The Implementation of Makerspaces in Schools

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Cameron Fard

Spring 2020

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

Within the last half-decade or so, education has undergone a somewhat drastic change, as educators attempt to push back against archaic, standardized pedagogical methods, and find new and innovative ways to guide the learning of young engineers and creatives. One such attempt in this regard has been the adoption of makerspaces, both in grade school and on college campuses. The maker movement has taken hold globally, with some estimates placing the number of makerspaces worldwide at 2000 as of 2016 (Robbins and Langan, 2016). “Makerspace” is often used as a catch-all term for a space with relatively open access, where people can come and create something, usually without any outside guidance. These spaces often include computers with programming languages and IDE’s, CAD software, and 3D printers among other things. The spaces are intended to promote creativity and learning through experience, and they (as well as other programs and spaces modeled off the same principles) have been appearing in more and more schools in recent years. These spaces, as well as the other programs and academies that have been created for similar purposes, demonstrate a coordinated push toward creating a better educated population, focused on the values of creativity, and modern 21st century learning.

This research was conducted in order to investigate makerspaces and maker programs in K-12 education, and to determine they are able to fill a gap left by the current standardized education system. That gap is creativity and problem solving, a gap that I hypothesize has the potential to be filled by makerspaces. This paper attempts to address this hypothesis in two parts, the first of which is to understand the relationship between makerspaces and creative competence. The second part is to understand how makerspaces and maker programs can fit into the highly structured and standardized world of K-12 education. In order to understand these topics completely I studied the case of the MESA program at Albemarle Highschool, a school within the Albemarle County public school district in central Virginia. The research on this case study attempted to observe how or if the school implements maker values into the curriculum, and how this differs from other schools in the area. The research also attempted to ascertain if students involved in this makerspace and others received an increase in creative ability. Finally, the research attempted to better understand the tensions present in schools between the maker programs and the classroom.

Literature Review

The topic begins with understanding the new form of learning which makerspaces aim to provide, as well as the type of learning they are pushing back against. The latter is what one could describe as "traditional" learning in a standard classroom setting. For math and the sciences, students go to a classroom where they sit and listen to a teacher explain theories and methods, then, after memorizing necessary formulas and information, they attempt problems on their own. Finally, they are tested on the knowledge in typically high-stress testing environments. This learning atmosphere is by no means new, but in 2001, it was formalized by the No Child Left Behind Act (which manifested in Virginia in the form of the Virginia Standards of Learning, or VSOL's) and more recently by the Every Student Succeeds Act (ESSA, which was meant as a replacement for a poorly received No Child Left Behind Act). This formalization did not lead to a significant increase in math and reading scores in children 3rd-8th grade (Ladd, 2017). In addition, it spawned the VSOL's, which as shown later in this paper, stifle any instructor that strays too far outside the standard classroom setting I've just described.

Creative Learning

My research aimed to understand a new learning style, one based around creativity and individual problem solving capabilities. In addition, I wanted to understand how makerspaces delivered this type of learning, as well as how they fit into the highly structured environment of public schools. To the question of creative learning, research performed suggests that makerspaces do provide creative experiences for students who use them (Saorin et al., 2017). This research suggests that makerspaces allow students to move quickly from idea, to design, to final product. Saorin et al. (2017) suggest that this process, along with the collaborative aspect, and the fact that they allow students to experiment quickly with what they've been taught in class, all allow makerspaces to increase creativity in engineers. In this study, creativity is quantified using the Abreaction test of Creativity, a test designed to quantitatively measure the growth of an individual's creative ability.

The research done by Saorin et al. (2017) that completed this study builds off work done by Prince and Felder (2006), which looks at the more fundamental aspects of learning that makerspaces employ. Prince and Felder (2006) discuss the idea of inductive learning, a learning style in opposition to traditional engineering, math, and science education which is deductive. Deductive (traditional) learning is based on learning theorems, then applying those theorems to problems. Inductive learning flips that on its head, starting with the problem, and forcing students to think of a solution. In this research, inductive methods were found to be at least as effective, and sometimes more effective than deductive methods (Prince and Felder, 2006). Makerspaces promote this type of learning by giving students access to many projects and a large variety of equipment, and challenging them to experiment and use the resources to come up with a solution.

