Implementing the Flipped Classroom Method in Online Delivery: Applied Innovation During the COVID-19 Pandemic

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ABSTRACT

Higher educational institutions rapidly transitioned face-to-face courses to remote delivery during the COVID-19 pandemic. This article offers a case study focusing on a valuable innovation by a university instructor who had to transition a laboratory-based from face-to-face to fully online delivery. The instructor was able to adapt a face-to-face course's laboratory-based content and transition undergraduate students into an online learning environment. A key element in successfully meeting the unexpected educational challenge relates to how the instructor creatively used in a fully online environment an educational approach that inverts or "flips" students' engagement in their own learning, including hands-on activities and other practical experiences in the course. This article further shows how the rapid transition afforded a unique opportunity to help the university's local medical community to meet an urgent need for personal protective equipment (PPE) for healthcare providers. The course transition involved an innovative approach to online learning that actively engaged students in using 3D printers to produce components for medical-grade N95 respirator masks and in recruiting volunteers to assemble and distribute the masks. Throughout the 12-week undergraduate course, students were able to directly engage in manufacturing, assembling, and distributing new 3D-printed N95 masks. The instructor also incorporated into the adapted online course an application of process improvement techniques used in actual business enterprises. The primary purpose here is to show how innovation within a fully online learning environment effectively and meaningfully engaged students, thereby enhancing their learning outcomes while also making a valuable social impact.

Keywords: teaching innovation, online delivery, remote learning, experiential learning, flipped classroom

INTRODUCTION

Early in 2020 during the COVID-19 pandemic, nearly all educational institutions at each level made efforts to convert to some form of online delivery of instruction. Many instructors had to rapidly transition their face-to-face courses to remote delivery. This often required learning and using new technologies and methods for teaching. While the transition was mandated and mostly rushed, the results of such transition yielded evidence of certain benefits for student learning. Such evidence includes important examples of creative responses and process innovations thereby emerged during the pandemic. The present article describes a specific case of how technology and innovation in educational delivery enabled a university instructor to meet the unexpected challenge while also helping to meet a crucial need for the university's external community.

By early 2020, administrators in U.S. colleges and universities, had recognized the dramatically emerging crisis and uncertainties imposed by the sudden COVID-19 pandemic. Such was the situation at The Citadel, the Military College of South Carolina in Charleston, founded as a state university in 1842. Nearly all undergraduate students at The Citadel are residential and members of the South Carolina Corps of Cadets. By March 2020, The Citadel's senior administrators were deciding how to respond to the threat and were adapting the university's continuity of instruction (COI) plan. Under the revised COI plan, instructors of all courses that were not already online would shift fully to online delivery using the Canvas learning management system (LMS) (see The Citadel, 2020b). Canvas integrates effectively with online conferencing via Zoom software, thereby enabling either synchronous or asynchronous delivery, or a combination. This shift would occur during Spring Break week in mid-March while the residential students were already off-campus at home or elsewhere. The duration of this COI response was unknown, but it would last at least through the rest of the semester and the following summer months. This sudden crisis in 2020 confronted many of The Citadel's faculty members with the daunting challenge of immediately adapting face-to-face courses already were well underway in-progress and shifting the course delivery to engage students entirely online.

As COVID-19 was overtaking South Carolina, the pandemic threatened to overwhelm not just educators, but also healthcare providers. In particular, the Medical University of South Carolina (MUSC) had encountered a critical shortage of personal protective equipment (PPE). Medical providers especially needed medical-grade N95 respirator masks to help prevent transmission of the virus. But new N95 masks were becoming unavailable due to global supply chain disruptions (Laudenslager, 2020). MUSC issued a public service announcement seeking new N95 masks. MUSC is located in Charleston near The Citadel.

A Citadel instructor saw MUSC's public service announcement. This instructor had been teaching a face-to-face undergraduate course on Applying Innovation. The instructor also serves as the director of the Business Innovation Lab ("Innovation Lab") within The Citadel's Tommy and Victoria Baker School of Business. Until the crisis hit, the instructor's students had been actively using the Innovation Lab, located on-campus at the School of Business. The instructor recognized an opportunity to engage his students in helping the local medical community (see Detar, 2020). The instructor specifically envisioned a project in which online students would engage in producing, assembling, and distributing N95 respirator masks. The students themselves would use the university's 3D printers to manufacture the required components and would recruit volunteers to assemble and distribute the masks (see Detar, 2020). The project itself was no ordinary assignment because, as the students recognized, it afforded them an opportunity to make a meaningful difference in the lives of real people.

