

Article

iMakerSpace Model: Shaping the 21st Century Workforce

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Abstract: Innovations in engineering education are undergoing a noticeable transformation. Higher education institutions are practicing distance education, remote laboratories, studio pedagogies and several other approaches in order to increase their students' retention, success, and preparedness for the job market. In engineering education, maker spaces have become popular in the last ten years in universities as well as community colleges, high-schools and community innovation hubs. A large number of engineering colleges have allocated significant spaces, and at some universities entire buildings as maker spaces to be used for curricular and extracurricular activities. Success stories of these types of spaces are well documented. This paper describes the activities and programs held at Tennessee Tech University's maker space called 'iMakerSpace.' These accomplishments include several workforce development activities. The impact and effectiveness of the iMakerSpace is evaluated through analysis of survey data.

Keywords: Innovation, Maker Space, iMakerSpace, 3D Printing, COVID-19, Workshop, Manufacturing, skill, entrepreneurship

1. Introduction

Maker Spaces (MSs) are physical spaces located in community settings or educational institutions for group collaboration and social learning on innovative and technological projects [1, 2]. MSs are increasingly becoming popular worldwide due to the high potential for fostering essential skills needed for innovations and advancing creativity [2, 3]. They are usually collaborative environments inside a university, school, library or dedicated public/private facility for learning, exploring, making, and sharing, that uses high-tech to no tech tools [1, 4]. They are open to young children, adults, and entrepreneurs, and they are equipped with a variety of maker equipment including 3D printers, laser cutters, CNC machines, hand tools etc. [5]. These facilities can take the form of for-profit companies, non-profit corporations, organizations affiliated with or hosted within schools, universities or libraries, and more [6, 7].

The beginning of MSs is traced back to 1995 Germany when the first maker space called C-Base was launched. It started as a place in the community where computer programmers would meet, work, and share their ideas and they called that place "hackerspaces". Over the years, the price of maker tools such as 3D printers, desktop laser cutters and CNC routers became more affordable and hackerspaces naturally evolved into maker spaces. The MS idea is believed to have started in US with the emergence of the Make magazine in 2005, a magazine in the field of innovative manufacturing. Eventually, the movement grew when the Make magazine started a series of venues

for makers to express themselves and share their creations deemed “maker faires” [8]. Libraries took notice and began offering programs and redesigning spaces to address related interests within their communities [9].

A library MS is a successful example of maker space movement in universities, which offers students an opportunity to participate in developing innovative projects [10]. In a MS, students are empowered to use collaborative facilities and social connections, in addition to conventional instructional guidance and technical facilities to explore innovation [11, 12].

MSs combine fabrication equipment, community, and education for the purposes of enabling members to design, prototype and create manufactured works [13]. The goal of MS projects is to provide an opportunity for individuals to learn through direct experimentation and/or group collaboration [14]. MSs are usually developed around a certain type of medium, technology, or even patron age group. Each MS is unique to fit exactly the purposes of the community it serves.

These spaces intended to generate interest in science, technology, design, and lifelong learning for the general public [15]. They are also providing minorities and underrepresented populations, [15], such as people with disabilities, to become involved with technology and fields they may not have previously had the opportunity to engage in. The community atmosphere of MSs allows patrons to learn from each other and experiment rather than receive lessons [16]. University MS activities promote hands-on skills for students to support their theoretical coursework in engineering and other related disciplines. Other observed achievements include improving creativity, team-oriented problem-solving, and multidisciplinary collaboration skills [17, 18].

MSs improve critical thinking skills and boost self-confidence of learners [19]. Some of the skills that are learned in a MS pertain to electronics, 3D printing, 3D modeling, coding, robotics, and even woodworking. These spaces also foster entrepreneurship and are being utilized as incubators and accelerators for business startups [20].

This paper will report several best practices observed and documented at a MS located at Tennessee Tech University. The activities focused on helping the students and participants develop several soft skills and practical knowledge to prepare them for the 21st century workforce will be described here.

2. iMakerSpace

The MS at Tennessee Tech is located in the university library and is known as iMakerSpace. It is a university-wide, student-centered space supported by the College of Engineering with ongoing support from, and collaboration with the College of Business. The iMakerSpace serves as a focal point on campus to provide cutting-edge education, service, partnership, research, Innovation and Entrepreneurship (I&E) activities for all disciplines. iMakerSpace encourages interdisciplinary teams and provides support and education to extend I&E activities into research and the classroom. The iMakerSpace occupies a 2000+ square foot collaborative and fabrication space.

