Investigating the Expanding Role of Makerspaces in Fostering STEM Engagement and Inclusivity in K-12 Education

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Coke Matthews

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor
Sean M. Ferguson, Department of Engineering and Society

Introduction

The discrepancy between U.S. math and science scores versus other advanced industrial nations, along with the underrepresentation of women and underrepresented minority (URM) groups in STEM-related fields, has called into question the American education system. STEM, an acronym for the fields of science, technology, engineering, and math, is widely considered a driving force of our economy. The ability to produce a new generation of STEM professionals and entrepreneurs not only spurs innovation, but also provides the best shot at tackling local and global problems, from waste management to climate change.

Concerningly, recent data from international math and science assessments indicate that U.S. students rank an underwhelming 38th out of 71 countries in math and 24th in science (Desilver, 2017). This poor performance is linked to the failure of the education system to provide a sufficient STEM pipeline, or educational pathway, for women and URM students. Despite comprising nearly half of the U.S. workforce, women hold less than 25 percent of STEM jobs (Noonan, 2017). Similarly, the disparity in STEM degree attainment for URM students increases at each degree level (Estrada et al., 2016). Recognizing and addressing the institutional barriers that these students face is necessary for promoting inclusiveness in STEM education.

Experts agree that the inability to spurn interest in STEM at a younger age serves as one of these hurdles (DeSilver, 2017). Along with improving the quality of the standard curriculum, there needs to be an emphasis on making education more interactive and engaging. One attempt to do so that is recently gaining traction is the adoption of makerspaces into schools and libraries. Makerspaces serve as collaborative workspaces that promote learning and creativity through hands-on tinkering and experimentation. Typical makerspaces have a variety of equipment from computers with programming languages and digital art software to 3D printers, laser cutters, and even sewing machines. Strength lies in their versatility, as even a space with art supplies and Lego can be categorized as a makerspace. Maker programs help develop relevant technical skills in 3D modeling and printing, coding, electronics, art, and more. Most importantly, they stimulate STEM education by providing a creatively liberating platform for exploring ideas and hands-on projects. Developing a plan for their incorporation into k-12 education, done in a way that is accessible to all social groups, would certainly bolster STEM education and interest.

In order to explore the potential integration of makerspaces into k-12 education, the Charlottesville Public School System was examined as a case study. Further, this paper aims to identify the barriers that women and URM students face, and examine the role of makerspaces in addressing these issues. The Social Construction of Technology (SCOT) framework will then guide the analysis of relevant stakeholders' interests and the social construction of makerspaces.

Literature Review

In an effort to understand the contribution of makerspaces to STEM education and diversity, this literature review explores the following topics:

1. The characteristics of a successful makerspace.
2. Barriers and deterrents that women and URM students face in STEM.
3. How makerspaces have addressed these issues and promoted inclusivity.

John Burke's 2015 survey asked makerspace leaders what were the common characteristics of a successful makerspace, and most of their answers were similar: an emphasis on developing the space around the needs of the community, making sure that purchased technology creates the most valuable opportunities for users, developing relationships with community members, beginning with a modest start, piloting maker programs, and gauging community receptiveness for such programs (Small, 2017). Along with this, leaders who can clearly envision and communicate the purpose of the makerspace are vital, especially when it comes to getting the space funded. This funding is not just for the maintenance of the space and technology, but also maintaining a supportive and sustainable staffing model. Finally, there needs to be an emphasis on trusting users and giving them as much autonomy as possible, thus encouraging creativity and hands-on learning.

On the other hand, physical and financial accessibility serve as obstacles for students of similar academic programs. Makerspaces are typically covered by grants, school or library funding, and rarely the state government (Small, 2017). Halverson and Sheridan (2014) argue that the best way to democratize the space is through libraries, given their history as "free, embedded community resources open to all." This integration of makerspaces into libraries would help promote STEM proficiency, while remaining accessible to students of all ages and backgrounds. Julian and Parrott (2017) expand on this idea, claiming that "encouraging female and minority participation is another positive aspect of involving the library in this national push towards STEM subject mastery. Since the majority of librarians are female, they can act as positive mentors when modeling STEM and STEAM activities and projects in the library." Maintaining a diverse staffing model not only provides students with relatable role models in STEM, but a sense of inclusion and belonging that is often unfamiliar.

