that I could try it [Tinkercad] many times until I got it [design] right.” Sally sometimes felt initially frustrated when she could not execute her design the way she had planned. However, she was aided by the time afforded to her to complete the design. She commented, “Some of Tinkercad features [merge multiple objects and engraving text] are tricky. I was glad that I had more time to try them out.” Research (Ryoo & Kekelis, 2018; Vossoughi & Bevan, 2014) points out that in the context of Making, the instructors could reframe moments of struggle as essential to iteration and not consider them as failure when experimenting with new ideas. As such, because these youth embraced frustration and excitement in such processes and didn’t treat struggles as a form of failure, they may have been more willing to continue to try and, as a result, sustain their confidence.

**Theme Three: In the Making Activities, the Instructors Adopted Prompts in Journaling to Hone the Youths’ Science and Engineering Practice that Provided Fun and Challenging Elements Distinct from Formal Science Learning, which Sustained their Liking of Science**

Based on data obtained from the TIMSS “Student Like Learning Science” scale (Table 2), four out of the five students sustained their liking of science throughout the program. Sally’s, Gigi’s, and Aala’s scores stayed the same. Terry’s scores slightly decreased. All the scores fell into the “Like” level
in the three levels ranging from “Like,” “Somewhat Like,” and “Do Not Like.” However, Neal’s score substantially decreased and fell from the “Like” to the “Do Not Like” level. In their interviews, they regarded science as a subject full of fun and expressed how much they liked science. Terry and Gigi shared similar thoughts and commented, “Science is fun . . . I like to do projects.” Neal added, “I like science because I like to see chemical reactions . . . . I also understand how things in life really work.” Aala added, “It is fun to see many cool materials that I never saw before in science class.” Sally said, “I really like a triple beam balance and learn how much objects weigh.”

In the second interview at the end of the program, Terry said, “I still like science because I love doing experiments and learning new things.” Neal similarly stated, “I can still learn new things.” But he also added, “But most of time, for me, science is easy to get done.” Contrary to Neal, Gigi said, “I still do like science but it become a little challenging . . . . Well, I can still manage.” Sally’s and Aala’s comments were similar to Gigi’s and they thought that science became more difficult.

The analysis of weekly journals revealed that the students showed increased ability to use evidence to support their claim as they became better at observing and reflecting on scientific phenomena and on the engineering design process. During week three, when the students first learned how a 3D printer works, the prompt in the weekly journal was: “I think the 3D printer moves in ______ dimensions.” Sally entered “2,” while in the “My evidence is” prompt she wrote, “It looks like a printer.” In her journal, Aala entered “3” dimensions, but her evidence was, “It is called 3D printer.” During week four when they had more practice with a 3D printer, we asked them to fill out another journal with the similar prompts. The observation showed during week four that Sally, Gigi, and Aala spent more time standing next to the 3D printer and observing how it worked. Sally modified her answer from 2 to 3 dimensions and stated that her evidence was, “It goes up, down, and cross.” Gigi’s and Aala’s evidence was similar to Sally’s. Additionally, the observation showed that, compared to Sally, Gigi, and Aala, Nolan and Terry spent more time standing next to the 3D printer and observing how it worked during week three, and they did not modify their evidence very much from week three to week four.

During week five, the instructors integrated the isometric dots in the journal to help the students finish the shapes (i.e., cube, rectangular prism, triangular prism, and pentagonal prism) when they learned how to sketch 3D objects. The journal also prompted them to indicate whether the shapes were in two or three dimensions and to provide evidence for this. All students were able to finish the shapes and answered that the shapes were in three dimensions. Their evidence included statements such as “You can see the whole shape” and “It has more than 2 sides.”

Between week five and week eight, the students learned how to design in Tinkercad. The observations showed that that the students spent much time on rotating, reshaping, and scaling different objects in Tinkercad. During week eight when the instructors revisited the concept of 3D sketches, all students were able to finish the shapes on the isometric dots and answered that the shapes were in three dimensions. Their evidence became more solid and included, “You can see the depth,” “They pop out at you,” and “You add depth to it.” Additionally, Sally, Aala, Gigi, and Nolan sketched 3D objects in shapes other than the shapes appearing on the isometric dots to support their evidence (see Figures 5 and 6).