The iMakerspace serves three general groups: 1) University community (Students, faculty and staff), 2) Maker Members (students that undergo special training to operate iMakerspace equipment at an advanced level) and 3) General public. All three groups are welcome and encouraged to utilize the iMakerSpace and its facilities. It is open Monday through Friday from 8:00 AM to 4:30 PM. During this time, the space is open to the public as well as the university community. The staff, comprised of an engineering graduate student, a part-time R&D engineer, a faculty director, and a team of trained undergraduate students are available to support the iMakerSpace activities. Access to the iMakerSpace outside regular hours is restricted to Maker Members as long as the library is open.

3. Background

Since its establishment in 2015, the iMakerSpace has increased both services and outreach activities to further provide students, faculty, and staff with the resources for effective instruction, hands-on/project-based learning, and research projects. Figure 1 demonstrates the area in iMakerSpace allocated for lectures and discussion. Figure 2 shows the space allocated for fabrication and small-scale working area. Figure 3 presents the area accommodating several 3D Printers which are accessible remotely via iMakerTrack.



Figure 1. iMakerSpace Studio for team meetings and discussions, lectures, and events



Figure 2. Fabrication and student clubs' area of iMakerSpace

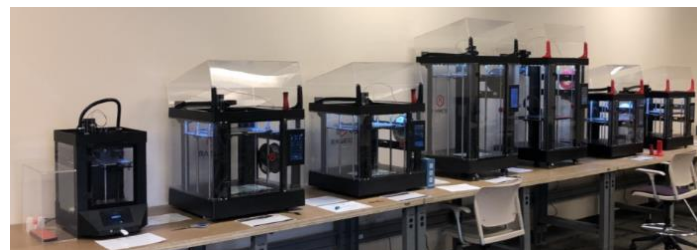


Figure 3. 3D Printing section of iMakerSpace

The iMakerSpace provide various services to the entire campus. The meeting area can be used for team meetings and discussions, lectures and events. The workshop space provides an environment where both individuals and teams can utilize the equipment, supplies, and resources

for projects. The 3D printing section of the space has a number of printers running with Fused Filament Fabrication and Stereolithographic techniques.

Due to the iMakerSpace's combination of education, learning by doing, and fabrication, several I&E events utilize the facility for lectures, training and student competitions. Student senior design and capstone projects are fabricated with the support of the iMakerSpace team.

The following section provides a list of available equipment and resources.

- 7x Raise3D Printers: advanced additive manufacturing – large build volume, high-resolution, power failure recovery, filament run-out sensor, digital monitoring, dual print heads.
- 2x FormLabs Printers: advanced additive manufacturing – laser-based, extreme precision, ultra-high quality.
- 2x Monoprice Printers: hobbyist additive manufacturing – smaller build volume, reliable quality, perfect for beginners to experiment with.
- 2x CNC: large cutting area, ability to cut wood, plastic, and soft metals.
- 4x Desktop Computers: equipped with appropriate hardware and the most up-to-date software, used for 2D and 3D modeling.
- 9x Low-top Desks: arrange able to many configurations.
- 4x High-top Work Stations: large workshop tables to accommodate projects.
- 2x Display Screens: high definition, computer input friendly, easy to use.
- 7x Mobile White Boards: large dry-erase surface for drawing/writing, arrangeable.
- 1x Studio: Space accommodating 50 people
- Hand Tools: large assortment of both manual and powered hand tools.
- 1x Instruction Station with Laptop Hook-up
- 1x Electronics and Soldering Station

4. iMakerSpace Activities

iMakerSpace hosts a large number of activities throughout the year. This paper highlights the following selected core activities.

4.1. Golden Eagle Additively Innovative Virtual Lecture Series

The iMakerSpace is home to the “Golden Eagle Additively Innovative Lecture Series.” These lectures are each about half-an-hour long and feature guest speakers from all around the world. The lectures are open to anyone via the free ZOOM platform. Listeners can hear experts in their fields talk about additive manufacturing and other related processes. To tune in, participants can use an easy access link at any of the times listed on the lecture series. This program is active for the past five years and it helped to train a high number of people on the latest trends and technologies of additive manufacturing. Students who are interested in attending the lectures via iMakerSpace studio are also encouraged.

