Is it possible to sustain and expand the makerspace experience during a pandemic?

connecting students to the makerspace through an online workshop

by Jessica D. Ventura and Mary Hatton

Future engineers need to be prepared for rapid global change with technological advancements that require them to be flexible, innovative, practical, and agile multidisciplinary thinkers (NAE, 2017). The makerspace movement in secondary and higher education, equipped with additive manufacturing tools, creates opportunities that promote the development of this type of creative and innovative mindset. Unfortunately, students were sent home in March 2020 to complete the semester remotely, and many campuses are still practicing social distancing and remote instruction. Separated physically from labs and the makerspace, instructors have to become creative when it comes to hands-on learning. This unforeseen situation led to the authors' initiative to promote interest in the makerspace through a virtual workshop focusing on manufacturing techniques and hands-on experiences with 3D printing.

Endicott College was founded in 1939 with the idea that higher education should combine theory with practice. The college prides itself in being a supportive environment where students and faculty come together as a true community of learners. *The Maker Gulls Online Workshop* was developed during the summer of 2020 with these principles in mind. The goals of the online workshop were

Figure 1. Contents of the *Maker Bag* sent to each participant prior to the workshop.

Table 1: Workshop participants grouped by gender, STEM major, and academic year.

Gender: Female	*4*	*Male*	*7*
Major:	**#**	**Year:**	**#**
Engineering	7	Freshman	6
Bioengineering	2	Sophomore	1
Computer Science	1	Junior	3
Applied Mathematics	1	Senior	1

to engage students in the space during the campus closure, to jumpstart interest in the makerspace in anticipation of the college's reopening, to help incoming freshmen connect with upperclassmen during the summer, to provide a platform for upperclassmen to lead and mentor, and to trial a hands-on laboratory experience in the online environment.

In developing the workshop, the authors asked the questions: *How can we nurture and sustain the makerspace experience with our students during disruptions like a pandemic? Would students be motivated to engage in learning about 3D printing? What maker skills can be taught remotely? Is it possible to introduce the maker culture to incoming students before they come to campus?* Focus for the workshop was placed on 3D printing because students had previously expressed both an interest in and lack of experience with the printers that were available to them in the college's makerspace. Specific learning outcomes were that participants achieve a basic understanding of 3D printing with *MakerBot* equipment and software, of design and modeling for additive manufacturing, and of post-processing techniques. The intention was to ignite interest through basic training, so topics were covered with more breadth than depth.

Workshop Structure

It was decided to hold a three-day workshop, with two hours of instruction and practice each day. By the end of the workshop, participants would have completed an interesting 3D-printed project and have earned a workshop certificate. The workshop was scheduled for mid-week (Tuesday through Thursday) beginning at noon. The intention was to avoid hours that participants would likely be spending with family.

The two-hour sessions presented through *Zoom* were divided into *Greetings* (5min); *Theory Lesson* and break (25min); *Basic Hands-On Lesson* and practice (40min); *Advanced Hands-On Lesson* and practice (50min); and *Wrap-Up* (10min). Each hands-on lesson ended with an assignment that brought participants closer to earning their workshop certificate. Whenever there was a break or a time for practice during the workshop, a countdown timer was displayed on the screen to remind participants when to rejoin the live meeting.

Each day, the workshop instructor opened up a poll with a "Would you rather…" question. All participants were invited to share what answer they chose and why. The purpose of this short exercise was to begin developing community among the workshop participants. Guest instructors taught one or two of the three daily lessons; these instructors included an industry representative and two engineering students who had experience in the college's makerspace. The workshop instructor led the wrap-up lesson and stayed online afterwards to help any participants who struggled with the assigned tasks or had additional questions. She reviewed participant work before the next session to provide feedback and any additional instruction needed to complete the task correctly. Session materials, including recordings, PowerPoints, and links to assignments, were shared in the *Google Chat* room for easy access during and after the completion of the workshop.

Recruiting

Engineering, Bioengineering, Computer Science, and Applied Mathematic students who had registered for the fall semester at the college were invited to the workshop. Incoming freshmen attending online orientation sessions were invited verbally to the workshop, followed by an email invitation. Continuing students only received an invitation via email. The flyer in the emails invited the students to "join us online and earn an Angle Makerspace 3D Printing Certificate." Daily themes and a list of skills they would learn were also included. Students were provided a link to a short registration form for the workshop.