Engaging in argument from evidence is an essential science and engineering practice (Schwarz et al., 2017). In this study, the prompts for claim and evidence in a weekly journal showed potential for honing students’ observation skills and empowering them to provide more substantial evidence in the various after-school program activities. Literature on youth development shows that journaling is an effective way to support students’ ability to reflect on the activities in an after-school program (Marttinen et al., 2019; Safron, 2020). In Marttinen et al.’s study, non-dominant youth in an urban area in the eastern United States (New York) worked on basketball skills and responded to prompts through journals that revolved around weekly themes such as sportsmanship, culture, power, and communication in an after-school program. The prompts led them to reflect on how they changed their behavior and attitudes toward schooling over time. Research shows that prompts are appropriate means to focus learners’ deep processing of specific aspects of learning (Lin et al., 2016; Schworm & Renkl, 2007). The current study revealed that integrating prompts of claim and evidence into a journal had potential to support students’ development of scientific argumentation in the context of science and engineering practices.
In summary, the Making activities involved the youth in the essential science and engineering practices that they had not experienced in the formal science classroom. Having engaged in these activities, they could regard science as a challenging but fun subject to explore, which helped sustain their liking of science.

**Implications, Limitations and Conclusion**

This study found that equity-oriented pedagogy infused with Making activities showed great potential in sustaining non-dominant youths’ positive attitudes toward science. The use of discussion and storytelling was effective in sustaining or increasing non-dominant youths’ value of science. This study found that the discussion in the after-school program might motivate the youths to engage in conversations with their parents about career choices. Thus, the results from this study suggest that is important to provide youths with ideas to start conversations with their parents about STEM career choices and to provide parents with guidance about how to engage their children in this type of conversation. Research shows that parents play an essential role in promoting students’ motivation to study in STEM (Šimunović & Babarović, 2020).

This study also showed that experimenting with design ideas was effective in sustaining non-dominant youths’ confidence. The Making activities had potential in diminishing non-dominant young
adolescents’ anxiety toward science and engineering, particularly among girls, and thus helped sustain their confidence in science.

However, there are a number of limitations in this study. First, in this qualitative study, we used survey data as one of the data sources to supplement qualitative data and demonstrate how the students changed their attitude over time. We acknowledged that the sample size was small, however we did not intend to generalize the findings to a larger population. Another limitation of this study involved the use of biodots to help gain insight into the students’ anxiety levels. Because the biodots were located on the students’ hands and their hands were small, it was difficult for the observer to monitor the color changes. To ensure a more precise measure, we suggest the use of more advanced tools such as wearable technology to track and record students’ anxiety levels (Gjoreski et al., 2017). The study also showed that journaling allows youths to explore the interesting and challenging practices of science, which sustains their liking of science. This study suggested that research on different types of prompts (Lin et al., 2016) in a journal to support the

Figure 6. Neal’s 3D sketches in a journal.
reflection of STEM-related activities and the development of scientific argumentation is needed in informal science learning contexts.

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References

Banks, C. A. M., & Banks, J. A. (1995). Equity pedagogy: An essential component of multicultural education. Theory into Practice, 34 (3), 151–158. https://doi.org/10.1080/00405849509543674

Bevan, B. (2017). The promise and the promises of Making in science education. Studies in Science Education, 53(1), 75–103. https://doi.org/10.1080/03057267.2016.1275380

Blikstein, P., Kabayadondo, Z., Martin, A., & Fields, D. (2017). An assessment instrument of technological literacies in Makerspaces and FabLabs. Journal of Engineering Education, 106 (1), 149–175. https://doi.org/10.1002/jee.20156

Calabrese Barton, A., & Tan, E. (2018). A longitudinal study of equity-oriented stem-rich making among youth from historically marginalized communities. American Educational Research Journal, 55(4), 761–800. https://doi.org/10.3102/0028312118758668

Carlton, S., Harrison, A., Honoré, S., & Goodman, L. B. (2020). Conceal, don’t feel: Gender differences in implicit expressions of emotions. Modern Psychological Studies, 25(1), Article 10.