All the lectures are also recorded and placed on a server maintained by the Center for Manufacturing Research [21]. Eventually, lectures are also disseminated via YouTube Channel located at [22]. It was observed that the lecture series had attendees all over the world from India to Azerbaijan, Brazil, and England. University students also indicated that these talks were beneficial to them as they helped them enhance their learning of today's R&D and workforce needs in additive manufacturing [23]. In Spring 2020, the team creating this virtual lecture series were awarded with the College of Engineering Innovation Award [24]. Figure 4 presents the Spring 2020 Lecture Series.



Golden Eagle Additively Innovative Lecture Series
11 – 11:30 a.m. CST Spring 2020
 Join from anywhere via
tntech.zoom.us/j/432789883

Thursday, February 6
New functionalities for metal AM by embedded intelligence
 With Puukko Pasi, Research Team Leader, Advanced Manufacturing Technologies
 VTT Technical Research Centre of Finland Ltd., Espoo, Finland

Thursday, March 5
Integrated statistical/experimental methodologies for rapid and cost-effective optimization of process parameters in additive manufacturing
 With Ehsan Toyserkani, Ph.D., Professor and Canada Research Chair in Additive Manufacturing,
 Director of Multi-Scale Additive Manufacturing Lab, Director of Pan-Canadian NSERC/CFI Strategic Network for Holistic Innovation in Additive Manufacturing (HI-AM), Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada

Thursday, March 26
A holistic approach to achieving the best possible component quality for AM architectures for vat photopolymer and laser powder bed fusion systems
 With David Bue Pedersen, Ph.D., Senior Researcher, Department of Mechanical Engineering, Technical University of Denmark

Thursday, April 9
Additive Manufacture with High Temperature Polymers
 With Oana Ghita, Ph.D., Chair and Professor of Materials Science and Manufacturing in the College of Engineering, Mathematics and Physical Sciences, Academic Lead of Centre for Additive Layer Manufacturing (CALM), University of Exeter, United Kingdom

Thursday, April 23
From 3D Printing to Digital Manufacturing
 With Wenchao Zhou, Ph.D., Assistant Professor, Department of Mechanical Engineering, University of Arkansas

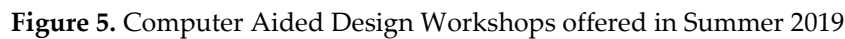
www.tntech.edu/engineering/imakerspace
 Golden Eagle Additively Innovative Virtual Lecture Series is partially funded by the NSF Award 1601587, "AM-WATCH: Additive Manufacturing-Workforce Advancement Training Coalition and Hub".
 CENGROB4-SEL-20

Figure 4. Flyer of the Spring 2020 Golden Eagle Additively Innovative Virtual Lecture Series

4.3. Computer Aided Design Workshops

iMakerSpace hosts a series of Computer-Aided-Design (CAD) workshops for both Tennessee Tech students and non- Tennessee Tech students. In 2019, three workshops were organized. Each workshop was about five hours long, and gave participants a basic understanding of SolidWorks, Inventor, and AutoCAD design software tools. At the end of each workshop, participants were given a certificate of completion by the University. The goal of the workshops was to give participants an idea of how each program works as well as some tips and tricks of the design process.

The workshops provided some foundational knowledge for the attending students. Students indicated that the workshops helped them increase their design skill sets and capabilities. Since this program needed to have the extra certification and continuum education credit responsibilities, the registration and certification tasks were managed by the Office of Extended Programs and Regional Development. Figure 5 shows the workshops offered in 2019.



iMakerSpace hosts a number of workshops, studios, and workforce development activities during the summer months. These two-day events are a part of externally funded research projects disseminating the findings of several additive manufacturing and digital manufacturing projects funded by the Advanced Technological Education (ATE) Division of the National Science Foundation (NSF). Participants who are the educators of several high school, community college, and university, come from several states in US, i.e., Alabama, Florida, Georgia, Kentucky, Ohio, Washington. The training events are framed with several hands-on activities and guest speakers coming from the partnering institutions of the funded projects.

The scope of the workshops delivered in summer months was on hands-on training of Additive Manufacturing, Digital Manufacturing, Virtual Reality, and Smart Manufacturing. In all workshops, after the fundamental concepts were delivered a number of active learning practices was provided. Teams were formed and attendees who are from various STEM disciplines built their 3D printers, learned the maintenance issues of 3D printers, used DELL Visor Headsets in programming and practicing several VR programs. Figure 6 presents the attendees' practice in using DELL Visor VR Headsets. Figure 7 shows the participants of one Summer 2019 Additive Manufacturing Studio Workshop.

