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Girls and 3D Printing: Considering the Content, Context, and Child

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Interdisciplinary and International Perspectives on 3D Printing in Education

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Chapter 7
Girls and 3D Printing:
Considering the Content, Context, and Child

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ABSTRACT

Using Guernsey's framework for technology use with young children, this case study examines two middle elementary grade female students as they experience 3D printing in a Makerspace environment. In this case study, the girls spent a day working with a Makerspace staff member to learn how to 3D print a design of their choice from Thingiverse. The case study provides a chance to analyze the reactions, discourse, and activities of two girls introduced to 3D printing in a makerspace. The authors sorted the verbalizations, behaviors, and actions of the two girls into a reflection on the concepts of content, context, and child put forth by Guernsey.

INTRODUCTION

Around the globe, educators are scrambling to keep pace with the development and deployment of technological devices. Within the United States, early childhood and elementary school students are routinely using tablets, laptops, and programmable robots. Technology classes are introduced as young as kindergarten and skills that were once considered advanced in the curriculum, such as coding and typing, are now considered basic skills that should be in place in the elementary years. Sophisticated devices such as three dimensional (3D) printers, conceived of mainly for science or manufacturing purposes, are now sought after in well-funded elementary schools.

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Even experts in the field such as the National Association for the Education of Young Children (NAEYC) and the Fred Rogers Center for Early Learning and Children's Media in their 2012 joint position statement refer to 3D printing as "represent[ing] the next frontier in digital learning for our youngest citizens, leaving it to talented educators and caring adults to determine how best to leverage each new technology as an opportunity for children's learning in ways that are developmentally appropriate" (p. 3). One of the most troubling issues with the rapid adoption of these devices in public schools is the prevailing view that they should be purchased first, with integrating into the school curriculum and childhood activities as a necessary second step. This approach runs contrary to the detailed work outlining objectives and growth slopes in most areas of the United States public education system and it risks facilitating uneven or unequal experiences with technology by leaving unexamined the biases or differing expertise of the teachers or caring adults referred to in the statement. The onus for responsible decisions is on individual educators, leaving it in their hands to "...make informed decisions about how, when, and why to support early learning and healthy development through technology and digital media" (Donohue & Schomberg, 2015, p. 36). And reports show that while educators look favorably on technology as a whole, seeing it as a way to motivate students, respond to differing learning styles, and to reinforce content lessons (PBS Learning Media, 2013); they also delay adopting new technologies or limit their use because they do not feel prepared to meet the needs of all students with unfamiliar technology (Hew & Bush, 2007).

One of the many factors for which teachers need to account in technology education is the inequality of technology experiences across genders. Viewing technology adoption and use through Guernsey's (2007) lens, the efficacy will be greatly increased if educators consider the factors of child, context, and content. Looking at the current state of females in STEM fields in the United States, it is obvious and necessary that early experiences with technology such as 3D printing take gender into account. For example, research continues to indicate that women account for a small percentage of professionals in the technology and engineering workforce (National Girls Collaborative Project, 2017; National Science Board, 2016; Turner, Burnt & Pecora 2002; Beede, Julian, Langdon, McKittrick, Khan & Doms, 2011). In order to address this challenge educators and parents need to examine and address biases, opportunities, and curriculum for girls during the elementary and middle school years. Previous research indicates several themes, which create barriers to girls' interest in engaging with science, technology, engineering, and mathematics (STEM) activities and entering the workforce in technology and engineering fields. Main themes include cultural and environmental challenges, lack of relevance, and insufficient support structures.

Stereotypes and biases reveal the impact that our culture and environment have on perceptions on the success that girls have in STEM fields. Stereotypically, technology and careers associated with technology tend to be gendered towards males and perceptions that males are more successful than females in math and science education are prevalent (Andersson, 2012; Dell, Christman & Garrick, 2011). In addition, relevancy of content and activities have been shown to deter girls from pursuing course work or careers in the areas of technology and engineering (Chatoney & Andreucci, 2009; Amador & Soule, 2015). Traditionally, curriculum and activities in technology education have been created in closer alignment with typical male interests and hobbies, which does not provide girls with content that is engaging or relevant to their learning. Finally, there are insufficient support structures, including role models and peer groups, that are needed to provide a foundation for girls who are interested in pursuing technology related activities or careers (Dell et al., 2011; Hill, Corbett, Rose & American Association of University, 2010; National Science Foundation and Extraordinary Women Engineers Coalition, 2005).

Previous research suggests a variety of strategies for engaging girls with technology. The age at which it is introduced in a school setting matters. Technology and engineering curriculum should be introduced to girls at the elementary and middle school levels to provide them with experience and confidence in the STEM disciplines (Dell et al., 2011; Mammes, 2004). Also, girls should be introduced to technology with their peers. Previous studies indicated that girls are more successful and confident when working with other girls in a male-dominated discipline (Dell et al., 2011). In addition to peers, educators and parents should be positive role models by providing encouragement and academic support. Previous studies suggest that girls should be engaged with technology, take ownership of their project, and complete it on their own (Amador & Soule, 2015; Dell et al., 2011; National Science Foundation and Extraordinary Women Engineers Coalition, 2005). Girls will build their own confidence if they understand their personal abilities and make achievements in the areas of math and science. (Andersson, 2012; Hill et al., 2010).

MAIN FOCUS OF THE CHAPTER

There is very limited research on the use and impact of 3D printing in the K-12 learning environments, especially with girls. Providing girls with 3D printing activities can support strategies that are successful in engaging girls with technology. Activities should allow girls to take ownership of their project and work with peers, which will create a supportive environment. The content and problems included in a 3D printing activity should be flexible, ungendered, or geared towards females, thus creating relevancy. This chapter will use a case study to investigate strategies and planning that facilitate girls' engagement and learning in the 3D printing experience. The authors will thoroughly review the literature, using the framework provided by Guernsey (2007) to examine best practices integrating technology into elementary level classrooms. The case study observations and notes will be presented within the context of this framework, with special attention paid to those factors that align with or significantly deviate from the best practices as understood in general technology integration.