Another reason that makerspaces foster creativity noted by Saorin et al. (2017) is that they promote divergent thinking, a concept discussed by Liu and Schonwetter (2004) in their research published in the International Journal of Engineering Education. They say that divergent thinking is a learning style in which there are multiple correct solutions to a given problem, any of which would be acceptable. When thinking divergently, students must necessarily be creative, as there is not one clear cut solution or task. Makerspaces do not force students into a single solution, but give them all the resources they could possibly need, and let them figure things out for themselves. Inductive learning and divergent thinking go hand in hand, and according to the research already completed, are two of the major ways that makerspaces can increase creativity in users.

Makerspaces Within an Institution

The other important aspect of makerspaces I wanted to explore with my research was their place within school systems. To this end, there has been some research already conducted. In the Journal of Science Education and Technology, Michael Tan (2019) investigates a school in Singapore, a country known for a powerful centralized testing system, where a makerspace was implemented. He found that the makerspace was able to exist within this rigid school system by defining itself as a club or extracurricular. It was separate, but students would go to the space with problems from classes and receive assistance from older students who led the makerspace. The space had teachers as its formal leaders (different from the next case study) and this gave it more validity and helped justify it as a worthwhile learning endeavor. This case study is fascinating, as it shows a clear example as to how a makerspace, and a community surrounding it, can thrive, even in the most rigid of school environments.

Furthering this approach is research completed by Campos et al. (2019), which first acknowledges the strict environment of K-12 education, then attempts to analyze the tensions that any maker movement will present within this environment. Among the tensions they observed in schools, one was a tension between the maker culture and the schooling ethos. They describe this tension as the conflict between "a highly supervised learning process, and non-directed exploration." They describe a split between the volunteers who ran the makerspace they were observing, and the teachers at the school. The makerspace workers wanted to give the students free reign and let them "play" with the technology as much as possible, while the teachers wanted more direction. This tension is indicative of the K-12 school environment, where teachers feel the need to provide structure and direction, and can have trouble incorporating something like a makerspace, which doesn't seem to fit into this structure.

This research by Campos et al. (2019) also included an account of a student debating an instructor as to what constitutes "work." To me this conversation hits at the crux of the issue, which is how makerspaces can operate in an environment where everything needs to have a metric and a purpose. How can one quantify the learning that happens in a makerspace? How can teachers understand the benefits? These are questions that must be answered as makerspaces attempt to find their niche in K-12 schools. In attempting to learn more about a makerspace's role in education, as well as if it was able to provide creative education to students, I studied a successful maker program within the Albemarle County school system, known as the MESA program.

Framework

In the analysis of makerspaces' role in promoting creativity, I will use the social construction of technology (SCOT) framework in order to analyze the different stakeholders that have input on the creation of makerspaces within schools. This framework attempts to analyze how different social groups involved in the use of makerspaces have viewed different iterations of makerspaces, as well as the conflicts that exist between different social groups (touched on in the previous section when looking at common tensions when creating a makerspace) (Pinch et al., 1984). In order to use this framework, I will first analyze each relevant social group, looking at their wants and needs, as well as what value they stand to gain from a makerspace. I will then analyze the conflicts present between these social groups.

One such group is teachers, whose perspective will be analyzed more closely in later paragraphs. Teachers want to help students learn, but they also have strict guidelines and metrics that determine what they must teach and when. Another is students, who want to gain both theoretical and practical knowledge, while also being able to think and learn in a creative and independent way. Finally there are administrators, the people tasked with the smooth and effective operation of either one school (principal, vice principal) the entire school system (superintendent), but who usually never directly interact with the students. These people are focused on other metrics which they are judged on, which may or may not correctly correlate with educating successful, creative professionals. Furthermore, in cases where a makerspace is sequestered from the rest of the school, the person who oversees the creation and day-to-day operation of the makerspace becomes an important stakeholder.

Methodology

I first wanted to better understand the public school system, and specifically, the requirements placed on teachers for what is taught in school. Furthermore, I wanted to understand the teachers' current relationship with technology, and with any existing maker programs at the school. In order to accomplish this I gathered information both from an interview with a teacher at Hollymead Elementary (in the Albemarle County School system) and from a conversation with a person with knowledge related to creating and administering a makerspace within a grade school. For the sake of anonymity, I will refer to the teacher interviewed as "Teacher A," and the unnamed makerspace worker as "Jane Doe."