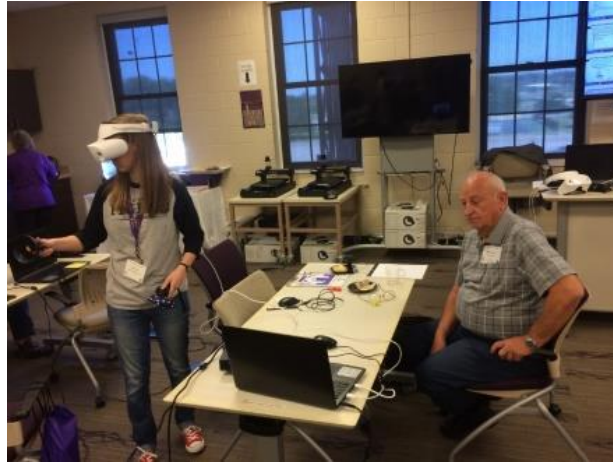


Figure 6. Summer 2019 Workshop attendees learning Virtual Reality and using DELL Visor headset



Figure 7. Attendees of Summer 2019 Additive Manufacturing Studio Workshop

4.5. Supporting Student Extracurricular Activities

iMakerSpace is used by several campus organizations as a meeting space or fabrication unit for their project related tasks and deliverables. These organizations are also active in presenting their projects and building prototypes to prospective students, their families and K-12 students.

The iMakerSpace is the home of two campus student organizations: Students for the Exploration and Development of Space (SEDS), and Autonomous Robotics Club (ARC). SEDS is an awards-winning group which takes part in rocket competitions and high-altitude rocket competitions. ARC is currently working on many robotic projects like Totally Autonomous Legless Useful System (TALUS) which, when complete, will be an interactive greeting system able to answer questions from visitors and be able to shake their hand as well. SEDS and ARC have joined forces to design a rocket and a 3D printed hover drone to explore other planets in which this rocket can successfully carry the drone to its destination. Figure 8 demonstrates ARC Students working for a competition in iMakerSpace.



Figure 8. ARC Students working for a competition.

4.6. Hosting Eagle Works Activities

The iMakerSpace hosts a series of workshops for the Tennessee Tech I&E Competition, the “Eagle Works,” an event for aspiring entrepreneurs first launched in Spring of 2015. These free events are usually held on Wednesdays at 5pm in the iMakerSpace on the dates provided on the Tennessee Tech website. These workshops talk about topics such as effective communication and branding. These events are extremely helpful for students who want to get involved with Eagle Works [21].

Figure 9 shows the training activities held in Spring 2020 to prepare the campus students for Eagle Works competition.

SPRING 2020 EVENTS		
Wed. 1/29, 5 p.m.	Spring Kickoff and Info Session	iMakerSpace
Wed. 2/5, 5 p.m.	Effective Communication	iMakerSpace
Wed. 2/12, 5 p.m.	DESIGN CHALLENGE	RUC 282
Wed. 2/19, 5 p.m.	Business Model Canvas	iMakerSpace
Wed. 2/26, 5 p.m.	Q&A and Coaching	iMakerSpace
Wed. 3/4, 5 p.m.	Branding	iMakerSpace
Wed. 3/11, 5 p.m.	Effective Presentations	iMakerSpace
Fri. 4/3, 6 p.m.	EAGLE WORKS: PRELIMS	TECH PRIDE RM
Sat. 4/18, 1 p.m.	EAGLE WORKS: FINALS	BELL HALL
WWW.TNTECH.EDU/EAGLEWORKS		

Figure 9. Spring 2020 Programs hosted by iMakerSpace

4.7. Celebrating Annual Manufacturing Day

Manufacturing Day takes place on the first Friday of October and is a celebration of American manufacturing and an opportunity for manufacturers to educate people on manufacturing. The Tennessee Tech iMakerSpace has held manufacturing day events since 2016. These events showcase work from both Tennessee Tech students and industry partners with the goal of showing what manufacturing has to offer.