BACKGROUND

There are many potential benefits to incorporating STEM education in elementary classrooms, particularly for female students. Generalized goals for young students in the United States educational system have been summarized as: enhancement of cognitive, language, and socials skills (Hyson & Tomlinson, 2014). Increasing experience with STEM tasks may help facilitate those general goals. Researchers have previously linked STEM education with inquiry-based learning and the 'maker-mentality' allows students to collaborate, explore, create and discuss (Coiro, Castek, & Quinn, 2016; Dewey, 1938/1997). The overall goals of STEM education have been summed up in two areas: intellectual and academic. The intellectual goals are: reasoning, hypothesizing, predicting, and the development/analysis of ideas. The academic goals are more concrete skills such as counting and measuring (Highfield, 2015). 3D printing, in particular, is theorized to allow students to engage in both the intellectual and academic goals of STEM tasks (Highfield, 2015; Schaffhauser, 2013). However, as with any instructional technique or device, the power of such experiences is best documented by uses with actual students. New technologies such as 3D printing require reference to principles of learning as a way of integrating the challenges and capabilities of the technology with the previously established frameworks for instruction. When considering integration of new technologies into education settings such as elementary schools, educators are encouraged to consider the technology within a learning theory framework. Most studies reference the TPACK framework (Mishra & Koehler, 2006) to provide this theoretical model for connecting technology with learning. However, for young children and in practical considerations, the *Framework for Quality in Digital Media for Young Children: Considerations for Parents, Educators, and Media Centers* (2012) by the professional group National Association for the Education of Young Children and the Fred Rogers Center is often preferred (Hutchinson & Woodward, 2014). Work by Guernsey (2007) helped establish the framework put forth by the Fred Rogers Center and NAEYC (2012) and provides the most specific and applicable structure for integrating technology into a learning environment for young children. Guernsey looks at the interrelationship between the content, or task, the environment, and the user as the most important aspect of incorporating technology or devices into the learning experience. Essentially, Guernsey defines each area as:

- **Content:** How does this help children engage, express, imagine, or explore?
- **Context:** How does it complement, and not interrupt, children's natural play?
- **Child:** How do we choose the right technology tools and experiences for each child's needs, abilities, interests, and developmental stage?

While 3D printing may be fairly recent as a technology development, the framework or model for integration into a learning environment should be well-established and applicable across multiple iterations of new technology, thus Guernsey's work, much like the TPACK framework, need not change for each new technology. Instead, it should serve as a guide to educators as they endeavor to incorporate new and ever-changing technology tools into a developmentally appropriate learning experience.

Considering the Context

The first aspect of experiences that Guernsey (2007) specified was context, defined as: appropriate tools for the setting, complementing but not competing with childrens' play. For female students within the United States, that context must include: the STEM and technology explosion within public schools; the inequality of experiences between genders; the lack of peer groups, role models, or support structures; and the stakes - academic and social standing riding on the success or failure with technology tasks.

Technology Explosion

Technology is widely integrated into modern k-12 classrooms (Ritzhaupt, Dawson & Cavanaugh, 2015; Freeman, Adams Becker & Cummins, 2017; Delgado, Wardlow, McKnight & O'Malley, 2015). On a typical day, students use laptops and tablets to complete activities. Ebooks have replaced many print textbooks. Students use technology to communicate and create. (Ritzhaupt et al., 2012; Liu et al., 2017; Delgado et al., 2015; Freeman et al., 2017; Wiese & Du Plessis, 2017). Teachers utilize online instructional resources, use technology for assessment, and communicate with parents electronically (Ritzhaupt et al., 2012; Freeman, et al., 2017).

In addition to computer based classroom technology, schools are investing in makerspaces. Adams Becker et al. (2016) describe makerspaces as informal workshop environments that include technology such as 3D Printing, robotics, coding, and virtual reality. They are designed as spaces where users can tinker and use their creativity to solve hands on problems while develop skills that will help them succeed the future workplace.

Students develop valuable skills during their makerspace activities, including critical thinking, problem-solving, resilience and patience (Adams Becker et al., 2016). Students can practice collaborative, project based, and student directed learning in these spaces. They can discover new passions and become motivated to explore real world outcomes to classroom lessons (Adams Becker et al., 2016). These technologies provide hands on opportunities for students to develop multi-disciplinary, cross disciplinary, and interdisciplinary skills to solve modern day problems (Freeman et al., 2017). The 2016 Horizon Report predicted makerspaces would be the most common technology adaptation in schools within one year (Adams Becker et al., 2016). At best, this explosion of technology usage reflects the ideals of pioneers such as Englebart (1962, 2004) and Kay (2013) to augment human learning, center around the learner, and focus on problem-solving. They refer to technology as "...amplifers that add or multiply to what we already have…" (Kay, 2013, N.P.).

Peer Groups/Role Models/Support Structures

At the core, learning is a social activity. Educators such as Dewey (1997) have spoken of a child's instinct to communicate with others and have considered that their conversations reveal their cognitive interests and thinking processes. Because of this instinct, children may learn very efficiently in groups (Robb & Lauricella, 2015). Conversations may serve to extend understanding, to question peers or content, and to develop ideas. Specifically, with technology, children's verbalizations include cooperative play, encouraging each other, exploring, or problem-solving together (Sharapan, 2015). Peer groups allow students to learn more efficiently because of these types of verbalizations and they may be particularly helpful if the co-learners are perceived to be trustworthy and socially relevant. Additionally, the peer group should be seen as helpful, smart, and competent (Robb & Lauricella, 2015). In other words, the peer group needs to include role models to truly boost learning as much as possible. "Learning happens best when they act in the role of 'apprentice thinkers' who learn directly from more skilled partners" (Rogoff, 1990, p. 15).