Registration was limited to ten workshop participants. The intention was that with ten students and two instructors, the live sessions would host a total of twelve, allowing meaningful interaction. One additional student was admitted to the workshop as an asynchronous participant due to a time conflict with the live sessions. Participant major, standing, and gender are presented in Table 1. One participant connected asynchronously using *Google Chat* for the entire workshop. Another used the chat materials to catch up after unexpectedly missing the first two live sessions. Thus, nine students participated synchronously on the first two days and 10 on the last day. All 11 participants completed the six assignments and earned a 3D-printing certificate issued by the makerspace. The student instructors earned leadership certificates for their contributions to the training.

An open-ended question was asked during the registration process: *What do you hope to get out of this workshop?* Seven participants indicated a desire to acquire new skills related to 3D printing. Two participants wanted to practice skills that they had already learned. One had some 3D printing experience, while the other had only 3D modeling experience. Four participants wrote about new knowledge that they wanted to learn, and one participant hoped to meet other students and become part of the makerspace community.

Early Communication

Registration closed two weeks prior to the commencement of the workshop. That same day, the instructor emailed registrants to welcome them and provide more details about the workshop, with instructions to join a *Google Chat* room to connect with other participants. One week prior to the workshop, the instructor emailed registrants again to provide them with the address of the *Zoom* meeting room and assign four tasks: RSVP to the *Google Calendar* invitations for the workshop meetings (sent out the same day); respond to the first question in the workshop chatroom, which was to introduce themselves; download and install *Makerbot Print*; and create a personal *TinkerCAD* account.

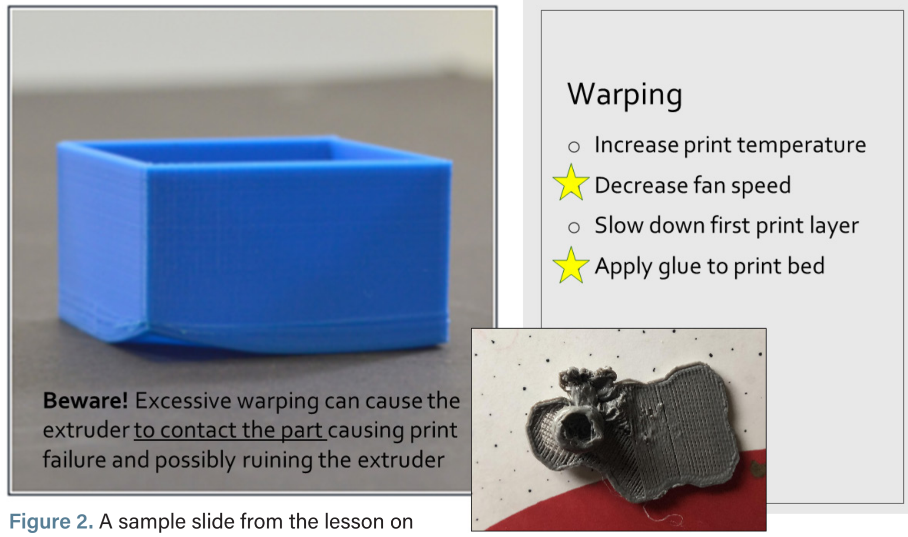

Figure 2. A sample slide from the lesson on print-quality issues. The starred options are viable solutions to the problem of warping.

An important feature of this online workshop was to have participants handle and work with 3D-printed parts. The instructor filled a *Maker Bag* (Fig. 1) with the following contents: overhang test piece (www.thingiverse.com/thing:2806295); support demo piece (www.thingiverse.com/thing:4038181); prosthetic hand parts (www.thingiverse.com/thing:1489003); a college keychain; a piece of sandpaper, model paint and brush; and a piece of filament. Bags were delivered to the front porch of local participants or sent in the mail. The prosthetic hand parts included 3D-printed parts made of polyactic acid (PLA) and thermoplastic polyurethane (TPU), small nuts and bolts, fishing line, and elastic. Assembly of a prosthetic hand (Verdu, 2016) was chosen as the final hands-on activity because, not only had students expressed interest in prosthetic design during the previous semester, but the hand showcased interesting design elements and allowed for practice of a variety of post-processing skills.