Standard Classroom Teacher

I first interviewed Teacher A, asking a number of questions about the teaching requirements, metrics for success (both for the teacher and her students), and the current use of technology in learning at the school. In regards to teaching requirements, I learned that there is a list of "Essential Knowledge, Skills, and Processes," laid out by the Virginia Standards of Learning, which all students are expected to have learned by the time they complete a grade (Virginia Department of Education, n.d.). Teacher A told me that the teachers have a large degree of freedom in the way in which they choose to teach the students, but all students are required to take the SOL test at the end of the year. This is a standardized test (usually multiple choice) that aims to assess whether the students learned the required knowledge for a given year of school. That said, there are apparently no consequences for the student should they fail the test, and no official repercussions for teachers who have a high percentage of their students fail (although Teacher A told me that if a teacher did have a high percentage of their students fail, they would be expected to "show progress" toward improving).

Things got incredibly interesting though when I began to ask about technology and its use in the classroom. The students at this school each had access to their own laptop which they could bring home with them. That said, it seemed that the limits of what the students did with the laptops in class amounted to using google drive and google classroom, as well as the internet sometimes. I also learned that the students have access to a server maintained by Albemarle

County which is filled with useful programs and tools, but that the vast majority of teachers did not have anything close to the required training to understand and use those tools (most didn't even know how to access them). The teacher also told me that there is opportunity to become certified in these programs, but that it was all voluntary, and the school and county offered zero incentives for teachers to be trained. Finally, I learned of a person hired by Albemarle County with the job of incorporating technology into the classroom. This person is assigned upwards of three schools which they are responsible for, and as such each classroom receives a very low number of visits. Furthermore, Teacher A had obvious disdain for this person, stating that she no longer invited him to lessons as the last time he was there, his pitch for incorporating technology into the classroom was to give the students access to Minecraft (a popular video game) and to have them create things there. The teacher saw no value in this idea, and even felt that giving her class of fifth graders access to a video game during class time would disrupt class, and decrease learning rather than increase it.

Makerspace Administrator

Jane Doe has actually built and operated a makerspace in a school, and began by speaking about the definitive lack of training she received to run the makerspace. Jane was not a science or math teacher but was brought on by the school to run the makerspace. She learned everything she needed to about the technology in the makerspace on her own, through online forums and workshops (paid for out of pocket sometimes). She continued, saying that the teachers and school administration (principals, vice principals, etc.) have been less than accommodating toward her, and there is a complete disconnect between the makerspace and the classroom. She also has limited class time and planning compared to the other teachers, and on top of that, has clashed with administration over the lack of traditional grading in the makerspace.

She however, mostly blames the Virginia Standards of Learning, and is frustrated that they contain no language to promote creative design at all. She feels that they stifle her ability to give students a creative outlet, and she finds herself having to provide loose justifications based on the standards when assessed by administration. She is also forced to adhere to some archaic requirements within the standards such as teaching keyboarding.

In addition, Jane spoke to the funding concern, specifically, that the county was spending lots of money creating makerspaces, but did not provide the continuous funding needed to pay for materials and training for teachers. Jane said that her budget for the makerspace was very low, and with the incredible cost of 3D printer polymer, 3D printers are all but useless. She is frustrated with all these limitations, and does not see them improving any time soon.

Case Study: Albemarle High School

After gathering information about the state of the public education system in Albemarle County, as well as learning about the point of view of a makerspace leader in a school, I moved on to interviewing a student enrolled in the MESA program at Albemarle High School. I will say as an initial disclaimer that this is a High School program rather an elementary school one, but this program acts as a proof of concepts for similar programs at all levels. I interviewed a current high school senior who has been a part of the MESA program for all four years of high school to gain a better understanding of this program. In addition, I have my own experience as I was part of this program for the four years I was in high school.

The MESA program is an academy within Albemarle High School, but any student, regardless of their school districting zone may apply and attend the academy. The program has its own large space (the size of two very large classrooms with a large connecting room between them) outfitted with lots of outlets, and tables and chairs that can be moved around to accommodate a wide range of activities. Within this space is a wide array of technology and maker equipment including 3D printers, a laser cutter, large touchscreen desktops, a variety of arduino supplies (servos, lights, motors, breadboards, wires, resistors and more), and lots of tools for wood and metal work (hand saws, table saw, drills, dremel tools, drill press, saw horses, and almost any small hand tool one could think of).