Conversations within peer groups for STEM tasks are particularly relevant with female learners because for young children language is the 'common space' for constructing social identity meanings. For example, it is through language that young children determine what it is to be a girl or boy. "... children themselves are producing and regulating gender by constantly 'doing' and 'redoing' femininities and masculinities that are available to them" (Blaise & Ryan, 2012, p. 83). Given the perceptions that males are more skilled and successful in STEM tasks (Andersson, 2012; Dell et al., 2011), these conversations with peer groups provide a basis from which that skill and success may be incorporated into 'doing femininity'.

Female role models are essential for girls to feel supported and confident when working in STEM fields (Dell et al., 2011). Providing exposure to female role models who are successful in STEM fields is a good way to demonstrate that females can excel with technology. Role model examples include female teachers, guest speakers, and articles or case studies that highlight successful females. Educators should also consider creating peer groups that include other female peers. Groups that include more than one female reduce the barriers of feeling isolated and provide opportunities to overcome the stereotype that males have higher achievement in STEM areas.

Finally, considering the context would imply also that one needs to think of the 'stakes' involved with 3D printing experiences. The recent direction of education policy in the United States public schools has been assignments and assessments which carry considerable consequences for the students. This may include academic consequences such as determining eligibility for graduation or grade promotion; or social consequences such as attention or approbation from peer groups or role models. Early childhood curriculum experts, however, recommend that developmentally appropriate practice always includes tasks that are authentic, appropriate, and in the best interests of the student rather than serving the purposes of the policy-makers, lesson objectives, or standards (Hatch, 2012). Appropriate tasks, in this case, include those which are drawn from students' own experiences and which extend those experiences for greater understanding or skills. These types of tasks are found most often in project work, where students seek answers to questions revolving around a topic of interest and largely direct their own learning (Helm, 2012). Van Horn, et al. (2005) found that young children in developmentally appropriate practice classrooms performed better on general cognitive measures than did students in classrooms with skill-driven instruction. Project work is also associated with the educational philosophy of Dewey, who saw the primary aim of formal education being to develop the capacity for learning (Helm, 2012).

Project work is the basis for many STEM tasks. Whether it be solving an engineering issue, or considering a way to use technology to solve a daily life problem, project work is a collaborative way to connect new ideas and STEM focused learning opportunities. Completing STEM projects, such as 3D printing, increase student confidence in learning new concepts (Sahin & Top, 2015). Project based work methods increase student involvement and engagement in the learning process (Sahin & Top, 2015). When students work in teams to solve problems, they can support each other to discover information and build confidence in new subject areas. Critical thinking, problem, solving, communication, creativity, self-control, negotiation, empathy, collaboration, open-mindedness, and active learning are all developed as the student works on STEM projects (Lasley, 2017). Practicing these 21st century literacy skills is essential for developing student abilities in STEM.

Considering the Child

When planning for the incorporation of new technology, especially for female students, teachers must consider the factors associated with the child. Guernsey (2007) defines the child considerations as: interests, abilities, needs, and developmental stage. In the case of female elementary students, research indicates that some of the additional considerations need to be: the perception of technology as a male domain; the need to build confidence; and the need to provide engaging and relevant experiences.

Technology as a Male Domain

"The fact remains, however, that while the students we teach become increasingly diverse, we have yet to find ways to level the playing field so every child succeeds" (Blaise & Ryan, 2012, p. 89). While this is not new or ground-breaking information, it is worth considering specifically and explicitly in this situation. Historically, technology and overall the STEM fields have been seen as a male domain. STEM as a male domain can be attributed to cultural stereotypes and high achievement by males in science and math. Males are consistently more prevalent in the photos and activities that are used in STEM education curricula. Parents also tend to encourage their children to play with toys that are typically associated with their child's gender (Mammes, 2004). For example, legos, construction sets, and tools have been traditionally marketed more towards boys, while kitchen sets and dolls are typically marketed towards girls. In addition, research suggests that boys have higher achievement levels in spatial skills and some math tasks, which contributes to sustaining these cultural stereotypes that STEM fields are a male domain (Hill et al., 2010). We know from related education fields that students need to see themselves in the areas they study to make consistent and steady progress closing achievement and representation gaps (Blaise & Ryan, 2012).

Ensuring that STEM learning experiences are relevant to girls is essential to increase the number of females who continue on in STEM-disciplines through the education and careers choices. In addition, girls should be encouraged to keep a growth mindset in STEM disciplines, which provides girls with an expectation that their intelligence can continue to develop as opposed to thinking that their intelligence is fixed and cannot develop (Hill et al., 2010). Presenting a relevant learning context that encourages a growth mindset provides girls with an opportunity to overcome stereotypes. Even though research shows that there is no different in achievement between girls and boys in STEM disciplines, the stereotype still exists. For example, Correll (2001, p. 1697) notes that

…individuals are exposed to gender beliefs associated with mathematics from various sources (teachers, parents, counselors, published results of standardized test scores by gender), and likely become aware that "most people" believe that males, as a group, are better at math." Thus, providing an encouraging learning environment is vital to female success in STEM.

Building Confidence

There is a plethora of research documenting the relationship between persistence and school success (Sharapan, 2015). Confidence is the key to persistence because children have to learn to continue to try through mistakes. Having confidence in oneself, seeing oneself as capable despite, and eventually because of, mistakes will lead children to persist in the face of struggles. One of the key arguments for increasing technology and STEM-related tasks in U.S. public education is the idea that the intrinsic motivation inherent in most technology-based tasks will help develop that persistence, and with it, confidence, in young learners.

