



## **Work in Progress: Exploring the Role of Makerspaces and Flipped Learning in a Town-Gown Effort to Engage K12 Students in STEAM**

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## **Introduction**

The Maker movement is a grassroots effort to transform consumers into people who create, produce, and innovate. In many ways, the Maker movement represents a logical extension of synthesis of current trends in education such as active learning, problem based learning, team-based learning, flipped classrooms, and community-service learning. At the national level, makerspaces have garnered attention for their potential to inspire engagement with science, technology, engineering, and math (STEM) learning. The White House proclaimed a National Day of Making on June 18<sup>th</sup>, 2014, and released the same month a report entitled “Building a Nation of Makers: Universities and Colleges Pledge to Expand Opportunities to Make”. The University of Massachusetts Amherst (UMass Amherst) is in the beginning stages of building a Town-Gown Makerspace. This is a partnership between the “town” of Amherst through the non-profit local Information and Communications Technology (ICT) center known as Amherst Media and the academic or “gown” community of UMass. Within the makerspace, students at all levels can pursue independent projects collaboratively and learn about technology and entrepreneurship. This paper discusses current trends in the Maker movement and educational learning theory; presents efforts at UMass Amherst to combine these concepts to engage students in STEM fields by also incorporating art; and discusses some the challenges and opportunities for this model. An underlying goal of the work is to identify the key elements of the Maker movement, which may help engage underprivileged youth as well as retain undergraduates in STEM fields.

## **Institutional designs of makerspaces and makerspace networks**

A Makerspace can mean many things, but in this context we are describing a physical space where people with an interest in Science, Technology, Engineering, Art and Math (STEAM) can meet up, work on projects, and learn through “Doing-it-Yourself” or “Doing-it-Together”. It is also a place where Makers of all ages can come together and help and learn from one another. Most current definitions of “making” include elements of fabrication, physical computing and programming<sup>1</sup>. In this section we provide a brief overview to illustrate range of existing institutional designs for makerspaces, including their goals and funding mechanisms.

Recent articles have described “milestones” of the maker movement, including fablabs and hackerspaces<sup>1, 2</sup>. Many educators are beginning to explore the potential of makerspaces to support learning in formal primary, secondary, and university settings as well as outside of formal learning environments<sup>1, 3, 4, 5, 6, 7</sup>. Numerous universities provide makerspaces for their students<sup>4</sup>. A growing number of museums and libraries are also beginning to host makerspaces, often supported by private foundations, in part to make these opportunities open to all

community members regardless of their ability to pay. Other communities are beginning to host makerspaces to serve as business incubators, offering tools, educational, mentoring, and networking opportunities in an effort to impact economic and workforce development. Detroit, Michigan is one city where maker and entrepreneurial networks are reclaiming and vitalizing abandoned spaces<sup>8</sup>. In several major cities, retail establishments offer supplies, classes, afterschool programs and workspaces that are maker themed (for an idea of the range of activities in one community, Boston, see <http://boston.mommypoppins.com/kids//science-technology-engineering-arts-and-math-steam-classes-for-boston-kids>).

Long-term funding and sustainability for these spaces is a potential challenge. Some state governments, such as Massachusetts, are considering bills that would provide competitive funding opportunities for collaborative workspaces<sup>9</sup>. Most makerspaces, however, are nonprofit organizations governed by elected boards; only a few run as corporations<sup>2</sup>. Membership fees provide the principle means of support for most makerspaces, but others are supported through donations, sponsorships, volunteer labor, revenue raised through classes and events, grants, and local partnerships<sup>2</sup>. Programs that rely solely on membership fees and class revenues can face challenges providing the space and equipment to meet their needs, and some spaces have been forced to close if they cannot sustain a membership high enough to cover their costs. Many universities have partnered with industry to provide support for their makerspaces.

There is general agreement that the maker movement has a strong potential to positively impact K-12 and university education, but there are different approaches and theories. Some educational settings focus on “making” to teach a concept or standard, others focus on having students identify a problem and creating a tool or machine to solve the problem, while yet others aim to provide a “material toolbox” and allow students to independently develop fluency and push the technology in the direction they wish<sup>1,10</sup>. The heart of the maker movement is strongly aligned with theories of “constructionist” activity or “learning-by-doing” which are accepted successful learning principles<sup>1,3,11</sup>. Providing youth with an avenue to bring the technologies they utilize in their “free” time into their learning environment can be very powerful. The “connected learning” initiative, for example, has created a model of learning which emphasizes the power of interest-driven learning to engage students who may be underserved by traditional education spaces<sup>12</sup>. This model highlights how cultivating out of school literacies and interests can have powerful implications for learning, economic opportunities, and civic engagement. “Connected learning” as an educational model “is based on evidence that the most resilient, adaptive, and effective learning involves individual interest as well as social support to overcome adversity and provide recognition”<sup>12</sup> (p. 3). Combining social support structures with these concepts of learning-by-doing may provide a valuable sense of achievement to students that do not perform as well based on traditional performance evaluation metrics. The maker alignment with learning theories and models of student engagement are explored further in the next section.