Activities during the Manufacturing Day include several student manufacturing research and capstone projects presenting their unique accomplishments, and networking with the regional manufacturing industry representatives and educators. Food and refreshments were served with a support provided by senior SME chapter (sme43.com) or national SME (sme.org). Figure 10 shows the high school students from Putnam County Schools attending the Manufacturing Day 2019.



Figure 10. High School Students attending the Manufacturing Day 2019.

5. COVID-19 Modified Operation

During COVID-19, the iMakerSpace remained open to accommodate course projects, student needs, and community outreach. The following measures were implemented to abide by the state legislature's health requirements.

- 3D print requests were submitted remotely through the iMakerTrack system and picked up with limited social contact.
- The utilization of the space is limited to 10 occupants at a time.
- The equipment and surfaces are cleaned and disinfected routinely.
- Usage of social distancing and face masks are strongly suggested.
- High volume production needs are accommodated with the approval of the management team.
- Outreach and group tours are suspended until university opening and will follow established guidelines.

6. iMakerTrack

iMakerTrack is the online part design file submission system created to systemize and automate the 3D printing fabrication tasks of the unit. The system can be accessed through its website [26]. It is designed to improve efficiency of printing projects for research, showcases, and class projects through remote submission of 3D printing requests. Due to the growing number of students' clientele and the increasing 3D print implementation in classes, the development of such a system was essential. Prior to implementing iMakerTrack, students had to find a time out of their busy schedules, navigate to find the iMakerSpace, and design what they needed, hoping a printer was available to use. This unique system has reduced the problem significantly by allowing students to submit their designs online, and letting the iMakerSpace staff handle the rest. The management team has noted a decrease of printer problems after the implementation of this system. Furthermore, by using this online submission tool, grouping multiple submitted prints for one printing session becomes much easy, leading to a reduction of time and power consumption. Figures 11 to 13 show the iMakerTrack website.

3D PRINT

All submitted files are subject to review and may be denied for any reason. This includes prints that contain weapons, weapon parts, phallic objects, etc.

iMakerspace provides free printing services for academic use only. This includes class projects, research projects, Capstone projects, etc. Personal prints require that you bring your own material to the lab.

Title *

Email *

Print Purpose *

- Select a value -

Figure 11. iMakerTrack website – part 1: collecting information

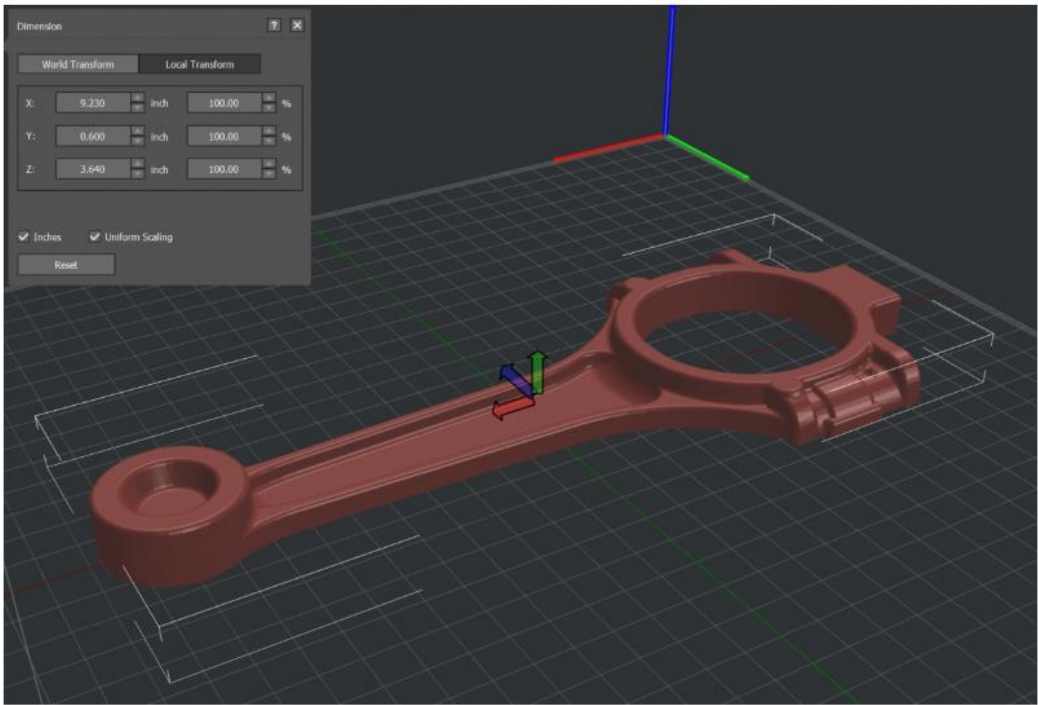


Figure 12. iMakerTrack website – part 2: reviewing the solid model

Additional Information

Please tell us anything important about the project. Specific needs, quantities, questions, etc. The more we know, the better.