Day 1: Diving Into 3D Printing

The purpose of this session was to introduce participants to the 3D-printing industry, provide a tutorial with *Makerbot Print* software, and show participants how to fix common print problems using advanced settings. For the first *Theory Lesson*, a representative from MakerBot spoke about how 3D printing is used in industry and gave examples of how he used 3D printing as an engineer in the automotive industry. The lesson concluded with a lively question-and-answer session.

To kick off the *Basic Hands-On Lesson*, the instructor brought participants into the makerspace virtually and demonstrated the basic use of a 3D printer. Then a student instructor taught participants how to find 3D models online, prepare the model for printing using *Makerbot Print*, and send the print file to the queue in the cloud. The first assigned task was to submit the print file to the makerspace queue using a *Google Form*.

For the *Advanced Hands-On Lesson*, the instructor walked through a presentation with images of 3D-printed parts with quality issues. Alongside each image she provided a list of possible setting adjustments to make in the software to fix the problem. To make this lesson interactive, the instructor provided some options that were not viable solutions and asked the participants to identify which options they thought would fix the problem (Fig. 2). She then showed them where to adjust these settings in *Makerbot Print*. For the second task, the instructor assigned a quiz in *Google Forms* to assess the participants' ability to recognize print problems and describe how to fix them. During the day's *Wrap Up* the instructor led a discussion through the quiz, soliciting participant responses and providing feedback.

Day 2: Designing and Modeling

The purpose of this session was to introduce additive manufacturing techniques, guide participants through modeling considerations for this type of production, and show them how to construct a 3D model with *TinkerCAD CodeBlocks*. For the *Theory Lesson* the instructor provided an overview of manufacturing processes for plastics, touching on differences in technique, pricing versus quantity, ability to handle complex designs, and required lead time. Students watched short videos about Fused Deposition Modeling (FDM), Stereolithography Apparatus (SLA), and Selective Laser Sintering (SLS). They learned about the similarities and differences between these three 3D printing techniques and saw specific examples of how each was used as part of a design solution.

Some of the 3D-printed parts in the *Maker Bag* were important for the *Basic Hands-On Lesson* on design for FDM. Workshop participants held the pieces in their hands to examine their details while learning about different print bases, overhang angle, tolerancing, and text. A small statue was printed with supports. After discussion about computer-generated versus user-defined supports, the participants' third task was to respond to two questions about the statue: *(1) If you were to design your own supports, where would they need to be placed? Explain.* and *(2) If you wanted to redesign the statue without supports, what alterations can you make to its features? Be specific.*

The purpose of the *Advanced Hands-On Lesson* was to have workshop participants create their own 3D model. Because participants were expected to come to the workshop with different levels of experience with 3D modeling and would likely be using a trackpad instead of a mouse, *TinkerCAD CodeBlocks* was selected for this lesson. Users simply drag one of many predefined blocks of code into the design space. They define a few parameters and press "*run*" to watch the program create a 3D model from the code. A student instructor introduced the workshop participants to *CodeBlocks* by explaining how the program works as he walked through an example on his shared screen (Fig. 3). The participants' fourth task was to make changes to a sample *CodeBlock* model and submit the link on a *Google Form*.

Day 3: Post-Processing Techniques

The workshop instructor had observed that many students using the makerspace printers during the school year did little to no post-processing. The purpose of this session was to ignite an interest in projects that involved more hands-on techniques. The *Theory Lesson* began with a short video showing of entrepreneurs using 3D printing to create props. Topics for the lesson included cleaning, bonding, finishing, painting, and assembly. A student instructor followed with the *Basic Hands-On Lesson*, having the workshop participants join her in breaking off supports, sanding and painting a piece from the *Maker Bag*. She shared tips from her own learning process and showed examples of her work. The fifth assigned task was to snap a photograph of their painted part and submit it.