## **Intersections with current learning theories and models for effective engagement of students**

Perhaps one of the most exciting potential outcomes of bringing the maker movement into the formal and informal education conversation is the opportunity to revisit our conceptualizations of what counts as learning, what it is to be a learner, and what makes a positive learning environment *from a more diverse perspective*<sup>3</sup>. There are exciting opportunities at the K-12, college and university levels, particularly if makerspaces can serve as an integrative continuum along this pipeline, weaving together both formal and informal educational environments. An underlying question we seek to address is: Can makerspaces help to both stop leaks and open doors along the STEM pipeline for all students, but in particular for women and multicultural students?

According to Brown, Collins, and Duguid (1989)<sup>14</sup> the tools one acquires from instruction must be seen working within authentic contexts for learning to be realized. They term this theory “situated cognition” and posit that “[l]earning and acting are interestingly indistinct, learning being a continuous, life-long process resulting from acting in situations”<sup>14</sup> (p. 33). Learning within authentic contexts (e.g. apprenticeships) immerses the learner within that culture of practice. More formal learning environments such as traditional K-12 schooling face challenges in creating such authentic learning environments as these institutions have their own practices and norms. To address this challenge, educators have attempted to incorporate methods of experiential, project-based learning such as the Problem-based Learning (PBL) approach which encourages learners to solve real-world problems<sup>15</sup>. PBL position the instructor in the role of guide or facilitator of the problem solving process and encourage self-directed learning through collaborative and iterative problem-solving<sup>15</sup>. Such experiential and project-based learning models are crucial for creating conceptual bridges between the various disciplines of STEM and provide support for the inclusion of “arts and design” in the move to STE(A)M.

The inclusion of arts and design in the move to STEAM can be thought of as a natural extension of STEM as design consideration are often crucial import in the building of technologies and systems. Not only do the branches of STEAM complement one another in practice, they support a holistic view of knowledge creation. For example, research on project-based learning such as Learning by Design (LBD) has demonstrated that design considerations assist in overall science literacy for complex systems<sup>16</sup>. The multi-disciplinary focus in STEAM education should not only be thought of on the instrumental level, however. Another crucial aspect of the STEAM framework is the creation of more openings for exploration and discovery among youth. When scientific and technical literacy receive equal emphasis as that of artistic literacies, students with varied interests can share the same space and their work can inform one another.

E-textile creation through the use of sewable technologies like the Arduino Lilypad is an excellent example of how artistic crafting activities can create openings to explore circuitry and computer programming. The design and creation of these e-textiles requires aesthetic and design considerations while also introducing students to basic programming and electronics. Moreover, these e-textile technologies have the potential to engage young women in influential ways. In a program with middle school students<sup>17</sup> young women were very engaged in troubleshooting and planning discussions: “From videotaped observations of subjects working in mixed-gender pairs, we found that both boys and girls equally engaged in e-textile activity, as evidenced by body language, gaze, talk-on-task, and other indicators, but girls tended to play a greater leadership role” (p. 40). STEAM activities such as e-textile creation can broaden the opportunities for interest-driven engagement with technology by providing more varied entry points.

With new technological developments, the importance of STEAM literacies will only increase. In the mid-nineties, the New London Group began theorizing toward a set of “multiliteracies” which would assist youth in navigating the digital environment with increasingly diverse modes of communication<sup>18</sup>. Their literacy framework forwarded a view of education focused not only on skills but on social participation in order “to ensure that all students benefit from learning in ways that allow them to participate fully in public, community, and economic life”<sup>18</sup> (p. 30). Since their pioneering work, numerous scholars have worked to catalog the literacies need to take full advantage of the affordances of today’s technologies. Selber (2004)<sup>19</sup>, for example, described a broad framework that includes how to use information technologies or “functional literacy,” the ability to question the uses and designs of current technologies or “critical literacy,” and the ability to redesign or produce technologies or “rhetorical literacy.” Constructionist approaches as outlined above provide can encapsulate the various literacies and competencies needed for more meaningful social participation. These approaches must remain cognizant, however, of the social dimensions. Efforts like that of the maker movement to transform consumers into producers and innovators must move beyond mere content learning or functional competencies and foster purpose-driven collaborative practices. Coupling STEAM learning with the makerspace model has the potential to re-center social dimensions of learning to foster supportive, collaborative learning communities.