Cheng, L., Antonenko, P. D., Ritzhaupt, A. D., Dawson, K., Miller, D., MacFadden, B. J., Grant, C., Sheppard, T. D., & Ziegler, M. (2020). Exploring the influence of teachers’ beliefs and 3D printing integrated STEM instruction on students’ STEM motivation. Computers & Education, 158, 103983. https://doi.org/10.1016/j.compedu.2020.103983

Chu, S. L., Angello, G., Saenz, M., & Quek, F. (2017). Fun in Making: Understanding the experience of fun and learning through curriculum-based Making in the elementary school classroom. Entertainment Computing, 18, 31–40. https://doi.org/10.1016/j.entcom.2016.08.007

Cline, T., Odenwald, S., Davis, H., Stephenson, B., Mirel, P., Boyer, K., & Sasser, L. (2020). The STEAM innovation laboratory: Beyond the Makerspace paradigm. Journal of Computers in Mathematics and Science Teaching, 39(4), 291–313.

Cohen, B. (2018). Teaching STEM after school: Correlates of instructional comfort. The Journal of Educational Research, 111(2), 246–255. https://doi.org/10.1080/00220671.2016.1253537

Cohen, J., Jones, W. M., Smith, S., & Calandra, B. (2017). Makification: Towards a framework for leveraging the maker movement in formal education. Journal of Educational Multimedia and Hypermedia, 26(3), 217–229.

Dawson, E. (2017). Social justice and out-of-school science learning: Exploring equity in science television, science clubs and maker spaces. Science Education, 101(4), 539–547. https://doi.org/10.1002/sce.21288

Dyke, R. (2016). Neurosurgery and stress: How much stress are surgeons under? Inspire Student Health Sciences Research Journal, 34 (1), 34–37.

Fisher-Maltese, C., Fisher, D. R., & Ray, R. (2018). Can learning in informal settings mitigate disadvantage and promote urban sustainability? School gardens in Washington, DC. International Review of Education, 64(3), 295–312. https://doi.org/10.1007/s11159-017-9663-0

Gjoreski, M., Luštrek, M., Gams, M., & Gjoreski, H. (2017). Monitoring stress with a wrist device using context. Journal of Biomedical Informatics, 73, 159–170. https://doi.org/10.1016/j.jbi.2017.08.006

Hedges, H., Cullen, J., & Jordan, B. (2011). Early years curriculum: Funds of knowledge as a conceptual framework for children’s interests. Journal of Curriculum Studies, 43(2), 185–205. https://doi.org/10.1080/00202272.2010.511275

Herborn, K. A., Graves, J. L., Jerem, P., Evans, N. P., Nager, R., McCafferty, D. J., & McKeegan, D. E. (2015). Skin temperature reveals the intensity of acute stress. Physiology & Behavior, 152, 225–230. https://doi.org/10.1016/j.physbeh.2015.09.032

Hong, Z.-R., & Lin, H. (2011). An investigation of students’ personality traits and attitudes toward science. International Journal of Science Education, 33(7), 1001–1028. https://doi.org/10.1080/09500693.2010.524949

Klopfer, L. E. (1971). Evaluation of learning in science. In B. S. Bloom, T. Y. Hastings,
G. F. Madaus (Eds.), *Handbook of formative and summative evaluation of student learning* (pp. 549–561). McGraw-Hill.