The majority of the parts in the *Maker Bag* were pieces of the prosthetic hand that participants began assembling during the final *Advanced Hands-On Lesson*. The instructor first highlighted some of the hand's design characteristics related to production and use, and then led participants through the step-by-step process of assembling a single finger. Participants shared their progress with one another during the final *Wrap-Up*. Most participants were able to successfully assemble one finger during this final session, and some were able to assemble two. The sixth assigned task was to complete the workshop's exit survey.

Assessment

All participants completed an anonymous exit survey as their final activity. Ten questions asked participants to indicate on a Likert scale the degree to which they agreed or disagreed with a statement (Fig. 4). Two optional open-ended questions asked them to share their favorite aspects of the workshop and to suggest changes for next time. Every participant answered at least one optional question, with nine answering both.

Mean scores can be quantitatively analyzed by assigning a value from 1 for "strongly disagree" up to a value of 5 for "strongly agree." Mean scores over 3.0 indicate agreement with the statement. The acquisition of skills related to 3D printing, modeling, and post-processing received an average rating of 4.33 ±0.75. The likelihood that participants will use the makerspace more often as a result of the workshop was rated at 4.09 ±0.87. Professional development outcomes of using the design process, solving problems, and thinking creatively were rated at 4.21 ±0.65. Finally, the workshop's impact on the participants' identity with STEM and the college was rated at 4.55 ±0.60.

When asked to share their favorite parts of the workshop, four participants mentioned theory lessons: 3D Printing & Industry; Manufacturing Techniques; or the lessons in general. Two participants liked basic hands-on lessons, starting the build process, and learning to design for additive manufacturing. One participant was proud to have coded for the first time using *TinkerCAD CodeBlocks*. The favorite part of the workshop for four participants were the hands-on, post-processing activities. Three participants simply enjoyed participating in a class at the college during the summer.

The question seeking advice to improve the workshop was met with overwhelming support that there was very little to be changed. Many participants stated that there was nothing to change, even before providing one suggestion. Five participants wanted the workshop to be longer, either more hours a day or more days total. Two wanted to see it repeated in person, and one even offered to help run a camp for middle-school students. One

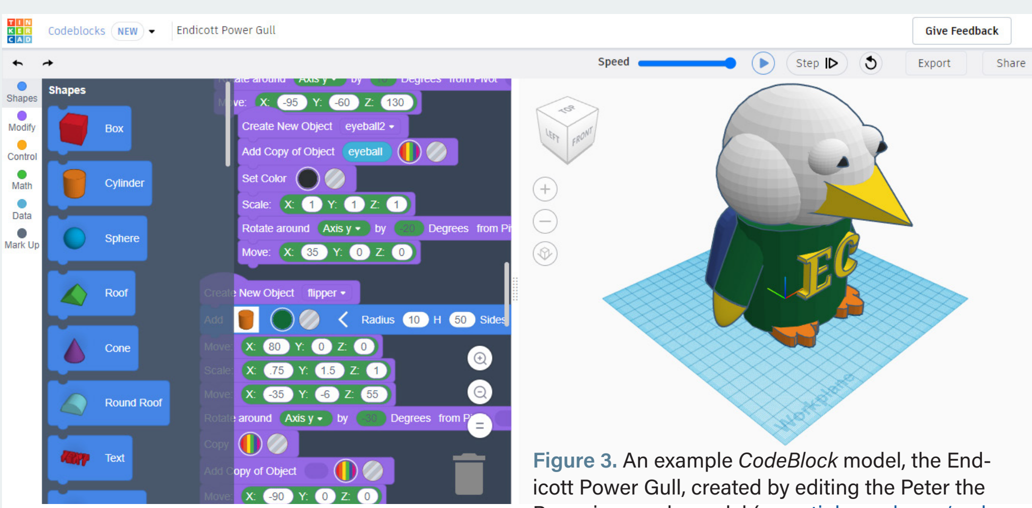

Figure 3. An example *CodeBlock* model, the Endicott Power Gull, created by editing the Peter the Penguin sample model (www.tinkercad.com/codeblocks/2YQoZ9liQpF)