Upload Print Files [Show row weights](#)

File
 No file chosen
 Files must be less than 20 MB
 Allowed file types: obj, stl
 X-Axis Maximum Dimensions (in inches)

 Y-Axis Maximum Dimensions (in inches)

 Z-Axis Max Dimensions (in inches)

CAPTCHA
 This question is for testing whether or not you are a human visitor and to prevent automated spam submissions.
☐ I'm not a robot

Figure 13. iMakerTrack website – submitting the design file with further details

iMakerTrack has the following features to automate the operation of iMakerSpace tasks.

- Online submission of fabrication request
- Online tracking of job queuing
- Online status monitoring of 3D Printers
- Email alert to students who are tasked to handle the fabrication operation.
- Online monitoring of filament usage
- Historical/statistic data extraction and report generation (See Figure 14)

Current version of iMakerTrack is an outcome of collective contributions from a number of developers in the iMakerSpace. The beta version was designed from scratch and developed in fall 2017 and spring 2018 by a computer science Capstone Design team supervised by an iMakerSpace staff. A number of iMakerSpace team members made tremendous modification to turn the beta version into the current version. This project is an example of successful teamwork of multi-disciplinary individuals.

iMakerTrack system also helps the unit administration and users generate a number of data related to the outcomes of iMakerSpace. Figure 14 shows the utilization outcomes of 3D Printers in iMakerSpace.

Printer	Start Date	Number of the files printed (#)	Printing time (hours)	Filament usage (kg)
N2A	3/29/2017	643	4881	56.3
N2B	3/29/2017	359	2625	32.99
N2+	3/29/2017	566	5134	66.93
PRO2+	3/23/2019	125	2103	30.96
PRO2A	5/17/2018	231	2936	45.86
PRO2B	3/23/2019	160	2127	32.11

Figure 14. Utilization data for the iMakerSpace 3D printers

7. iMakerSpace Sustainability

In order to support the needs of regional industry, several small-scale parts were printed and delivered to design and manufacturing companies. Also, campus professors who need fabricated parts for their research and consulting projects used the space. The revenue generated were used to cover the supplies and consumables of the MS.

Students working in the space have designed and prototyped 'Tech Tables' to establish a small-scale sustainability model. They were designed and fabricated to latch onto the side of the beds and provide a handy charging station for cell phones and other personal effects. They are sold for \$10 at the iMakerSpace and over the years there have been dozens of them sold, filling the immediate needs of the space as a sustainability model. Figure 15 shows the flyer of Tech Table built by the iMakerSpace team members.

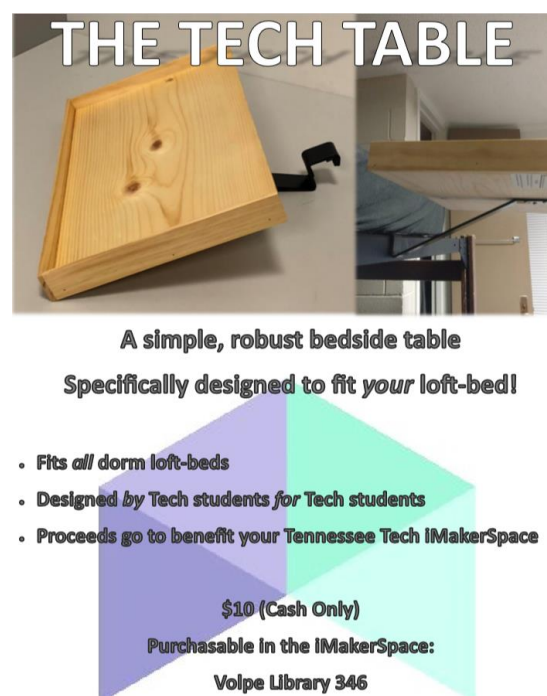


Figure 15. The Tech Table Flyer

8. Evaluation Study

Contained in this section are the results of a survey that was administered to users of the Tennessee Tech University's iMakerSpace during Spring 2020. The purpose of the survey was to gauge the level of use and effectiveness of the iMakerSpace by students, faculty and alumni. The

author team developed the survey in early 2020. The survey, which was anonymous and administered via Qualtrics, was sent to a total of 35 people, 18 of whom responded. Of the 18 respondents, five were students, three were either alumni, staff, or faculty. Five others (who were presumably students) selected Maker Members, work- study, and student assistant. The other five did not respond to the question.