Kumpulainen, K., & Kajamaa, A. (2020). Sociomaterial movements of students’ engagement in a school’s makerspace. *British Journal of Educational Technology, 51*(4), 1292–1307. https://doi.org/10.1111/bjet.12932

Lin, L., Atkinson, R. K., Savenye, W. C., & Nelson, B. C. (2016). Effects of visual cues and self-explanation prompts: Empirical evidence in a multimedia environment. *Interactive Learning Environments, 24*(4), 799–813. https://doi.org/10.1080/10494820.2014.924531

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

Mallow, J., Kastrup, H., Bryant, F. B., Hislop, N., Shefner, R., & Udo, M. (2010). Science anxiety, science attitudes, and gender: Interviews from a binational study. *Journal of Science Education and Technology, 19*(4), 356–369. https://doi.org/10.1007/s10956-010-9205-z

Martin, L. (2015). The promise of the Maker Movement for education. *Journal of Pre-College Engineering Education Research (J-PEER), 5*(1), Article 4. https://doi.org/10.7771/2157-9288.1099

Martin, L., Dixon, C., & Betser, S. (2018). Iterative design toward equity: Youth repertoires of practice in a high school maker space. *Equity & Excellence in Education, 51*(1), 36–47. https://doi.org/10.1080/10665684.2018.1436997

Martin, M. O., Mullis, I. V. S., Hooper, M., Yin, L., Foy, P., & Palazzo, L. (2016). Creating and interpreting the TIMSS 2015 context questionnaire scales (Chapter 15). In M. O. Martin, I. V. S. Mullis, & M. Hooper (Eds.), *Methods and procedures in TIMSS 2015* (pp. 1–312). TIMSS & PIRLS International Study Center.

Martin, M. O., & Preuschoff, C. (2008). Creating the TIMSS 2007 background indices. In J. F. Olson, M. O. Martin, & I. V. S. Mullis (Eds.), *TIMSS 2007 technical report* (pp. 281–338). TIMSS & PIRLS International Study Center.

Marttinen, R., Johnston, K., Phillips, S., Fredrick, R. N., & Meza, B. (2019). Reach Harlem: Young urban boys’ experiences in an after-school positive youth development program. *Physical Education and Sport Pedagogy, 24*(4), 373–389. https://doi.org/10.1080/17408989.2019.1592147

Moitra, K. (2014). Storytelling as an active learning tool to engage students in a genetics classroom. *Journal of Microbiology & Biology Education, 15*(2), 332–334. https://doi.org/10.1128/jmbe.v15i2.815

Muindi, F. J., Ramachandran, L., & Tsai, J. W. (2020). Human narratives in science: The power of storytelling. *Trends in Molecular Medicine, 26*(3), 249–251. https://doi.org/10.1016/j.molmed.2019.12.001

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.

Oakes, J., Ormseth, T., Bell, R., & Camp, P. (1990). *Multiplying inequalities: The effects of race, social class, and tracking on opportunities to learn mathematics and science*. RAND.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education, 25*(9), 1049–1079. https://doi.org/10.1080/0950069032000032199

Papavlasopoulou, S., Giannakos, M. N., & Jaccheri, L. (2017). Empirical studies on the Maker movement, a promising approach to learning: A literature review. *Entertainment Computing, 18*, 57–78. https://doi.org/10.1016/j.entcom.2016.09.002

Paris, D., & Alim, H. S. (2014). What are we seeking to sustain through culturally sustaining pedagogy? A loving critique forward. *Harvard Educational Review, 84*(1), 85–100. https://doi.org/10.17763/haer.84.1.9821873k2h16m77

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. SAGE Publications.

Piaget, J. (2013). *The construction of reality in the child* (Vol. 82). Routledge.

Quinn, D. M., & Cooc, N. (2015). Science achievement gaps by gender and race/ethnicity in elementary and middle school trends and predictors. *Educational Researcher, 44*(6), 336–346. https://doi.org/10.3102/0013189X15598539

Reaney, M. J. (2019). *The place of play in education*. Routledge.

Ryoo, J. J., & Kekelis, L. (2018). Reframing “failure” in making: The value of play, social relationships, and ownership. *Journal of Youth Development, 13*(4), 49–67. https://doi.org/10.5195/jyd.2018.624

Safron, C. (2020). ‘No perfect image’: Health, fitness and visual affects with youth after-school. *Physical Education and Sport Pedagogy, 25*(3), 225–239. https://doi.org/10.1080/17408989.2020.1741535
Sahler, O. J. Z., & Zhao, J. (2017). Effect on healthcare utilization of incorporating biofeedback into the management of pain and anxiety in adolescents. *Alternative and Complementary Therapies, 23*(4), 139–143. https://doi.org/10.1089/act.2017.29122.ojs

Saldaña, J. (2015). *The coding manual for qualitative researchers*. Sage Publications.