Social spaces of learning must be discussed within their institutional contexts to better understand the challenges facing the creation of inclusive and effective educational opportunities. In engineering, four interrelated factors have been noted as barriers to the persistence of academically talented students that face financial limitations, as is the case for many of our multicultural students<sup>20, 21, 22</sup>:

- Lack of Engagement/Sense of Belonging
- Underdeveloped Professional Work Ethic & Goal Setting
- Insufficient Opportunities to Gain Practical Competence & Reflect on Learning
- Working for Pay

Talented young women, as well as multicultural students, too frequently pursue careers in other fields or leave engineering because they are not exposed early enough or often enough to the societal relevance and impact of the profession. Others leave due to poor academic performance, often linked to a lack of engagement. At our institution, we view engagement of undergraduates in outreach, makerspaces and maker courses as an important element of student development, college impact, and personal engagement that can help address these barriers and which are aligned with “BEST,” Building Engineering and Science Talent, principles<sup>23</sup>.

Broadly speaking, student success theories and models can be categorized into two general groups: *student development* and *college impact*<sup>24</sup>. Taken together, these factors give rise to a complex system of behaviors, structures and programs that affect student success. Kuh (2007)<sup>25</sup> posits that student engagement is at the intersection of student behaviors and the institutional conditions, and considers student engagement to be a “key factor to whether [students] will survive and thrive in college”<sup>26</sup> (p. 7). Self-efficacy is the belief in one’s capability to successfully perform a given task or domain<sup>27</sup> and is a key construct in Lent et al.’s<sup>28</sup> (1994) social cognitive career theory. The theory suggests that mastery experiences, feedback from influential people, vicarious experiences and physiological responses all contribute to the person’s sense of self-efficacy<sup>29</sup>. Multifaceted networks for student support are necessary, particularly at the college and university level where students can too readily become disenfranchised. As Dr. Shirley Ann Jackson has noted, “...we have to meet the students where they are: we have to give them personal attention. Programs that are structured this way see the value of personal attention at every stage of higher education and are committed to meeting students’ individual learning needs, which includes mentoring and tutoring”<sup>22</sup> (p. 24). With such support immediately available, problems in transitioning (housing, financial aid, course selection, building study networks, etc.) and feelings of isolation<sup>30</sup> will be addressed quickly.

### **Town-gown makerspace initiative**

Universities have a large impact on the surrounding communities. A report released last year by the UMass Donahue Institute estimates that UMass Amherst contributed \$1.9 billion to the commonwealth’s economy in the 2012-2013 fiscal year<sup>31</sup>. Typically the positive economic benefits far outweigh negative impacts, but this is not always the case. Relationships between the town of Amherst and UMass (e.g., “gown”) have been strained in recent years due to the influx of student off-campus housing into previously family dominated neighborhoods, and in 2014 campus received negative nationwide press coverage when 80 were arrested at a pre-St. Patrick’s Day ‘Blarney Blowout’. There are few opportunities for college students to “give-back” to the local community. This is particularly true because of a campus focus on outreach to two nearby high needs school districts, rather than the local district. Local schools, however, are facing their own challenges in terms of racial tension. Opportunities for UMass Amherst and other local college students to work with and mentor local K-12 students could provide a means of forging a more positive town-gown relationship.

## ***Motivation***

Our goal is to explore the potential of a makerspace community to serve as a focal point that:

- Forges a positive relationship between UMass and the town of Amherst;
- Provides an effective mechanism for interesting K12 students, particularly women and multicultural students, in pursuing degrees in STEM fields;
- Improves retention of undergraduate women and multicultural students in STEM fields; and
- Provides a parallel training path including elements of interdisciplinary collaboration and entrepreneurship to encourage students to pursue advanced degrees.

To date we have focused on introducing students to open source or low-cost commercial technologies (e.g., Lilypads, Arduino, Gemma, Raspberry Pi) that can be utilized to create E-textiles, jewelry or responsive electronic devices and, ultimately, be applied to solve real-world environmental management problems.