The lack of exposure to STEM at an early age also inhibits the ability of the education system to provide a sufficient STEM pipeline. Brophy, Kelin, Portsmore, and Rogers (2008) show that interest in STEM subjects as career options peak in middle school years, especially for minorities and younger women. The authors also clarify that k-12 grade levels frequently encounter problems in instructional resources, funding, curriculum, teacher training, etc. As a result, there is rarely an implementation of innovative practices of STEM exposure into schools.

Banks-Hunt, Adams, Ganter, and Bohorquez (2016) state that “it is commonly known today that many children who might thrive in a STEM-related career don't even know what an engineer does. This incongruence urges an importance upon increasing the visibility of engineering in the education of young students at early stages to increase the numbers of future engineers.” Makerspaces serve to address this issue by providing a fun and interactive platform for students to explore STEM principles through hands-on projects.

Despite the older audience, Georgia Tech’s student-led makerspace serves as an insightful case study in combating the disparity of women in STEM. The “Invention Studio,” as it's called, hosts a series of “Ladies Nights” as a means of generating more female interest in the space. One such event utilized the space’s laser cutter as a tool for cutting 3D acrylic and wood puzzles. While most of the participants had no experience with the equipment involved, they were all able to successfully print their personalized puzzle with the help of the makerspace staff. Previous knowledge in engineering is not required, and relevant technical skills can be easily taught to a large group. More importantly, the space cultivates a tighter-knit community of women interested in STEM (Diamond, 2014). Studies of similar maker programs in K-12 settings have been promising, and a notable number of engaged younger girls have shown an interest and aptitude for STEM disciplinary concepts and practices (Keune, Peppler, & Wohlwend, 2019). Despite the progress being made, Holbert (2016) notes that STEM programs “tend to revolve around conventionally masculine projects such as cars, robots, and rockets” (as cited in Masters, 2018). In order to counteract this imbalance, it is imperative that maker programs cater towards all participants, with an emphasis on targeting women and URM students.

Theoretical Framework

The Social Construction of Technology (SCOT) framework suggests a complex social component to innovation in which relevant social groups assign meaning to technological artifacts, and then shape their development accordingly (Pinch, Trevor, & Bijker, 1984). These groups hold shared and diverging interpretations of these artifacts, and often encounter conflicts between criteria that are hard to resolve technologically. With respect to integrating makerspaces into k-12 schools, students, makerspace staff, teachers, and school administrators represent groups with separate and conflicting perceptions of the technology. The differences in each group's interpretation of the technology will shape the potential role of makerspaces in k-12 education. In an attempt to characterize these interpretations of makerspaces, interviews were conducted with members of each relevant social group. Further, makerspaces that cater towards different age groups were analyzed to provide a more comprehensive analysis.

Promoting STEM Interest and Engagement

The desired outcomes for students include generating new interests, gaining real life skills, and working in teams, among others (Li and Todd, 2019). The STEAM Team at Johnson Elementary serves as a testament to this. STEAM is a modification of the typical STEM acronym, with the addition of “art” as a category. As a result of parent and community support, along with volunteers from UVA’s chapter of Alpha Omega Epsilon, Johnson Elementary has recently refurbished its library to include a new makerspace for the STEAM Team. The makerspace accommodates the interests of its younger audience with technology better suited for children, such as Lego, Makey Makey Invention Kits, and Magna Tiles. These are not just for fun, but also encourage creativity, hands-on learning, and problem solving. A.O.E. volunteers help develop interactive programs and challenges for the students, which are allocated towards different age groups accordingly. For example, preschool-1st grade students might spend a week building their dream house with Lego and Magna Tiles, while 2nd-4th grade students learn the basics of electronics through the Makey Makey Invention Kits. Mrs. FitzHenry, the librarian spearheading the program, applauded the space's ability to engage with students "When students first saw our new engineering tools, they were so excited they didn't know what to do. They immediately started building, experimenting, and pushing themselves out of their comfort zones" ("Engineering the Future: Building Stuff (and Dreams), a project from Ms. FitzHenry"). Notably, these younger students are focused on having fun, working in teams to solve problems, and expressing creativity through their projects.