The case described in this study is useful because it contributes an understanding of how an instructor creatively reconstructed laboratory-based course content to effectively and actively engage online students in hands-on learning. This case thus illustrates a valuable teaching innovation that emerged from process innovations driven by a pressing need to adapt this laboratory-based, face-to-face course for fully online delivery. The authors also show that teaching innovations can reflect dynamic adaptive responses that hold important potential for making a valuable social impact.

One of the key aspects of the process innovations manifested in this case relates to how the instructor applied the flipped learning approach for online delivery of a laboratory-based course. In this regard, the authors' purpose is to show how in a fully online environment an instructor's implementation of the flipped learning approach enabled him to effectively engage students for enhanced learning outcomes. The authors recognized that, while the flipped classroom approach itself has become more familiar as a method of teaching, demand for online delivery is likely to continue and even increase, and thus educators in a fully online environment will need new and innovative insights for gaining the benefits of the flipped approach. To better understand the educational context of this case study and its teaching innovation and social impact, the following section briefly describes how The Citadel's Innovation Lab came into existence.

THE BUSINESS INNOVATION LABORATORY

The Citadel in 2017 was expanding students' opportunities for online learning opportunities and experiential learning. Simultaneously, the university's School of Business (now known as the Tommy and Victoria Baker School of Business) was substantially revising its core business curriculum, including to enrich its emphasis on critical thinking and quantitative reasoning, and on entrepreneurship and innovation. The School of Business also sought to establish a business innovation laboratory, with scanners and 3D-printers, as key resources for practicing creative processes and for experimenting with innovation projects that could lead to entrepreneurial initiatives and new enterprises. The School obtained approval to add a new faculty member specializing in entrepreneurship and then selected a well-qualified person to launch the innovation laboratory and to serve as its first director.

To launch the Innovation Lab, The Citadel had to accomplish the desired educational purpose within certain constraints, especially physical space. One solution, for example, was to procure equipment that one could move and use in other locations, so purchasing portable 3D scanners helped to alleviate this constraint. In addition, The Citadel placed another 3D-printer on-campus inside Daniel Library's "Makers Space" (The Citadel, 2020a).

Innovation students began using the scanners at various museums to scan collections and to create 3D printer files and virtual-reality files of artifacts. Using virtual reality software and related equipment, museums and researchers can study the scans of these artifacts and can even create physical replicas. Students continue to scan collections at museums in Charleston, and in North Carolina at Fort Liberty's Special Operations and Airborne Museum. The latter collection includes a rotor from one of the helicopters shot down in Somalia in 1993, a well-known event portrayed in the book and film *Black Hawk Down* (Novelly, 2020).

This study next addresses the theoretical basis of the flipped approach's potential for enhanced student learning and shows how the flipped approach can foster active learning within a virtual environment.

THE FLIPPED CLASSROOM METHOD

In the rapid shift to fully online learning caused by the pandemic, the instructor of this innovation course creatively applied the specific educational approach that inverts or "flips" the students' assignments to directly engage them in the initial encounter with an unfamiliar topic and to encourage more active participation in their own learning. This was not the only process innovation the instructor applied in reorienting the online students toward a production of N95 masks. But the instructor recognized that a flipped approach could afford more opportunities for students to engage in and learn through student-centered activities, including assignments that incorporate hands-on activities and other practical experiences through the course, which would be important for achieving the student learning of this laboratory-based course.