## ***Structure***

Our Maker community was originally formed in 2012 with a focus on organizing classes and workshops for community teens. In January 2014, we partnered with a local non-profit Amherst Media to begin offering regular hours for a community Maker Meetup and to hold a pilot 3-day long “Makerspace” event which highlighted on-going Maker activities across a local consortium of colleges (UMass, Amherst College, Hampshire College, Smith, and Mt. Holyoke) and including a two-day workshop for middle school students. In May 2014, we received funding to continue the drop-in Maker Meetups and expand these efforts to include additional workshops for middle school students. This fall, through a partnership with the Amherst Regional Public School District and funding through the District’s 21<sup>st</sup> Century Community Learning Center grant, we offered a weekly afterschool Maker curriculum for middle school students that is continuing through the spring. UMass Amherst supports the afterschool program, Maker Meetup, and weekend K12 workshops through several mechanisms, including a Public Service Endowment Grant and faculty, staff and student partnerships across three campuses (UMass, Hampshire College, and Amherst College) and multiple departments.

Perhaps most transformative is the integration of an experimental University “flipped”, service learning, Makerspace course with both the afterschool and Maker Meetup programs. In recent years, several definitions of “flipped learning” have emerged. We refer to the common definition recently proposed by the Flipped Learning Network<sup>32, 33</sup> - “Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter.”

The UMass Makerspace Course<sup>34</sup> meets concurrently with the Maker Meetup drop-in hours, and students from this course presented their work, which utilized a wide range of open engineered (non-proprietary) technology and software including Arduino microcontrollers, Raspberry Pi computers, electronic sensors, “e-textiles”, 3-D design and printing, and video creation, to the middle school students in their efforts. Through our on-going work, we aim to identify the elements of our program that are most effective in advancing our goals and how these programs may be sustained.

The Maker community has the potential to create an environment supportive of flipped learning and which engages and supports the next generation of students in STEM. However, there is a risk that we may leave some of those that might benefit most - women and multicultural students - behind if we are not thoughtful in their design. Research into technology-centered production fields like open source software and low-power FM communities, for example, have found that these spaces can create cultures of exclusion<sup>35, 36</sup>. Although more than a decade old, comments made by then Princeton University President Dr. Shirley Tilghman<sup>37</sup> during the Broadening Participation in Science and Engineering Research and Education Workshop help illustrate this point: “Carnegie Mellon developed a very successful program to increase the participation of women in computer science. This program began by trying to understand why the participation of women in computer science had been declining with time, not increasing. The faculty knew that adolescent boys who are future computer science majors can often be found in their bedrooms, the lights out, the curtains closed, playing on their computers. Yet it is the rare thirteen-year-old girl who would be engaged in such activity. As a result, by the time those teenagers reach university, they have had different experiences and acquired different computer skills that make it difficult to put them into the same classroom (page 29)”. For makerspaces to make significant contributions to enhancing the participation of women and multicultural students in STEM fields, we must make them attractive environments for these constituencies. In the paragraphs below we illustrate how the various elements of our programs try to achieve this.

### ***Discussion***

One way in which we have tried to attract a variety of audiences is by providing multiple formats for participation: (1) a long-term after school program, (2) periodic “Maker Meetup” workshops in our space, and (3) introductory outreach events. The 21st Century afterschool program provides an opportunity to work with the same group of middle school students over the course of a semester, which enables us to cover more content and to develop an environment of mutual trust, respect, and exploration. Our 21st Century students tend to be more diverse and of lower socioeconomic status than the general middle school population. They are more likely to lack the family resources and support to attend evening or weekend events, even if there are no fees associated with these events. These students are also least likely to be exposed to computing or the technologies and potential applications we introduce through other avenues, such as home or school. They are at a critical age for exposure to these worlds, need a supportive environment to pursue their current interests and learn alongside peers, and mentors may lead them to consider



an academic pathway and/or pursue degrees in STEM fields. The community Maker Meetups are the more traditional format and cater to audiences that have been previously exposed to the world of technology and computing. In many ways, the Maker Meetup audience is comprised of the “thirteen-year-old boys” referred to by Tilghman. However, the Meetup provides an environment more conducive to flipped learning and opportunities to more deeply explore areas of interest, leverage the on-line Do-It-Yourself (DIY) / Do-It-Together (DIT) communities, and be innovative and entrepreneurial. We aim to push the Maker Meetups to be a multi-generational community that is attractive to a wider audience - namely women and multicultural students. Our Maker Workshops are designed to build a bridge to the Maker Meetups for a third group of K-12 students, in particular girls and those involved in athletics. These are students that have the resources to participate in a workshop if the content intrigues them, but don’t have room in their schedules for a routine commitment. Finally, to reach community members that may not be familiar with our programming, we seek out opportunities to meet with existing groups and workshops. For example, we have again partnered with the local school district to discuss our makerspace during “Family Night,” a periodic event for students and their families to visit the schools and learn more about school activities and members of our makerspace have volunteered to speak at local IT training programs.