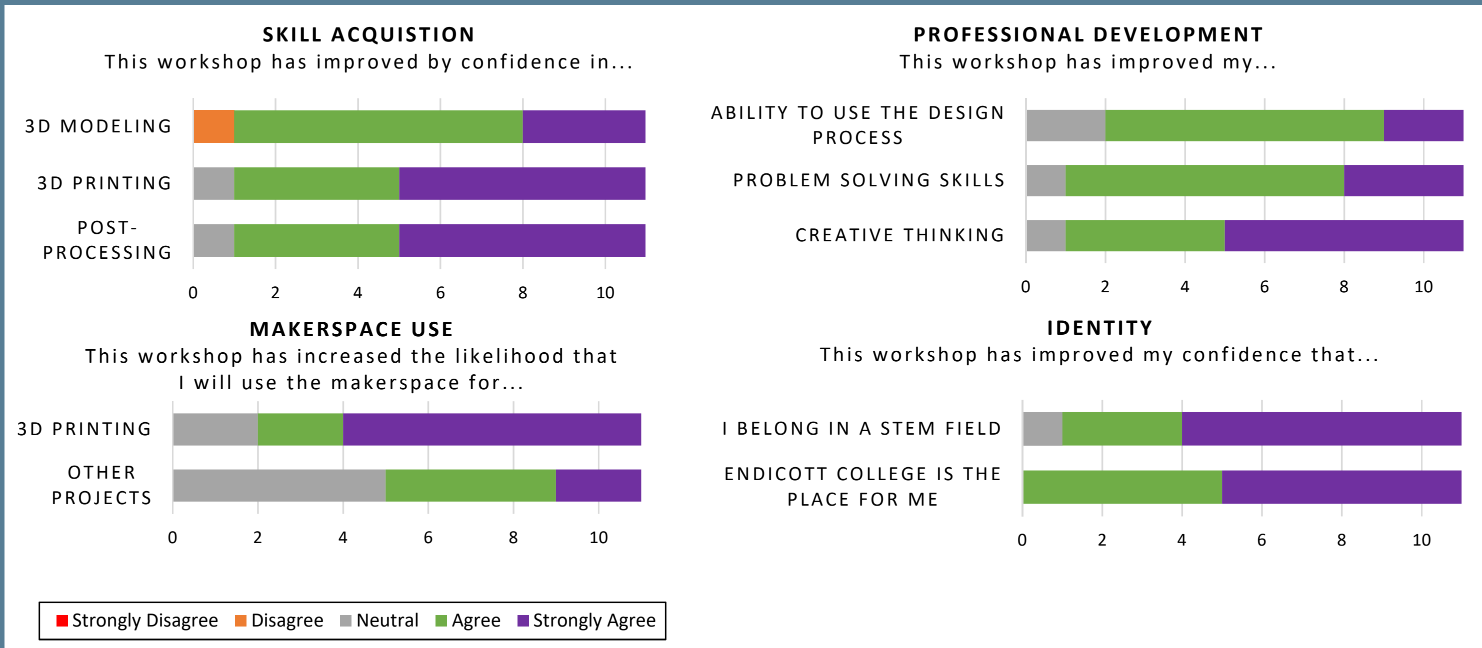

Figure 4. Responses to the ten Likert-scale questions on the exit survey, administered the final day of the workshop.

suggested replacing the *CodeBlocks* tutorial with a more basic 3D modeling tutorial.

Outcomes

This online workshop was successful in introducing students to and interesting them in 3D printing and the makerspace. Every student who registered completed the workshop; their reflections indicate that the workshop and its experiences improved confidence in the 3D design process of modeling and printing as well as post-processing.

Students demonstrated a basic understanding and gained practice with 3D printing using *MakerBot* equipment and software; design and modeling for additive manufacturing; and post-processing techniques through discussions, lectures, guest speakers, and hands-on laboratory experiences in the online environment. As with other in-person makerspace programs, the online experience was received positively; students indicated that this workshop helped them acquire skills in 3D printing, modeling, and post-processing (Galaleldin & Anis, 2017, Khalifa & Brahimi, 2017). Students also felt that this workshop helped them improve in problem-solving skills, creativity, and using the design process. The workshop proved to be a way to inspire students to consider using the makerspace for 3D printing in the future. Most students indicated that they would use the makerspace for 3D printing as a result of this experience. Encouraging awareness and workshops about equipment and uses of the makerspace early in one's engineering career can bring participants together as a community of practice that could impact sustaining makerspace interest and participation. Furthermore, when incoming students express that this experience allows them to identify more with the college, it seems likely that these experiences may have a positive impact on student retention in STEM.