The Scholar's Lab Makerspace was similarly analyzed to understand an older audience. Located in Alderman Library, the space is equipped with several 3D printers, electronics, and a sewing machine, to name a few. Inclusivity and accessibility are an emphasis of the space, which is available to the entire Charlottesville community free of charge. Nora Dale, a Makerspace Technologist in the Scholar's Lab, detailed a typical student's desired outcomes and experience with the space:

> We typically divide student projects into 3 categories: preservation, prototyping, and presentation. That said, there is something in the space for everyone, and we receive students from all different departments and age groups. Art and archaeology students come to 3D print Ancient Greek and Roman sculptures. Entrepreneurial-minded students come to ideate and design prototypes for products they are developing. Over the last summer, several elementary school children came to 3D print a model wind turbine for a national design competition. Being able to share our love for STEM with a wide range of

> students is what keeps the job exciting. (N. Dale, personal communication, January 20, 2020)

This ability to cater towards a wide variety of students and disciplines while cultivating interest in STEM demonstrates the effectiveness of the space. Ammon Shepherd, the Manager and Lead Research Technologist of the Scholar's Lab Makerspace, further elaborated on the benefits of makerspaces in k-12 education:

> [Makerspaces] are great at helping students think spatially and tactilely, giving them the ability to think with their hands and put things together. They connect different aspects of learning, and make schoolwork more interactive rather than memorization based. Which in turn helps attract students from different fields. (A. Shepherd, personal communication, April 2, 2020)

A visual learning environment, assisted by makerspace technology, provides an interesting opportunity for increased engagement with STEM courses. For example, instead of studying an illustration in a textbook, students in a biology class might be inclined to 3D print a molecule's geometry. This makes abstract concepts easier to grasp, more interactive, and appealing to a wider audience of non-visual learners.

Ability to Promote Inclusivity

Makerspace staff strive to foster engagement, creativity, and curiosity in STEM while encouraging participation and inclusivity. To accomplish this, Fang Yi, an Educational Technologist at UVA, has recently initiated a Women's Maker Program in the Robertson Media Center's makerspace. The program serves to generate more female interest in STEM through a community-focused project that utilizes the space's technology. When asked about the challenges that women face in STEM, Yi noted that:

> There is a lack of female and minority mentors in STEM. Young girls, for example, suffer from a lack of role models in their community. And the media typically portrays STEM as a field almost exclusively reserved for men. The male dominated culture makes girls less comfortable in classrooms, and less likely to pursue a career in STEM. (F. Yi, personal communication, March 3, 2020)

To address these obstacles, similar maker programs seek to cultivate a community of like-minded women and minority groups interested in STEM. Yi expounded on this purpose, claiming that “We need to take action to include females in STEM - they won’t necessarily do it on their own. It’s important to give them a safe-space to build confidence over a longer period of time.”

Providing this safe-space is imperative for comfortably exposing women and URM students to STEM without confronting the glaring disparity in representation.