The program is split into two distinct halves, the first two years and the second. During the first two years in the program, students take an accelerated course load in math and science taught by the MESA teachers and a few other select teachers. During this time, they don’t have assignments that directly use the maker equipment, but for personal projects they can get assistance from teachers and use the space and the equipment. During the second two years, they begin a more engineering focused curriculum with a high percentage of the assignments being project based. During these two years, they complete a number of projects specifically designed to allow for creativity and problem solving. When talking to the current student, she said that for almost all projects, coding or physical (the current version of the program contains a heavy programming section), they are given a task with specifications, as well as some light restraints, and told to find a solution in any way they can.

The current student says she feels like she enjoys projects more, and learns more when she has to struggle to solve problems on her own. She seemed to especially feel this way regarding MatLab, a programming language taught heavily in the program. She said the open ended coding assignments forced her to really learn the language, and she feels confident in her ability to build unique solutions to problems using MatLab. In addition to all this, she said that her MESA teachers are incredibly knowledgeable, especially when compared to her other teachers. She said that the MESA teachers all know what they are talking about when explaining coding languages, modeling software, and the 3D printers and laser cutters. Overall the MESA program seems like a successful implementation of maker values within a public school.

Analysis

Through my review of existing literature, I found that there is a wide body of evidence suggesting that makerspaces and maker programs can provide meaningful creative experiences for students. They are able to do so via inductive learning, which forces students to be creative and arrive at solutions on their own. Once the effectiveness of the makerspaces is established, the other half of the problem is how to incorporate them into a public school system that is inherently rigid, and based on a grading system, as well as standardized testing system.

To this end, there have been a number of studies conducted that focus on the integration of maker programs into school systems. The first study I looked at by Michael Tan showed how a segregated makerspace could blossom and have a community form around it in certain conditions. These conditions I believe were key in the success of the school Tan studied, as the school was one of the top schools in the country, with first class students and a large amount of money. Furthermore, in Singapore (where the study was conducted), teachers are required to have far more education than in the US, and teaching as a whole is a more revered position. (Stewart, n.d.) Because of this, Teachers had the skills to be effective leaders and did not require additional training. Furthermore, the government planned on this school being a test case, and as such adjusted curriculum (even later excusing students from this school from taking the national exams) to allow for more freedom. In this near perfect environment, the maker program was able thrive as its own sequestered unit, but not all schools are in the same position, and the research by Campos et al. (2019) explored the specific tensions created through the implementation of a makespace in a school.

The case study performed by Campos et al. (2019) more closely resembled a typical American school, and they spoke of a number of tensions, one of the most salient being the tension between "the maker culture and the schooling ethos." This tension cuts to the heart of what I learned from my interviews with teachers, and it is primarily this tension that drives this research. These tensions showed that there are still a number of problems and conflicts between social groups when it comes to makerspaces. Furthermore, given that there are a wide variety of implementations of makerspaces, both documented in the literature and in my own case study, it is clear that this a flexible environment.

After establishing a scholarly basis, I then looked to my interviews and case study. These interviews, especially the ones with Teacher A and Jane Doe, helped me to narrow my focus to the specific problems and conflicts present. The interview with teacher A showed me that although there is access to technology, there is no training or knowledge on the part of the teachers, which renders the technology useless, and allows for a whole server full of cutting edge software to sit collecting dust on the county server. From what I've seen, the administrator stakeholder group is putting money and resources into technology in schools, but in the wrong areas. They are able to easily say that they are spending X amount of money on technology in the classroom by buying every student a computer and having a technology "expert" (the teacher interviewed seemed very skeptical about this person's skillset) come to classrooms once in a blue moon.

Teacher A and Jane Doe told similar stories from different perspectives. Teacher A was a normal teacher, working within the system set out by the standards of learning. Working in a normal classroom setting, she is given a high degree of autonomy when it comes to the actual activities that students take part in. On the other hand, Jane is working in a makerspace that is definitively separate from the classroom. Teacher A represents the “teachers” stakeholder group, while Jane represents the makerspace worker stakeholder group. Based on what I heard from both teachers, I believe that the immediate path to a better outcome for Jane could lie in coordination with traditional classroom teachers (such as Teacher A). By connecting with the classroom teachers, makerspace workers can utilize the autonomy they possess in the classroom and incorporate the makerspace into current lesson plans.