The flipped approach to learning assigns activities in ways that, as educational research has shown, encourages students' active involvement in their own learning and can improve learning outcomes (see Tang et al., 2020; see also Love, Hodge, Grandgenett, & Swift, 2014). This approach shifts away from traditional lecture-based lessons that initially introduce new content, and instead prompts students to initially engage basic concepts before entering the classroom (Tang et al., 2020). This permits more effective use of in-class time for actively applying those concepts through problem-based activities and other practices (Tang et al., 2020). The flipped approach enables instructors to use more in-class time for the kinds of value-added activities that foster active learning (Asef-Vaziri, 2015). The flipped approach can be integrated with participatory learning activities and methods, such as in-depth discussions, real-world applications, problem-based learning (PBL), and team-based learning (TBL) (see, e.g., Asef-Vaziri, 2015; Gopalan & Klann, 2017; Kang & Kim, 2021). As a specific example, Gopalan and Klann (2017) observed improvement in student performance and confidence gained by the flipped approach combined with TBL. Similarly, Kang and Kim (2021) blended flipped classroom design with TBL and likewise found positive impact on student knowledge, problem-solving ability, and learning satisfaction. Studies at the college level have shown that a flipped approach promotes active learning effectiveness by increasing students' involvement in the learning process (Bonwell & Eison, 1991). In the online context, the flipped approach logically translates into course assignments that students undertake before entering the collective, online classroom, followed by the equivalent of "in-class time" by which students virtually engage colleagues and others through collaboration and other collective activities.

The flipped approach intrinsically ties into technology-driven instruction. In the flipped approach, students mainly use online learning platforms for direct access to audio-video and similar online resources (Campillo-Ferrer & Miralles-Martinez, 2021). Technology can significantly alleviate resource restrictions, such as those imposed by limited access to physical course materials, and enables students to gain access to materials created by the world's leading authorities (Herreid & Schiller, 2013). Recent increases in the visibility and relevance of technology-driven resources supporting the flipped classroom method can translate into a variety of educational benefits, such as: (1) more effective and creative use of class time; (2) increased student autonomy, interest, engagement, and achievement; and (3) the ability to introduce, or convert into, other participatory learning methods, such as problem-based learning and active learning (Bergmann & Sams, 2012; Herreid & Schiller, 2013; Asef-Vaziri, 2015; Schwarzenberg et al., 2017; Campillo-Ferrer & Miralles-Martinez, 2021). Such beneficial effects on learning are particularly relevant for colleges and universities because of those institutions' ongoing need to adapt – especially as experienced during the sudden pandemic, and their need to utilize a wide variety of teaching modes and technologies (see Campillo-Ferrer & Miralles-Martinez, 2021). University students in fully online courses, especially adult learners, can engage individually and with each other through remote delivery technologies, and are better situated to accrue benefits from greater autonomy in their learning and from more responsibility for decisions about their learning (Money & Dean, 2019). In a study of student experiences using the flipped classroom approach during the pandemic, Campillo-Ferrer and Miralles-Martinez (2021) surveyed 179 student-teachers in a university program. The results indicated that student-teachers who had used the approach self-reported increased motivation to learn new active methodologies and more willingness to engage a wider range of online resources for technology-based, autonomous learning (Campillo-Ferrer & Miralles-Martinez, 2021). Accordingly, in light of the foregoing advantages and benefits derived from technology, this instructor's use of the flipped approach fit well within an online learning environment.

The next section of this study explains how The Citadel, during its initial COI response, rapidly transitioned to fully online learning. More specifically, the section shows how this instructor effectively adapted his course by incorporating flipped methods to encourage students to engage actively in their own online learning. The reconfigured course also incorporated a well-recognized methodology for process improvement used in business enterprise.

AN ADAPTIVE RESPONSE TO ENGAGE ONLINE STUDENTS

When The Citadel executed its COI plan in March 2020, many of its faculty members who had been teaching face-to-face courses were able to readily adapt course content for online delivery (The Citadel, 2020b). But the instructor teaching the Applying Innovation course faced especially difficult challenges in adapting the in-person course and transitioning students to the fully online context. This upper-division course included hands-on activities that had not been intended for remote learning. Laboratory-based courses are purposefully designed to be highly participatory.

During the course transition, the innovation instructor heard about MUSC's urgent need for PPE, especially for medical-grade masks. He began considering whether it might be feasible to use the online course on applying innovation to help MUSC. In redeveloping the innovation course for online delivery, the instructor considered a project assignment that could demonstrate process innovations. A project that could fit well with a remote learning environment had the potential to achieve most, if not all, of the learning objectives of hands-on assignments in the laboratory-based, in-person format. The instructor set as the online project's goal to develop a process for producing new N95 masks in the quality and quantity of masks needed by the local healthcare providers. Meanwhile in launching the fully online course, the instructor sent out to his 22 undergraduate students a call-to-action to engage directly in the real-world innovation effort.