The program Computers4Kids (C4K) embodies these same values, while also collaborating with Charlottesville Public Schools. C4K serves as a joint makerspace and mentoring program that exposes 6th-12th grade students from low-income households to STEM through project-based learning. Kala Somerville, the Executive Director, detailed the goals of the program:

> At Computers4Kids we match community mentors with underprivileged youth and give them access to the professional-grade technology our space holds. Our goal is to provide a better future for these members by exposing them to STEM, and teaching the skills that could translate to a future career in the field. We try to be as inclusive and accessible as possible, and collaborate with Charlottesville Public Schools to use their school buses –

> so students from farther distances can reach us after school ends free of charge. (K. Somerville, personal communication, January 20, 2020)

As of 2017, 92% of C4K participants were minorities, and 51% were girls ("Computers4Kids," 2017). The success of the program is well recorded:

> Since 2001, C4K has provided over 1,400 youth with one-on-one mentoring and technology skill-building opportunities that build a pathway to self-sufficiency. 97% of youth completing C4K program requirements have graduated from high school on time, versus the local 82% graduation rate for low income youth (2016 stat from Charlottesville High School), and 92% have gone on to college. ("Computers4Kids," 2017)

In addition, a Youth Impact Survey was delivered to participants of the program, and reported that youth members experienced an increased proficiency in STEM skills ("Computers4Kids History," n.d.). The success of the program is due to both the mentors' ability to remain enthusiastic and engaging, and the interest that youth members share for STEM and the space's technology. Evidently, maker programs such as C4K are capable of enhancing STEM education while remaining inclusive and accessible to different socioeconomic groups.

Challenges with Implementation

Unfortunately, these outcomes sometimes encounter conflict with other parties in the educational system. For instance, while teachers want to promote learning and engagement, they are restricted by the strict guidelines provided by the curriculum. The adherence to these guidelines is then measured by metrics such as standardized testing, which do not evaluate creativeness or interest in STEM. A teacher from Buford Middle School weighed in on the challenges that teachers face in incorporating similar programs into their curriculum: "Our flexibility is certainly limited by the material we have to teach. We are not necessarily rolling in money either, which makes it hard to justify experimenting with innovative programs." Teachers, who are typically not adept in makerspace technologies such as 3D printing and electronics, would also face a learning curve in effectively utilizing the space. Addressing this issue typically requires enthusiasm from teachers in implementing the maker program, and is facilitated by a collaborative effort between makerspace staff and students.

Not just this, the success of maker programs in k-12 education is often reliant on the will of a school's administration. School administrators, including principals, superintendents, and instructional coordinators, try to maintain high curriculum standards by making decisions about staff, spending, and programs to implement. Shepherd delved into their mindset:

> School administrators have a mix of reactions to makerspaces. Some are wondering "What do we need this for?" Others recognize their growing popularity, and are willing to provide an ample amount of resources without necessarily understanding their purpose. You are often left with a group of passionate members fighting to keep their space alive. (A. Shepherd, personal communication, April 2, 2020)

This lack of familiarity with makerspaces contributes to their lacking presence in k-12 education. Further, it underscores the value of leaders who can clearly envision and communicate the purpose of the space.

Conclusion

The analysis of several Charlottesville makerspaces and their effectiveness aligns with the existing literature of the work. Makerspaces are successful in bolstering STEM interest and engagement in k-12 education. Students in the STEAM club at Johnson Elementary, and participants of the Scholar's Lab Makerspace, were notably pleased with their respective makerspace and engaged with the activities provided for them. Makerspace staff noted their ability to promote inclusivity and cultivate a safe community of like-minded students interested in STEM. The success of the Women's Maker Program and Computers4Kids reinforces this point.

That being said, the Charlottesville Public School System is not necessarily representative of every American school system. Certain schools have access to different resources and funding, and are spearheaded by administrators with diverging interests. It should be noted, however, that makerspaces are versatile enough to not necessitate high-end, expensive technology in order to be successful. Future work on the topic might include a study on how to effectively integrate maker programs into a school's curriculum while taking resource inequality into account. The range of subject matters and lesson plans that would benefit from the incorporation of makerspace technology is still largely unexplored.

While realizing this potential is often met with administrative challenges, the success of makerspace integration into the Charlottesville Public School System should serve as a call to action for other k-12 programs. Garnering STEM interest while alleviating the disparity of women and minority involvement is a necessary step towards fixing America's "leaky" STEM pipeline.

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