My interview with the Albemarle High School student allows me to see how a system like this might work. The system at Albemarle is an interesting hybrid in that it is not inclusive for the whole school, and it doesn’t try to be. It is a system that only allows a select group of students access to the space, but one that solves nearly all the problems faced by “normal” makerspaces. For one thing, the teachers are more specialized, and are hired for their expertise. This solves the problem of trying to train existing teachers on equipment. Furthermore, the program is, in part, a set of classes that contain project work which uses the space. This immediately solves the disconnect between classroom and makerspace by making them one and the same. They are also able to work within the standards of learning by teaching regular classes the first two years, then transitioning to project work that makes direct use of the makerspace. The way it is marketed to the county is clever too. It is pushed as an advanced science math and engineering academy which preps students that want careers in the STEM field. It is all of these things, but in addition, it is able to insert creativity and maker values into the public school system. It satisfies all the different social groups who have influence on the creation of a makerspace, and although there has currently not been closure within the space, it is possible it could occur with a MESA-style program.

Conclusion

I conducted this research in order to understand if makerspaces could fill the creativity and problem solving void currently present in the public education system. Researching alternative learning methods I found that inductive learning (along with divergent thinking) can be a powerful tool in education. Furthermore, it is clear that makerspaces provide a pathway for students to experience this form of learning, and in the process, gain creative experiences and problem solving abilities. This is confirmed by student interviews, where students confirm that they have a better overall learning experience when they are able to think creatively and solve problems on their own.

In order to accomplish the feat of incorporating a makerspace into a public school though, a strict maze of rules and regulations must be navigated, and straightforward attempts to do so can prove frustrating. My research has shown that while directly inserting a makerspace into a school can work, given the right circumstance, it often does not fill the gap of creative learning and problem solving present in schools, and sometimes can create tensions that were not originally present. The MESA program at Albemarle High School has shown that with careful planning and marketing, a hybrid program, built from the ground up, can exist within the school system. This hybrid can still promote all the same values that makerspaces strive for, and can do so in a way that avoids the common problems that normally come with creating a makerspace in school.

Bibliography

Campos, Fabio & Soster, Tatiana & Blikstein, Paulo. (2019). "Sorry, I Was in Teacher Mode Today": Pivotal Tensions and Contradictory Discourses in Real-World Implementations of School Makerspaces. 10.1145/3311890.3311903.

Ladd, H. F. (2017). No Child Left Behind: A Deeply Flawed Federal Policy. *Journal of Policy Analysis and Management*, *36*(2), 461–469. doi: 10.1002/pam.21978

Liu, Z., & Schonwetter, D. J. (2004). Teaching Creativity in Engineering. *International Journal of Engineering Education*, *20*(5), 801–808. Retrieved from http://web.mit.edu/monicaru/Public/old stuff/For Dava/Grad Library.Data/PDF/Liu - Teaching Creativity in Engineering Education-2903413761/Liu - Teaching Creativity in Engineering Education.pdf

Pinch, Trevor J. and Wiebe E. Bijker. "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other." Social Studies of Science 14 (August 1984): 399-441.

Powell, D., Higgins, H. J., Aram, R., & Freed, A. (2009). Impact of No Child Left Behind on Curriculum and Instruction in Rural Schools. *The Rural Educator*, *31*(1). https://doi.org/10.35608/ruraled.v31i1.439

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: definitions, comparisons, and research bases. Journal of Engineering Education, 95(2), 123–138.

Robbins, E., & Langan, T. (2016). *How Cities can Grow the Maker Movement*. *How Cities can Grow the Maker Movement* (pp. 0–28). Washington, D.C., D.C.: National League of Cities.

Retrieved from https://www.nlc.org/sites/default/files/2016-12/Maker Movement Report final.pdf

Saorín, J. L., Melian-Díaz, D., Bonnet, A., Carrera, C. C., Meier, C., & Torre-Cantero, J. D. L. (2017). Makerspace teaching-learning environment to enhance creative competence in engineering students. *Thinking Skills and Creativity*, *23*, 188–198. doi: 10.1016/j.tsc.2017.01.004

Stewart, V. (n.d.). How Singapore Developed a High-Quality Teacher Workforce. Retrieved from https://asiasociety.org/global-cities-education-network/how-singapore-developed-high-quality-teacher-workforce

Tan, M. J Sci Educ Technol (2019) 28: 75. https://doi.org/10.1007/s10956-018-9749-x

Virginia Department of Education. (n.d.). The Standards & SOL-based Instructional Resources. Retrieved from http://www.doe.virginia.gov/testing/sol/standards_docs/