Sampson, V., Enderle, P. J., & Walker, J. P. (2012). The development and validation of the assessment of scientific argumentation in the classroom (ASAC) observation protocol: A tool for evaluating how students participate in scientific argumentation. In Khine, M. (Ed.), *Perspectives on scientific argumentation* (pp. 235–264). Dordrecht: Springer.

Sano, A., & Picard, R. W. (2013, September). Stress recognition using wearable sensors and mobile phones. In *2013 Humaine Association Conference on Affective Computing and Intelligent Interaction* (pp. 671–676). IEEE.

Schlegel, R. J., Chu, S. L., Chen, K., Deuermeyer, E., Christy, A. G., & Quek, F. (2019). Making in the classroom: Longitudinal evidence of increases in self-efficacy and STEM possible selves over time. *Computers & Education, 142*, 103637. https://doi.org/10.1016/j.compedu.2019.103637

Schwarz, C. V., Passmore, C. M., & Reiser, B. J. (2017). Moving beyond “knowing” science to making sense of the world. In C. V. Schwarz, C. M. Passmore, & B. J. Reiser (Eds.), *Helping students make sense of the world using next generation science and engineering practices* (pp. 3–21). National Science Teachers Association Press.

Schworm, S., & Renkl, A. (2007). Learning argumentation skills through the use of prompts for self-explaining examples. *Journal of Educational Psychology, 99*(2), 285. https://doi.org/10.1037/0022-0663.99.2.285

Semerci, Ç., & Batdli, V. (2015). A meta-analysis of constructivist learning approach on learners’ academic achievements, retention and attitudes. *Journal of Education and Training Studies, 3*(2), 171–180. https://doi.org/10.1111/jets.v3i2.644

Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4), 505–531. https://doi.org/10.17763/haer.84.4.brr34733723j648u

Šimunović, M., & Babarović, T. (2020). The role of parents’ beliefs in students’ motivation, achievement, and choices in the STEM domain: A review and directions for future research. *Social Psychology of Education, 23*(3), 701–719. https://doi.org/10.1007/s11218-020-09555-1

Smith, J. M., & Lucena, J. C. (2015). Invisible innovators: How low-income, first-generation students use their funds of knowledge to belong in engineering. *Journal of Engineering Studies, 8*, 1–26. https://doi.org/10.1080/19378629.2016.1155593

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Life Science, 312*(1), 1143–1144.

Toraman, C., & Demir, E. (2016). The effect of constructivism on attitudes towards lessons: A meta-analysis study. *Eurasian Journal of Educational Research, 16*(62), 115–142.

Vos, P., Cock, P. D., Munde, V., Petry, K., Noortgate, W. V. D., & Maes, B. (2012). The tell-tale: What do heart rate; skin temperature and skin conductance reveal about emotions of people with severe and profound intellectual disabilities? *Research in Developmental Disabilities, 33*(4), 1117–1127. https://doi.org/10.1016/j.ridd.2012.02.006

Vossoughi, S., & Bevan, B. (2014). Making and tinkering: A review of the literature. *National Research Council Committee on Out of School Time STEM* (pp. 1–55).

Vossoughi, S., Escude, M., Kong, F., & Hooper, P. (2013). Tinkering, learning & equity in the after-school setting. In *Annual FabLearn conference*, Stanford University. http://fablearn.stanford.edu/2013/papers/

Wagh, A., Gravel, B., & Tucker-Raymond, E. (2017, October). The role of computational thinking practices in making: How beginning youth makers encounter & appropriate CT practices in making. In *Proceedings of the 7th Annual Conference on Creativity and Fabrication in Education* (pp. 1–8). FabLearn 17.

Yin, R. K. (2018). *Case study research and applications: Design and methods*. Sage Publications.