Specifically, allowing girls to build confidence is key to their success in STEM disciplines. Girls should complete projects on their own without a lot of help and without parts of the activity pre-done for them (Dell et al., 2011). A sense of accomplishment, even if the accomplishment follows several failed attempts, provides girls with a foundation and knowledge that they are capable to successfully engage in STEM activities in the future. In addition to providing opportunities for success in STEM-related tasks, educators need to make a concerted effort to ensure males and females are evenly represented in educational content. Educators and parents need to thoughtful about recognizing biases towards females in STEM-related areas and intentional about including opportunities for girls to make their own accomplishments and view females as successful in STEM activities (Hill et al., 2010).

Engaging and Relevant Experiences

"Children make more gains from technology based learning when it is aligned with their developmental level" (Robb & Lauricella, 2015, p. 79). The idea of developmentally appropriate planning for young learners is well-accepted throughout the early childhood and elementary fields. The concept is particularly relevant for studies of technology because of the ambiguity involved in many of the published challenges and lessons. When incorporating a new technology such as 3D printing, many of the lesson ideas exist on websites or as adaptations from other sources (Heroman, 2017). Children's experiences with technology can vary widely, however, and when the engineering aspect of 3D printing is considered - the comfort with the problem-solving process, comfort with making mistakes and starting again, comfort with coding or spatial relationships - it is highly unlikely that even a set of children grouped by age will benefit fully from the same 3D printing experience. In this situation, it is particularly important to equip educators with a framework for considering their instructional decisions and a method of assessing student reaction to a task during the planning phase. In this situation,

…developmentally appropriate practice would suggest that with technology, as with everything else, we need to let children know what they can do, not just what they aren't allowed to do. If we want children to understand that digital media technologies can be used for art making, learning, and communication, as well as entertainment, we need to demonstrate those possibilities (Rogow, 2015, p. 101)

Considering the Content

The third area Guernsey (2007) recommended for consideration regarding the adoption/use of technology is content, simply defined as: *how the tasks help a child to engage, express, imagine, explore.* In the case of female students in the U.S. public schools, this means content and activities supportive to girls as they collaborate and create. The content also needs to align with STEM intellectual and academic goals. Intellectual goals encompassing reasoning, hypothesizing, predicting, the development and analysis of ideas. Academic goals encompassing more concrete skills such as measuring, counting, and comparing (Highfield, 2015). These goals reflect the inquiry-based, participatory stance of most early childhood curriculum theorists (Sullivan & McCartney, 2017). Achieving these goals in a manner supportive of all students is the overall aim of incorporating technology into early childhood settings. Research has previously shown that open-ended discovery or free play is not enough for students to develop the understandings inherent in the science, math, or technology fields. The complexity of these understandings is such that the students need instruction to accompany their project work and collaborative tasks (Hatch, 2012).

Similarly, technology based learning is best served by the incorporation of a concept called 'curricular integration'. This is the idea that learning will be most efficient when the technology is integral to the curriculum, in other words, the technology is chosen because it reflects or extends the understandings because of its' very nature. The type of integration seen most often in the U.S. public schools at this point is 'technological integration', in which the curriculum and technology are considered separate and co-exist, rather than complement each other in the lesson (Hutchinson & Reinking, 2011).

To summarize, the most effective lessons consider the child, context, and content (Guernsey, 2007) in an effort to achieve 'curricular integration' (Hutchinson & Reinking, 2011). This seemingly complex process includes: active teaching of mathematical or scientific processes and information; project work designed with developmentally appropriate practice; structure that allows for collaboration and peer/role model support; and tasks draw from authentic existing interests.

CASE STUDY

The review of the literature pinpointed the following aspects as crucial to successful incorporation of 3D printing for female students: the explosion of technology in schools within the United States; the inequality of technology experiences by gender; the role models, support structures, and peer groups provided during technology experiences; the perception of technology as a male domain; engaging and relevant tasks; and integration with learning experiences. This case study was devised to explore the impact of the factors in a 3D printing experience for female students.

Methods

Participants

Participants for this study were two female elementary students from schools in a mid-Atlantic state in 2018. One participant attends a private school and one attends a public school. Both participants are mid-fourth grade and are considered capable students. Prior to the 3D printing experience, both participants were asked their experience with technology class within school. Student A reported having technology for 30 minutes, twice in each eight day cycle. She reported learning to code and playing on coding sites. Student B had afterschool technology once each week for 1 hour. She reported learning to code and doing robotics. Both students indicated a medium level of interest in technology, calling it neither their favorite nor least favorite subject. Neither girl had experienced 3D printing at school. Student A had once seen it at a children's museum, Student B did not know of it.

The Makerspace

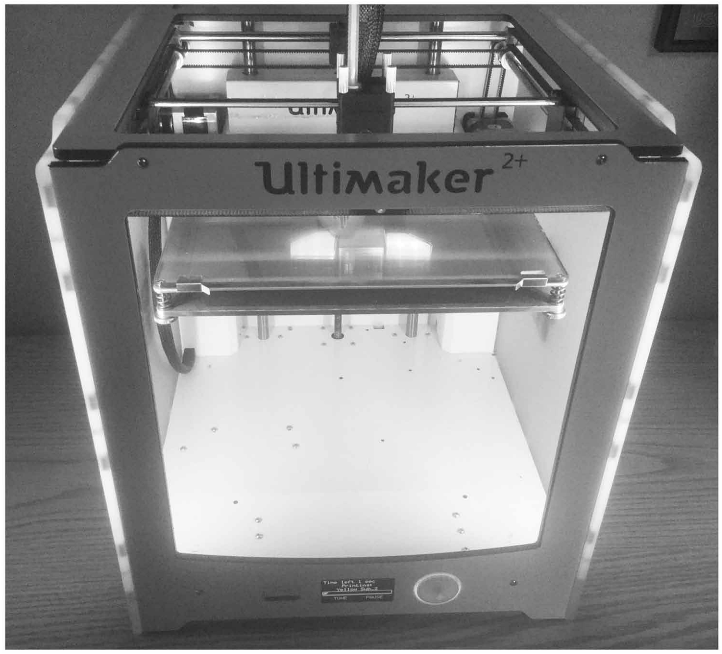
The makerspace used in this case study is a room located within the main library of a large public University in the Mid-Atlantic region. This makerspace has been in use for two academic years. The space is open to the public each day the library is open. This makerspace has a variety of maker tools, including computers for 3D printing design, five plastic and resin 3D printers, a Carvey Inventables woodcutter, and a high end virtual reality room. In addition to these maker tools, the makerspace also has video editing, audio recording, and lounge spaces.