The online project assignment incorporated the principles of a well-recognized process improvement method supporting process innovations in business enterprise. The project specifically integrated concepts and principles drawn from Lean Six Sigma (LSS). LSS consists of process techniques that reduce waste and save costs, reduce process variation, and improve quality (Andersson Eriksson, & Torstensson, 2006). LSS methods are used for process innovations in both manufacturing and service industries – including the healthcare and higher education industries (Rahman et al., 2018; Li et al., 2019; Bhandari, Badar, & Childress, 2021). The project applied the LSS framework as a means to find practical solutions to realistic business problems and to leverage LSS management tools to build effective processes (see Panayiotou, Stergiou, & Chronopoulos, 2020). LSS process improvement tends to follow a prescribed sequence of steps that can be repeated. The instructor observed that LSS Steps 1-3 paralleled a sequence of actions that one could readily adapt for flipped learning. Using the flipped approach to introduce students to the basic concepts and techniques of LSS, the online project prompted students to familiarize themselves with the process steps. Thus, the assignment asked students to follow the prescribed steps as identified and explained below.

Step 1: Problem Identification

Using the Canvas LMS and the Zoom application for the online course, the innovation instructor started by inviting each student to provide a 3-minute overview of general information each had gathered. The students collectively identified the problem as a lack of PPE, particularly new N95 masks. Having identified the problem, the discussion naturally moved into suggesting potential solutions. Eleven students proposed using cloth masks as a replacement, but several students were quick to point out that cloth masks lack filtration components and therefore do not satisfy the required efficacy standard of N95 masks. Further discussion of the problem and potential solutions focused on how to construct comparable masks using filters. As the ideas continued to flow, two students mentioned the Innovation Lab as a resource and suggested 3D printing masks. This idea excited the students, but they lacked the capability to design a mask that could meet the requirements for medical use. At the end of that class, the students committed to gathering information specifically on 3D-printing N95 masks.

Through the instructor's own information gathering, he learned that MUSC's Human Centered Design Program in Charleston had previously designed a 3D-printed N95 mask that could meet the requirements (as shown in Image 1). Although MUSC had a design, its program lacked the people and other resources required to produce N95 masks in sufficient quality and quantity to meet the crucial needs of healthcare providers (Hansen, 2020; see also Spence, 2020). The instructor pursued the idea by communicating with the head of MUSC to discuss whether this solution might be feasible (Hooker, 2020). MUSC subsequently provided to The Citadel MUSC's approved design files for 3D-printing N95 masks. In effect during this stage of the innovation process, the members of the online course had successfully identified the problem and had derived a solution.

Step 2: Define and Measure

The second stage involved defining the production process and measuring the amount of time needed to produce a single N95 mask. Students in this stage researched optimum ways to print, assemble, test, and distribute components for N95 masks. Using MUSC's design, Citadel faculty members initially made prototypes of the 3D-printed N95 masks to test The Citadel's capabilities and the feasibility of the project (as shown in Image 2). During this stage, students were able to see images of the prototypes that were generated.

Considering the urgent need expressed by MUSC, the production time for masks presented a crucial aspect of the project. Project participants measured run times for printing, cooling, and assembling the components for one mask. A single usable mask required approximately eight hours, assuming no quality errors in the manufacturing process.

Mask production also would have to be effectively scaled up to meet the quantities needed by healthcare providers. So, after defining and timing the process for a single mask, the participants brainstormed ideas on how to most efficiently assemble the masks within an assembly area. Participants also calculated the necessary quantities of materials used in production, such as PLA plastics, HEPA filters, sealant, and elastic bands. Students began to develop sources for procuring all the required materials.

Step 3: Action Planning and Implementation

Based on the students' analysis of the production process, they concluded the best option was to set up in the Makers Space a series of five stations operating in an assembly line fashion. These stations could accomplish the whole production process: printing and storing parts, constructing and assembling filters, applying hot glue for assembly, inserting liners for comfort and sealing, inspecting each completed N95 mask, examining mask cavities to ensure proper sealing, and finally, packaging masks for distribution. This became the action plan that was implemented and the process by which The Citadel began to produce and assemble components (as shown in Image 3), and then to inspect and deliver newly completed masks to MUSC (as shown in Image 4).