This workshop demonstrated the feasibility of hosting online experiences outside of the makerspace. A makerspace virtual workshop offers a type of apprenticeship learning experience in which participants learn skills around a common practice by observing and practicing with an expert. The hands-on activities and assignments allowed students an opportunity to practice skills and demonstrate their understanding. Hands-on experiences from the makerspace were brought into the workshop because the instructor developed and delivered bags of supplies to students to visualize different outcomes from 3D printing, observe and reflect on printing, and experience post-processing techniques. In addition students observed and practiced modeling using *TinkerCAD* and learned and demonstrated their ability to use *Makerbot Print* to prepare designs. Offering these experiences to introduce and practice some basic skills and techniques shows us that the learning does not have to occur in traditional defined spaces.

The presentation of this workshop was successful in having a single lead instructor who organized and interacted directly with students before and daily during the workshops and organized all assignments. In addition to structuring a program to train students in skills, this workshop also illustrated how it can support elements of a makerspace environment that supports a community of practice (Galaleldin & Anis, 2017). A community of practice is a space where participants come together through a shared interest in knowledge, working together as a community to share and deepen their knowledge around a common interest and a shared experience (Wenger-Trayner, 2010). The instructor organized different experiences that support a sense of community. Prior to the workshop the instructor developed a *Google Chat* room and encouraged all participants, both instructors and students, to introduce themselves. Seventy percent of the group participated in pre-workshop introductions. During the workshop, the instructor encouraged students and other experts to collaborate by sharing their knowledge, training new students, and sharing personal examples of projects from their makerspace experiences at the college. Involvement of various experts and students from the college makerspace offers new members different perspectives and the sense that the makerspace is a community of practice, and the workshop is an introduction to this culture as well.

This virtual workshop proved to help sustain and nurture a makerspace community despite the constraints of a pandemic. With the success of the workshop, it was clear that the makerspace should continue to offer more experiences outside the physical space. A similarly formatted workshop can easily be offered during school breaks, such as during winter and spring and multiple times during the summer. Only having two-hour sessions resulted in a somewhat rushed experience. Increasing the session times to three hours would allow more time for participants to work on the assigned tasks; this would give them the opportunity to go deeper into the practice. Alternatively, each day could be reduced to one theory lesson and one hands-on lesson, and the workshop could be increased to five days. The workshop can also be altered to meet educational goals of different grade levels, as discussed in the next section.

3D Printing Technology in Primary and Secondary Education

Technology and engineering education has become increasingly more important as the world becomes more complex and is taking on different forms in K-12 schools (ITEEA, 2020). However, engineering remains secondary to topics in the K-5 curriculum, and elementary teachers feel inadequately prepared to teach engineering or offer one-time experiences that promote interest but fall short in developing deep understanding about additive manufacturing technologies, including 3D printing (Banilower et al., 2018). A review of the literature indicates that when this technology is implemented in 6-12 schools, it is inconsistent and sporadic, where some programs lack funding for equipment and materials or programs have a different focus, i.e., teaching skills of 3D printing or using 3D-printed products (Ford and Minshall, 2019). These inconsistencies lead to a fragmented understanding about using additive manufacturing technologies as a tool and recognizing its multidisciplinary uses in our world beyond the scope of the engineer. A virtual program like what we have presented can enhance 3D-printing skills and using models to enrich students' understanding about engineering design and how 3D printing applies to the real world. The lack of opportunities for secondary students to identify with engineers, real-world technologies, and how non-engineers use them, leads to misperceptions about STEM literacy.

This virtual workshop experience demonstrates best practices and engineering-design skill development that aligns with K-12 technology standards shown in Table 2. This 3D Printing workshop could be integrated into secondary education curricula in engineering and makerspace education. Furthermore partnering with a university or industry could reduce the gap between district inequities,

Table 2. *Standards for Technological and Engineering Literacy* (*STEL*) addressed through virtual workshop experience (ITEEA, 2020).