Staff at the makerspace front desk provide supplies for the maker tools. This staff provides training and assistance to help users learn to operate the equipment. The space is lively with various activities during open hours. The 3D printers are constantly in use.

Of the five 3D printers, four are Ultimaker brand and one is Formlab. The Ultimaker printers use plastic spools and the Formlab uses resin. This case study will use the Ultimaker printer due to the relative ease of use and practicality for inexperienced makers. The space has the four Ultimaker printers in a row on one table. Plastic filament spools are available for free at the front desk and the staff spool the printers for the users.

A Macintosh computer near the 3D printers is used for design and selection of objects. The makerspace staff is available to provide assistance at all stages of the 3D Printing project. Tinkercad and Cura are the primary softwares used to design 3D printed objects in this space. Users commonly visit thingiverse.com to select pre-designed objects for printing.

Figure 1. Ultimaker 3D Printer



Planning the 3D Printing Learning Experience

The researchers selected a day for 3D printing early in the academic semester. During this time of the semester, the staff suggested the lab would likely be quietly buzzing with activity but not overly crowded as it is in later weeks closer to exams. This uncrowded and quiet environment would enable the girls to learn the software and to 3D print without competition from others in using the printers and space. While the makerspace is first come first serve, the makerspace staff reserved the primary 3D printer computer and printers got use on activity day (see Figure 1).

In preparation for this day, the researchers consulted Makerbot to find lesson ideas appropriate for first time 3D printing with young learners. To prepare the girls for their first 3D printing experience, the researchers selected the STEM topic of snowflake formation. Education databases had lesson plans available on the topic and snowflakes models are a popular recommended STEM 3D printing activity (Adams, 2016) based on the criteria of "curricular integration and project-based learning". This lesson plan was selected to guide the challenge the girls would try to solve using their choice of predesigned objects in thingiverse.com. Each girl would create her own 3D printed object, selected to solve the problem posed in the lesson. They would work together to determine which object to print and to troubleshoot during the printing process.

Prior to the 3D printing lab day, the researchers reviewed "Snowflakes" activity from the k-12 education database BrainPop. At the beginning of the lab day, the girls watched the accompanying short video on the science of snowflake formation. Afterwards they discussed the video concepts. They talked about factors that influence the shape, thickness, and design of a snowflake. Then the researchers posed a challenge for the girls to collaborate and design a snowflake based on these formation factors. The girls were instructed to describe what happened to the snowflake that caused them to make the changes they make on the snowflake machine. The snowflakes would then be modified as needed, allowing the girls to practice troubleshooting during the 3D printing process. After printing, they were instructed to share what they would do differently on another snowflake.

The researchers selected “Snowflake Machine” from Thingiverse.com as the model for this project. The “Snowflake Machine” is a widely used project recommended by MakerBot for K-12 STEM learning (Adams, 2016). Adams (2016) recommended to reinforce STEM concepts for young learners. The Snowflake Machine project encourages creativity, innovation, and experimentation. While completing the lesson, learners design, explore, and create their own unique snowflake. The Snowflake Machine uses Thingiverse’s Customizer application to combine STEM topics including mathematical algorithms, random numbers, and computer code to create snowflakes that are as unique as those in real life (Adams, 2016). Since it was created in 2015, the project files have been downloaded over 26,000 times, with some users sharing images and files of their own creations on the lesson plan website. MakerBot invites users to contribute to the Makerbot online community by sharing images of their complete projects, bookmarking the lesson, and posting their own “remix” snowflake design created using the application.

Findings

During the 3D printing experience, the students were observed by two of the researchers and were also audio recorded. Their statements were transcribed and sorted into the themes of Guernsey’s research.

Context

Context refers to experiences that complement, instead of interrupting, students’ play. Within the area of this study, that includes consideration of: the explosion of technology use in US public schools; the lack of role models, peer groups, and support structures for girls, and the idea of low stakes experiences.

Technology Explosion

Despite a vast increase in attention to STEM and technology with the US public schools, individual student experiences still vary quite a bit based on factors outside of their control such as school budgets, teacher comfort level, and access to makerspaces or tools. The students in this study already showed that disparity of experiences. Student A reported having technology as a class at school, similar to library, music, or art. She attends for 30 minutes twice in an eight day cycle, during school hours. Her technology projects and assignments are graded and included on her report card (high stakes). Student A reported learning typing skills and coding during technology class. Her school did not own a 3D printer, but she had seen it once on a trip to museum with her parents. Student B reported attending technology as an afterschool activity for this quarter. She reported going once per week for an hour with other students who had picked that elective. She reported learning coding and robotics. Her assignments and projects were not graded (low stakes). She did not think her school owned a 3D printer. Interestingly, both girls reported the technology facilitator at their school was a female. The girls were able to make the connection between their Makerspace experience and the experiences they wished they had at school.

Mentor: *If you come over here, I flipped this down, and these are the two called the printer cores or the printer heads. This is where the plastic comes out.*

Student A: *Batteries?*
Mentor: *No, it does look like batteries, it says AA. The AA means you can use this exact kind of filament in it. Filament is a fancy word for plastic. (Explains how the printer is working). If you look pretty close, you might be able to see it come out.*
Student B: *It's over here.*
Student A: *Oh, I see it.*
Student B: *Oh, cool!*
Mentor: *So that's a little practice to make sure it is printing right.*
Student A: *It's printing right.*
Student B: *And then you just scrape that off when it is done?*
Student A: *They should teach this at school.*

Peer Groups/Support Structures/Role Models

Another aspect of context is the support structures for experiences with technology. Simply put, the mentor/role model and the peer group play an outsized role in the student's view of their experience and learning. As discussed in the child section, we noticed a great difference in the amount and complexity of conversation between the students once they were able to choose an item on their own to print. The girls initiated more discussion between themselves once they were discussing their own chosen prints.