We have consciously tried to provide two “curriculum tracks” - one for students who have been programming and tinkering, and the other for those with no previous experience or interest - mimicking the Carnegie Mellon approach for increasing the number of women graduating in computer science. The “no previous experience” path has been very important for encouraging middle school students to sign up for our section of the 21st Century afterschool program. Using the STEAM model as a guiding philosophy<sup>38</sup>, the afterschool program aims to bring students with varied interests and experiences to the space. One draw has been the integration of multimedia communication and media production training within the program. After the training, students are free to record each other discussing their projects or create clips of themselves explaining what they are working on. Through our partnership with Amherst Media, we have been able to edit these and, with parent permission, highlight the students’ work on community television. During the fall, the afterschool program started with an introduction to Arduinos through use of e-textile “starter kits” from Sparkfun. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software and intended for artists, designers, and hobbyists. Each student then designed, built, and programmed an artistic “patch”, decorated with felt and other art supplies, which incorporated LEDs controlled by a tiny “Lilypad” microprocessor and powered through conductive thread. Our Maker Workshops have paralleled this approach, providing pathways for novice and advanced learners, introducing the “A” in STEAM, and appealing to a range of age groups: introduction to Arduinos weekend, build your own E-textile and holiday Adafruit Gemma neopixel earring workshops, and build your own home theater media server using Raspberry Pi. All of these projects introduce students to computing, basic electronic circuits, and engineered systems design. Ultimately we aim for

participants to apply these skills to solve real-world environmental management problems, another “hook” for many women and multicultural students.

Another focus has been to build a vertically integrated and interdisciplinary community, incorporating both intergenerational and peer support. At the most basic level, we have hired college students from a variety of disciplinary backgrounds to lead the afterschool program and workshops, as well as to help “host” the Maker meetups. Additional college students volunteer their time. We believe that our undergraduate and graduate students are the best “ambassadors” for STEM fields, and that, by interacting with them, K-12 students are better able to imagine themselves following similar pathways. Additionally, through informal discussions with these budding “experts,” younger students come to learn more about the cultures of practice of these fields<sup>14</sup>. For example, when a few students in the afterschool program became frustrated with having to redesign their e-textile sketches, an undergraduate facilitator brought out his design notebook and showed the students how many different sketches he went through before settling on a design. The ability to draw upon a large contingent of undergraduates, graduate students, and faculty from the four local colleges and UMass also enables us to provide more personal attention to each participant. While one goal is to provide the middle school students with mentors, another is to provide the college students with an opportunity to gain practical competence and reflect on their learning by applying what they have learned in class to teach others. We hypothesize that by providing intellectual support, advice, and guidance to K-12 students, the college level students advance their own academic and professional development.

Another key element of our vision is the introduction of all levels of students to elements of research and entrepreneurship as early as possible. For our purposes, rather than focusing on research (e.g., the systematic investigation and study about a subject to establish facts) per say, we instead focus on developing the skills of identifying a problem or goal, and bringing technology to bear in addressing that goal. For our younger students, we start with the simple e-textile, Arduino, and Gemma art-systems entry points. At the university level, through the Makerspace Course, students define a social and/or environmental problem they want to pursue and develop a technology to address the issue. Students begin the self-learning needed to implement their idea and generally follow an iterative cycle, as illustrated in Figure 1. Working as a “community of scholars” - teams of undergraduate and graduate students, engineering and natural or social sciences students - the students are able to accomplish much more than they possibly could working individually. This is one of the most attractive aspects of both academic life and careers in science and engineering, and it better prepares them for both the workforce and advanced studies. Ultimately we hope to push the K-12 students to identify and pursue similar projects by exposing them to the work of the Makerspace Course. Towards this end, the Makerspace Course students have involved the middle school students in the testing of their projects, work on their projects and solicit help/feedback during the community Maker Meetups, and have presented their work at Maker Workshops.