In the survey instrument, respondents were asked to rank several elements of the iMakerSpace to indicate which items had been of the most benefit to them. Figure 16 shows the percent of respondents who included each of the items in their top-3 rankings.

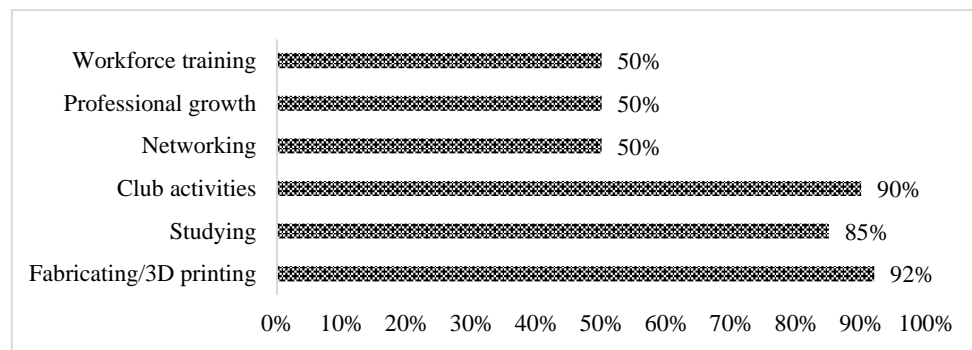


Figure 16. Percent of respondents ranking each item in the top 3

As shown in Figure 16, in the order of the highest ranked items, users of the iMakerSpace selected the following as the most beneficial to them.

- Fabricating/3D printing (92%)
- Club activities (90%)
- Studying (85%)
- Networking (50%)
- Professional growth (50%)
- Workforce training (50%)

Respondents were presented with a number of items and asked to indicate whether they had gained that experience from the iMakerSpace. Table 1 shows the percentages who responded with a yes or no to each of the items. In addition to hands-on skills in 3D printing and troubleshooting in printing, other noteworthy experiences the respondents selected were networking and teamwork. Users also indicated learning research skills from the iMakerSpace.

Table 1. Percentage of iMakerSpace users who experienced each of the listed items

	Yes	No	Count
Hands-on skills in 3D printing	92%	8%	13
Hands-on skills in solid modeling	58%	42%	12
Hands-on skills in post processing	62%	38%	13
Hands-on skills in soldering and electronic assembly	54%	46%	13
Networking	77%	23%	13
Teamwork	85%	15%	13
Troubleshooting in printing	85%	15%	13
Research skills	69%	31%	13

Table 2 shows the percentage and count of iMakerSpace users who took part in each of the events listed.

Table 2. Distribution of Respondents by their participation in iMakerSpace Events

	Yes	No	Count
EagleWorks	36%	64%	11
Club meetings	75%	25%	12
Pancake open houses	54%	46%	13
Additively Innovative lectures	46%	54%	13
Workforce training activities	42%	58%	12
Student research projects	67%	33%	12
Manufacturing days	38%	62%	13
Product demonstrations	31%	69%	13

In response to an open-ended item about improvements that they could make to the iMakerspace, respondents' main request was to add more 3D printers, including a Metal 3D Printer. Other suggestions were to have more and better advertising of the space, to increase supplies for the facility, to add a laser cutter, and enhance other matters e.g. improving accessibility to the space, having more events, and making the environment more relaxing.

9. Conclusion

MSs are becoming an essential part of post-secondary education in supporting the educational delivery. Their contribution to curricular/extracurricular delivery, hands-on learning skills, and creativity is reported to be high. The iMakerSpace model focused on workforce development in several curricular and extracurricular settings proved that it is very well received by students and educators. Though there is still a need for more diverse manufacturing equipment such as laser cutting machines, the activities of iMakerSpace were proven to be beneficial by the users and they are effective in engaging students and sustaining the operations.

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