Student B: *So I wonder how long yours will take?*
Student A: *Probably an hour or two.*
Student B: *Hmmm, if you make it smaller, it won't take as long.*

They interacted more freely with the mentor and the authors during their own printing as well. This example of their discussion during the snowflake print shows the mentor and one author asking multiple questions to keep them thinking about the technical aspects of the print.

Mentor: *For this object (snowflake), do you think we need build plate adhesion or no?*
Student A: *No, not really. Unless you cut the build plate off.*
Author: *Why would you use the build plate adhesion?*
Student A: *So it looks better.*
Author: *That's what build plate adhesion does, but what about your design makes you say that it doesn't need it?*
Student A: *Umm, I'm going to let her answer that. Ummmm, laughs…*
Student B: *I don't know.*
Student A: *I think it might make it more stable, but it might not look that good.*

Compared with the above, once they had the experience of designing their own print, they were much more involved with all aspects of the experience and confident enough to play with the mentor, as evidenced by the following quotes.

Mentor: *Alright, so I'm going to put this USB in here, we're going to click print, and we're going to click the file with the snowflake. So, do you see how It kinds of slides back and forth?*

Student A: *Yeah, it's kind of like one of those copy things where it starts in one place and then it goes up and then it goes back...*
Mentor: *Yeah, kind of. You can see there are two rods, there's one right here and there's one right here. There are also rods in the back. This also helps it move all the way around. So what does this say right now?*
Girls: *ABORT! (laughing)*
Mentor: *No, not that. Up here.*
Girls: *Just kidding, heat building plate, prepare to print.*

The importance of role models, support structures, and peer groups cannot be overstated in any learning environment, but it appeared to be particularly effective combined with an authentically engaging task for girls and 3D printing.

Child

The child considerations include: interests; abilities; stages; and needs. Within the exploration of girls and 3D printing, these include the perceptions of technology as a 'male' domain, provision of engaging and relevant experiences, and the need to build confidence.

Technology as a Male Domain

The transcript and behavioral notes indicate little to counteract the perception of technology or 3D printing as a 'male' domain. In retrospect, it is easy to see this being the case because the study was designed and implemented by women, notably, by women with an interest in female interactions with STEM activities. The authors created a completely female space, the students were mentored by a female college makerspace expert, and the experience was dominated by women all the way from conception through analysis. It would be interesting to replicate this study in a larger, mixed-gender group, to focus specifically on this aspect of the child considerations. The authors take as a positive that the topic never arose in this instance, clearly the perception of technology as a 'male' domain does not have to exist, but we recognize the limitation within this study of adding to the literature on that topic because of our study design.

Engaging and Relevant Experiences

The student experience in this study was relevant and engaging, though not exactly as it was intended to be. The college-aged mentor in the 3D printing lab provided an excellent example for teachers of engaging the students by piquing their interests and following their thoughts. For example, the mentor showed the students a variety of 3D printed items that were on display in the lab (see Figure 2). She used these objects to begin the discussion about 3D printing and how it works. However, once the students were engaged, she validated their thoughts, questions, or ideas and incorporated those into her explanation.

Student A: *Is that kind of like what they would use for replacing knees? Because I watched this thing on How It's Made about knee surgery and how they would make a 3D knee that fit the person exactly.*

Figure 2. Girls learning about the 3D printer with mentor

Mentor: *Yeah, so that's a great question...explains types of plastic and history of 3D printing for surgical uses...I know they've been 3D printing some ears recently.*
Student A: *Vincent Van Gogh! (Laughs).*
Student B: *He lost his ear?*
Student A: *Yeah, he cut off his ear because he went a bit crazy. He cut off his ear from misery.*

This level of scaffolding and following the student interest helps create a relevant, engaging experience and builds confidence for the girls as they realize they have expertise and knowledge to share. However, the greatest lesson in providing engaging and relevant experiences turned out to be unintentional. The authors, following all of the steps for integrating technology into curriculum, had designed a lesson on snowflakes, combining science with 3D printing and using a fun topic and video to engage the students. The girls dutifully took part in the video and discussion, but they were clearly attempting to please the authors, rather than being fully and authentically engaged. The discussion surrounding which snowflake to 3D print was brief and shallow.

Mentor: *So, if you both wanted to have a snowflake that looked like this you could do that.*
Student A: *What do you want?*
Student B: *I don't know. What do you want to do?*
Student A: *I say we make this one.*

During their discussion on the technical aspects of the print, though, the girls found their own source of inspiration.

Student B: *(pointing to displayed 3D printed objects) I like them.*
Mentor: *I think they are quite cool.*
Student A: *Wow! Yeah! I love this one, it is so cute. If I could 3D print anything… Oooh, look, a 3D printed phone case!*

The students pulled one author aside and asked for permission to print items of their own choosing. With permission from the Makerspace staff, the girls were told they could choose an item to 3D print, and they became truly engaged and excited.

Student B: *I love the puppy. Pup. Pup.*
Student A: *I think we might get to make a small sleeping puppy or a small...*
Student B: *(interrupting) No, I'm going to make it, remember the one that was so small?*
Student A: *I'm going to make a horse!*
Student B: *That is so cool.*

As they worked through choosing an object to print and the details of the print, they continuously returned to the topic of their own choices.