The need to scale up this production process highlighted the need for additional participants to help assemble the components. Notably, the individual volunteers from across the United States assisted in printing and shipping mask components for assembly. Participants considered ways to solicit interest and assistance from members of the broader community. The purpose was to add resources and capabilities drawn from a wider geographical area and thereby enable participants to achieve the project's production goals. Students were asked to reach out to their local communities for resources, such as 3D printers, HEPA filters, and adhesives. Many community members were willing and able to employ personal 3D printers to print and resources to ship N95 mask components. Students also started promoting these efforts through local media outlets (as shown in Image 5). Through the media coverage stimulated by students and by interviews, the project gained momentum and expanded well beyond The Citadel. Several local news outlets in Charleston, SC contacted and interviewed the faculty members who were involved.

A particularly successful example of efforts by students led to a student meeting in his community with the president of a local university. That university committed additional 3D printers and extra laboratory resources for masks. The Citadel's own president described the initiative to the South Carolina Commission on Higher Education (CHE), which oversees all public colleges and universities within the state. Through that connection, the CHE in cooperation with the South Carolina Department of Health and Environmental Control (DHEC) committed $350,000 in financial support to any state college or university for purchasing materials and helping to produce additional 3D-printed N95 (The Citadel, 2020a).

PROJECT RESULTS AND REFLECTIONS

The foregoing sequential stages of the N95 project were completed within the term of the online innovation course. By the end of the 12-week semester, Citadel students and faculty, supported by MUSC and other South Carolina institutions and volunteers had successfully financed, manufactured, and distributed over 1,000 new N95 masks for use by healthcare providers. The students had observed firsthand how the project manifested actual stages in applying creativity, developing processes, scaling production, and innovating along the way.

A concluding assignment in in this online course asked students to reflect individually on the project's successes and shortfalls, and to gather feedback from their communities. The purpose of encouraging reflections by students was to advance learning objectives, specifically those relevant to applying innovation. All input was analyzed by students for collective insights and for a better understanding of innovation processes refined through incremental improvement and iterative replication. This reflection assignment within the course encouraged students to consider ways to stimulate creativity and to adjust an ongoing process of applied innovation.

Using the flipped classroom approach became a key feature for enriching the learning experience of students. Data collected from a survey of students at the end of the course reflects the positive perceptions they gained from their greater involvement the course, essentially achieve through the nature of the N95 project and the sequencing of assignments in the course (see the results as indicated in Table 1). Using the flipped approach for engaging online students in this laboratory-based course content readily demonstrates how the approach can be effectively applied for remote, yet active learning. The flipped classroom approach afforded a significant dynamic, for the students and for the community. Students engaged actively and directly via online delivery in a laboratory-based project geared toward social impact. In this regard, healthcare professionals provided especially valuable feedback. According to a surgeon at MUSC, these efforts to produce new N95 masks had saved lives, (D. Mahvi, personal communication, January 2022). Indeed, perhaps most important to these online students was how they had personally been able to engage in a project that made a real-world difference.

THE ONGOING CHALLENGE

In the ways described above, the innovation instructor rapidly and successfully transitioned the laboratory-based, face-to-face course into a fully online course that used flipped classroom methods and integrated quality control processes to actively engage students and to enhance their learning outcomes. While the impact of the flipped classroom approach was clearly positive among these students in the online course, the unique circumstances driven by COVID-19 suggest further questions about how to continue using this approach for online delivery. The crisis conditions had generated a special opportunity. As the end of the course approached, society was beginning to adapt to the pandemic conditions and sourcing of new PPE also began to expand. Something like a new-normal condition was emerging.

The innovation instructor thus observed a new pedagogical challenge for active learning via online, laboratory-based course. Going beyond the pandemic era will require exploring ways to harness the same type of enthusiasm and impact of the online flipped classroom for problem-solving during times of normalcy (see Tawfik & Lilly, 2015). Accordingly, this study shows that the flipped approach can be highly effective in an online course, yet a creative challenge will remain in regard to helping online students to find purpose and meaning through laboratory-based activities delivered for remote learning. The ongoing question is whether online courses can infuse and sustain such purpose and meaning.