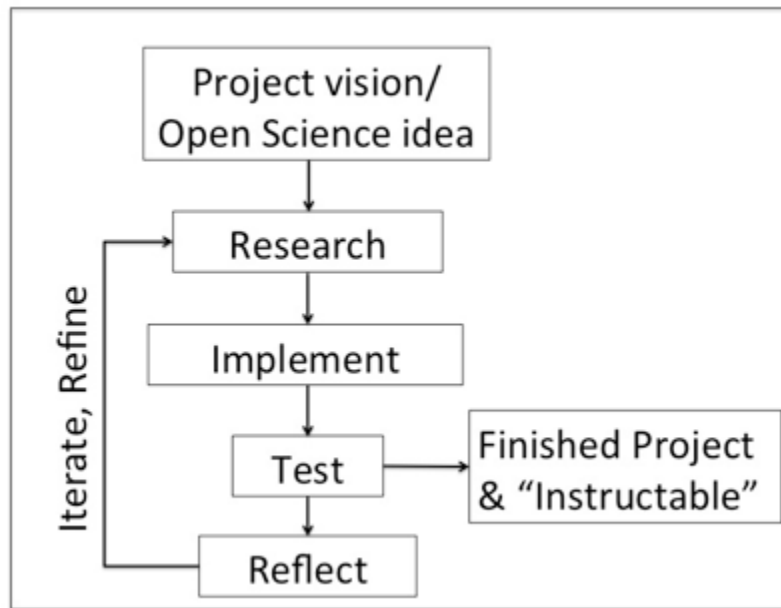


Figure 1: Iterative learning cycle approach utilized in the Makerspace course

Bridging to the next level (e.g., building a pipeline continuum linking students across institutional levels, from middle school to high school to undergraduate to graduate) is another key principle successful educational institutions have utilized to improve student self-efficacy and increase the STEM pipeline<sup>22, 29</sup>. We seek to emulate this concept through our blended makerspace efforts, which aim to build relationships between local colleges/universities, between these institutions and the local school district, and between the local colleges/universities and the broader community, including local governments and businesses. The result, we hope, will be a platform that moves beyond traditional education, encourages a more diverse population to pursue both undergraduate and graduate degrees in STEM fields, improves student retention at the university level within these disciplines, helps students develop the personal skills and work habits that enable them to transition into the workplace, and promotes innovation and entrepreneurship.

### Challenges and opportunities

Due to the focus on social and collaborative problem-solving, creating a sense of community is a central and on-going challenge. The openness of our makerspace model is meant to encourage new visitors and novices. However, the inconsistencies in attendance and the frequent new members make building trust difficult. To address this challenge, most makerspaces create community guidelines. Our afterschool program, for example, began with a discussion of expectations in which we all (facilitators included) created a list of expectations for others and ourselves. The STEAM model is also well-poised to address this challenge. The arts provide opportunities for creative team-building. We have a performance-arts educator visiting the after

school program to use theater to build trust among the group as we plan our collaborative final project.

A recurrent challenge for interdisciplinary collaboration is the intensive schedules of many students in STEM fields at UMass and the four local colleges. The encouragement of outreach needs to be addressed at the institutional level. Community Service Learning (CSL) courses are one approach that provide students course credit for participating in programs like ours. However, for many of the STEM fields, engineering in particular, CSL credits are not useful towards fulfilling their degree requirements. In addition, these students are already typically taking 18 credits, and thus do not have room in their schedules to add another class. Another challenge is with time conflicts between the afterschool program and university classes. Many of the UMass electrical engineering courses, for example, are offered only once per year and are prerequisites for subsequent courses; if a student does not take a course on schedule, they add a year to their degree. Despite these challenges, there are a number of individual students as well as student organizations (e.g., student chapter of the Institute of Electrical and Electronics Engineers - IEEE) that are participating through a combination of paid and volunteer positions.

Perhaps the biggest challenge is sustainability. Funding is necessary for undergraduate and graduate student leaders, supplies, equipment and space. While university, the local school district's 21<sup>st</sup> Century Community Learning Center grant, and corporate grants currently cover most of the costs, these need to be renewed year-to-year. Amherst Media allows us to utilize their space and equipment free of charge. However, they will soon be moving to a new building and will need some financial support to continue the arrangement. A Town of Amherst/UMass Steering Committee released their final housing and economic development plan in the fall. University financial support of the Town/Gown Makerspace at Amherst Media was mentioned as a "quick win" to demonstrate successful town-gown efforts. Finally, we are exploring membership and workshop fee structures, but it is unclear that there is sufficient draw from the relatively small local communities to attain sustainability based on this revenue alone, or that it can cover both personnel and supply costs.

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