Student A & B: *So, after this, are we going to make little ones?*
Student A: *I'm going to make a horsey. I'm going to make one.*
Student A: *I love horses.*

The authentic interest in printing a meaningful object to take home was so intense, it led to a much deeper level of engagement with every aspect of the print from choices in size and color to support structure and watching the plate warm up. This, in turn, built confidence in navigating the process of 3D printing for both students.

Content

Content refers to experiences that encourage students to engage, express, imagine, or explore. In the context of girls and 3D printing, content is specifically defined as: activities supportive to girls; tasks that allow collaboration and creativity; and encompassing both the intellectual (reasoning, hypothesizing; predicting, developing and analyzing ideas) and academic (concrete skills such as counting or adding) goals of STEM education.

Technological Integration

Since both of the students were unfamiliar with 3D printing, it was crucial that they found the confidence and support to allow them to explore. Exploring is a direct result of comfort level, discussed in previous sections as engagement or confidence and facilitated by support structures, peer group and role model interactions. During this experience, the girls showed a willingness to explore in the early part of the 3D printing.

Student B: *It looks like they were frozen.*
Mentor: *(explains support structure clear filament, shows how it works with the 3D printer).*
Student B: *That one's blue and clear.*
Mentor: *But actually that's water soluble on that one (the clear one)...*

Later in the process, though, they showed a strong inclination to explore.

Mentor: *So, if you click right here, you can make it bigger or smaller. If you look right here, that's how big it is. If you made it 50%, it would be half the size. And if you made it 200%, it would be double the size.*
Student A: *How big do you want it?*
Student B: *How big do you want it?*
Both Students: *10! No, 1000! That would be 10000.*
Student A: *I don't think it goes that far. Haha. Does it?*
Mentor: *The computer would probably show it, but it wouldn't fit on the printer plate. So you wouldn't be able to print it.*
Student A: *So if I press enter, what happens? Ok!*
Author: *That will probably take a while.*
Student A: *That'll probably take a thousand years. Haha!*
Student B: *Wait, I want to see what 10 looks like.*
Student A: *Oh, my gosh! Wait, that's so tiny!*
Student B: *Do 100000, press enter, I want to see what that looks like.*

The collaboration and creativity are evident in this task that is supportive to girls and facilitating their imagination and expression.

The girls' conversation showed extensive evidence of engagement with the intellectual goals of STEM education. They engaged in a great deal of conversation with the mentor (role model) and each other about the process and the likely outcomes of their choices during the print. That included predicting.

Mentor: *Remember when I told you what the build plate is? Can you point to what that is on here? Yes. So right now it's heating it. Why do you think this would need to heat up?*
Student B: *Sooo...the plastic will stay together?*
Student A: *and cause it to stick.*

Since the girls were unfamiliar with 3D printing before their experience, it stands to reason that they would spend some time predicting. However, they were also able to analyze ideas.

Mentor: *Ok, I'm going to do something over here. So these are the custom options, and normally for speed, now what do you think that is going to mean on the 3D printer, speed?*
Student B: *How long it will take?*

Student A: *Make it faster?*
Mentor: *Yeah, it's how fast the printer head, that what prints it, how fast it's going to go. If you make it faster, it's going to be a little bit sloppier. But if you make it slow, it's going to make sure it is…?*
Student A: *and if you make it incredibly slow, it's going to be absolutely perfect.*
Mentor: *It could be, or it might mess up.*
Student A: *So if you do it super duper fast it's going to look like…*
Student B: *Blob.*
Student A: *...a kindergartner drew it.*

Perhaps because these were older elementary students or perhaps because the experience was designed to familiarize them with 3D printing as the top priority, there was less evidence of a focus on more concrete academic skills related to STEM education. Although one student originally referred to the experience as "school on a Saturday" (Student B), there was little evidence of practicing concrete skills during this print. There was, however, ample evidence o reinforcement of vocabulary and other general knowledge.

Mentor: *Because we chose not to print a support structure, that water thing I told you about earlier, I was using a big word, soluble. Do you know what soluble means?*
Student A: *Yeah, dissolvable in water.*
Mentor: *Yeah, it sort of fizzles out like emergen-c tablets, it fizzes and dissolves in water.*
Students: *It does, it does!*

DISCUSSION

After completing the 3D printing day, the authors reflected on the experience and lessons learned. The day was full of learning and excitement for all involved. The girls were comfortable in the makerspace and were interested in playing with other previously printed 3D objects. Those objects gave the girls inspiration for picking their own designs. The makerspace happened to be empty of other patrons during this study, which perhaps allowed the girls to explore and talk more freely. Overall the experience went smoothly for the girls, and they were interested in all parts of the process.

The findings from this case study indicate several of the factors had a strong impact on the overall learning experience. Of the context factors, it appeared that the role model played a key role in facilitating learning with 3D printing. This was consistent with previous research from Dell et al. (2011). The mentor was invaluable in this experience. She was confident in her 3D printing skills and gifted in teaching young children. Her experience and knowledge was vital to giving the girls background in how 3D printing works and to guide them in the process. She should be ready to answer questions, and just as importantly, be ready to ask the girls questions to develop their learning. This guidance fostered problem solving and critical thinking skills (Adams Becker et al., 2016) and set the stage for dialog between the girls to show each other encouragement and to extend their understanding of the tasks (Robb & Lauricella, 2015; Sharapan, 2015). An important role of the mentor was being there to work through issues with them so they did not get too frustrated and abandon the process.