Virtual Workshop Activities	ITEEA Standards
Day 1: Diving into 3D Printing ▪ Heard a professional guest from *Makerbot* present how 3D printing is used in industry. ▪ Prepared a 3D model for printing. ▪ Observed and discussed overview of *Makerbot* 3D printer. ▪ Observed and discussed 3D printed parts and quality issues.	**Grades 6-8:** STEL-1M, STEL-2N **Grades 9-12:** STEL-1N, STEL-1O, STEL-3J
Day 2: Designing and Modeling ▪ Learned about different manufacturing techniques for plastics—their uses, benefits, constraints—compared with 3D printing. ▪ Learned about different 3D printing techniques, their uses, benefits, costs, constraints. ▪ Observed and analyzed 3D-printed products. ▪ Evaluated a 3D-printed model, considering supports and overhangs. ▪ Created a model using *CodeBlocks*.	**Grades 6-8:** STEL-2R, STEL-2S, STEL-5H, STEL-7R, STEL-7U, STEL-8I **Grades 9-12:** STEL-1N, STEL-1P, STEL-2W, STEL-2X
Day 3: Post-Processing Techniques ▪ Observed aesthetics of outcomes from entrepreneurs using 3D printing. ▪ Provided an overview of post-processing techniques and uses. ▪ Carried out post-processing of a 3D-printed model: removing supports, sanding, and painting. ▪ Assembled multiple parts for prosthetic hand. ▪ Observed and identified design features and parts to construct a model.	**Grades 6-8:** STEL-7P, STEL-7U, STEL-7Q **Grades 9-12:** STEL-3J, STEL-7AA, STEL-7CC, STEL-7DD

with resources for obtaining and maintaining high-tech equipment. The maker movement allows students to develop projects and experiences around their own interests while taking an interest in concepts and emphasizing problem finding, problem solving, and social learning.

Similar workshops can be used to prepare teachers to integrate these new technologies into their curriculum. Recently the authors developed a remote STEM enrichment experience and engaged third-year undergraduate education students into two modified workshops as part of their science methods course. The goals of this project were: (1) to learn about 3D printing and its applications and (2) to learn how to use *TinkerCAD* to design their own keychain. Following the completion of their keychains and need to redesign them, the students helped facilitate a virtual STEM *TinkerCAD* workshop. From this experience the undergraduate students indicated interest in learning more about 3D printing and using *TinkerCAD*. They all completed their projects and found our workshop to be informative and readily applicable for obtaining basic skills for using *TinkerCAD* and exporting a file for remote printing. Time for additional practice was the biggest request from this brief experience. This project showed that the virtual workshop is a manageable way to offer preservice teachers an introduction to digital skills and 3D printing, an introduction to engineering design thinking, the ability to demonstrate their use of skills, and the ability to apply these skills to present to others in an informal setting. The next step is to consider what it will take to sustain these skills and apply them to makerspace curricula for K-5.

Another aspect to consider while continuing remote learning, particularly for secondary and undergraduate education, is how to develop informal experiences to support a broader mindset about makerspaces rather than simply the mechanics of the 3D printing process (Prudha et al, 2020). Offering workshops or forums with guest speakers through the makerspace for students to learn more about opportunities provided by additive manufacturing may encourage innovation and continue sustaining a community of practice. An additional sugggestion would be to extend the workshop to have students demonstrate their understanding through a project-based learning or problem-based learning assessment that would require students to develop their own open-ended project (Hmelo-Silver, 2004) or solve a problem (Blumenfeld, et.al, 1991) while applying their understanding of skills.

As we move beyond this pandemic, we need to keep in mind the innovative opportunities we have explored and continue to expand and enrich traditional teaching and learning with technology beyond the traditional classroom setting. The virtual workshop model extends the scope of the makerspace movement beyond traditional physical structures.

Conclusion

This innovative workshop demonstrated one way to use the online environment to introduce students to basic skills associated with the engineering design process and manufacturing and to promote student interest in a college makerspace consistent with traditional in-person programs. Designing an online experience separate from a traditional program requires some creative thinking about how to bring elements of the makerspace to students and offer valuable practice experiences. With simple adaptations while moving content online, instructors can actively engage students of all ages when unable to do so in person. An online experience can also provide a forum that can sustain a community of practice in ways that would otherwise be lost when in-person experiences are unsafe.

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