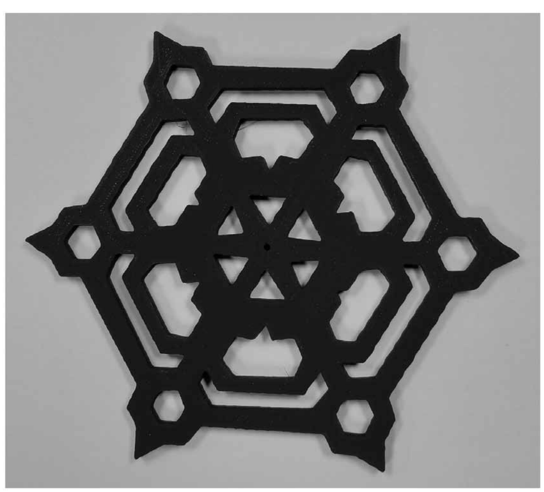
Of the child factors, it appeared that the engaging and relevant task factor was the key to facilitating learning. This finding is consistent with many previous studies (Helm, 2012; Robb & Lauricello, 2015;

Rogow, 2015; Van Horn et al., 2005). The girls were not particularly interested or invested during the snowflake lesson and creation. Their interest was much greater and their conversations were deeper when they selected, modified, and printed the object of their own choosing. They took ownership of the projects (Amador & Soule, 2015). This feeling of ownership led to persistence through the difficulties inherent in a 3D printing task which in turn facilitated a growth mind set and the idea that skills and techniques can evolve over time. One of the major issues researchers find with school-aged females involved in STEM tasks is the idea that intelligence and skills are fixed (Correll, 2001; Hill et al., 2010). Developing persistence and a growth mind set is crucial to success in 3D printing, in STEM fields, and overall in academics (Sharapan, 2015). The engagement with the personally relevant task encouraged the girls to adopt an inquiry-based, participatory stance when their previous behavior had appeared more similar to compliance.

Despite the research suggesting that the context factor of technological integration is a key consideration in planning for successful 3D printing and learning experiences (Highfield, 2015; Hutchinson, Reinking, 2011; Mishra & Koehler, 2006), the authors found that in this case study, free play was a more successful approach. As a general rule, technology is bound to fail sometimes despite proactive planning efforts. In this case study, on the day of printing the Snowflake Machine did not operate as tested by the authors and thousands of other users. The authors and mentor were able to adjust the lesson to still accomplish the lesson outcome goals, simply by allowing the girls to pick another snowflake on Thingiverse that was of their desired shape and style. Once this snowflake was customized and began printing, the printer gave an error message that cancelled the print. The mentor took charge and guided the girls to re-print the snowflake (see Figure 3).

This technical issue provided an opportunity for increasing engagement and excitement in the girls. This printing error could have been a frustrating and disappointing part of the day. The mentor avoided this and took advantage of the pause in printing to suggest the girls print new designs of their choosing, just for fun. This moment was a turning point for the girls because they became excited to print whatever they wanted. The authors learned that facilitators should be flexible and allow the child agency to print designs of their choosing. This increases investment and excitement in the process and is consistent with

Figure 3. Completed 3D printed snowflake



recommendations by Rogow, 2015. The girls shared their passions while searching for their favorite animals on Thingiverse. Then they spent significant time determining which design was their favorite. Then they used the software to resize the designs to their desired size. They debated with each other which size was best and how to best select scaffolding for the object so it would print correctly. Their conversations over these choices were active and engaged, and they were motivated to make their perfect design.

RECOMMENDATIONS AND FUTURE RESEARCH DIRECTIONS

It is important to note that this is a case study and, as such, represents an in-depth look at the use of 3D printing with a small sample of female students. It was designed to provide a look at the issues surrounding two unique factors in the current environment, namely the extension of 3D printing technology to the elementary level and the experience of female students in the context of a 3D printing task. While generalizations are difficult with case studies, due to the limited sample, the alignment of findings with broader published research does provide context for understanding these factors and allows the authors to recommend further research and practices.

The authors would do a few things differently to improve the girl's experience in future introductory 3D printing sessions. The authors noticed a significant increase in confidence and motivation between the two activities. In order to facilitate excitement and confidence for the 3D printing experience, the authors recommend scaffolding the 3D printing experience. This experience should employ a helpful and knowledgeable mentor who will guide the girls to first print something random of their choice. This gives the girls the opportunity to explore the Thingiverse design collections, understand the software design, and experience the printing process, all while completing a project that excites them.

In a follow up session, the authors would continue to explore the finding that free play added an aspect of ownership and excitement to the experience. Perhaps an exploratory session, with free play should be the first experience and then a learning experience with a lesson beforehand, similar to the Snowflake video and Snowflake Machine, to challenge the girls to solve a problem by 3D printing. This scaffolding would put their new skills to work towards designing and printing their object. Student B mentioned that STEM projects in her after school activities were not graded. The authors recommend that introductory 3D printing sessions are exploratory learning experiences and are not graded in order to minimize pressure for successful completion. This is important when technical issues are likely to happen outside of our control.

CONCLUSION

Given that there exist significant differences in STEM experiences and comfort with the United States public schools (Mammes, 2004), we found the following aspects of this experience to be most important in developing the interest, confidence, and engagement of these female students: a knowledgeable and high-status mentor; low-stakes activities; and most importantly, responding to their interests by giving them agency to print something that excites them. Our experience with female students in the Makerspace ended with both girls returning home to their parents and raving about the fantastic time they had. Both clamored for another opportunity to 3D print an object. Interestingly, when the objects they had chosen to print were available, they found that one had been successful, while the other had broken in several places. Upon seeing this, they initiated a discussion about what likely went wrong and collaborated on developing possible solutions. They pressed for a date to conduct their new print and planned questions for the mentor to ensure the new object print would be successful. For the authors, this solidified the conclusions drawn from the experience, 3D printing with girls will be most successful when the context factor of role models, the child factor of engaging and relevant experiences, and the context factor of free play are taken into account.

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KEY TERMS AND DEFINITIONS

3D Printing: Creating a three-dimensional object from a design.

Guernsey Framework: Theoretical rationale for choosing or integrating technology into educational experiences for young children.

Makerspace: Open-access laboratory space equipped with technological and other tools to create.

Mentor: Role model who provides support.

STEM Education: Instruction in the fields of science, technology, engineering, and mathematics.