This study suggests that the source of this project's meaning lay within an urgent need observed within the community. One solution to the ongoing pedagogical challenge is to creatively explore the naturally existing opportunities for meaningful impact. To find where new meaningful opportunities exist, instructors and students can be intentional in seeking out and communicating with the broader community members about community needs and problems they already face. Here, too, instructors and students would find the flipped approach to be valuable not only in identifying such needs, but also for locating key resources and collaborating with partners to address those needs through active learning.

DISCUSSION QUESTIONS

1. What drives the active and engaged learning that makes the flipped classroom approach valuable for online students?
2. Does the flipped classroom model hold any advantages for learning in urgent situations over non-urgent situations?
3. What kinds of naturally arising community needs or problems might be appropriate for a flipped classroom project?
4. What kinds of flipped classroom activities in various online courses might be used or adapted for societal impact?
5. How could another instructional method in an online course be combined with a flipped approach?

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APPENDIX

Table 1. Student responses to the Flipped Classroom environment and initiative

Respondent ID	Answer
2	"This class provided a senese of purpose alongside the material we were taught!"
5	"We directly had an impact on the community and lives, I felt like we were living what we were learning"
13	"I wish that all classes were taught this way. We saved lives"
15	"This class gave me real hands on experience with a real world problem"
19	"Being involved with a project like this made learning fun and meaningful"

Image 1. MUSC design and protype components of 3D-printed N95 respirator mask

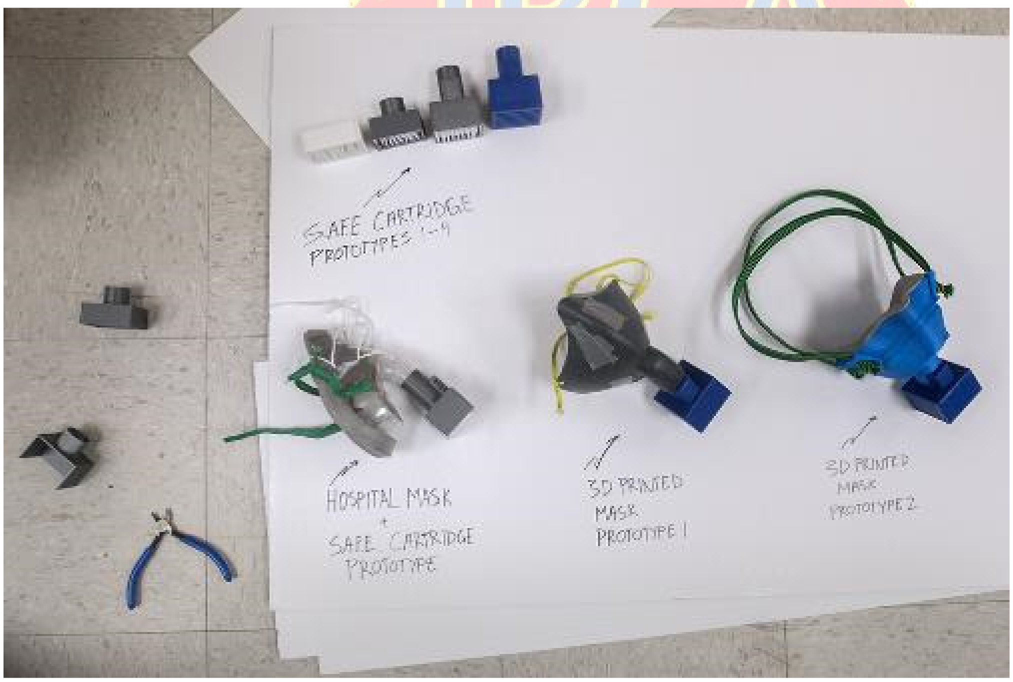

Image 2. Citadel faculty members examining feasibility of producing 3D-printed N95 masks on-campus (left to right, the directors of the Innovation Lab, and the Makers Space, and an associate professor of health and human performance).

Image 3. 3D-printed N95 mask components ready for assembly

Image 4. Completed 3D-printed N95 masks ready for distribution

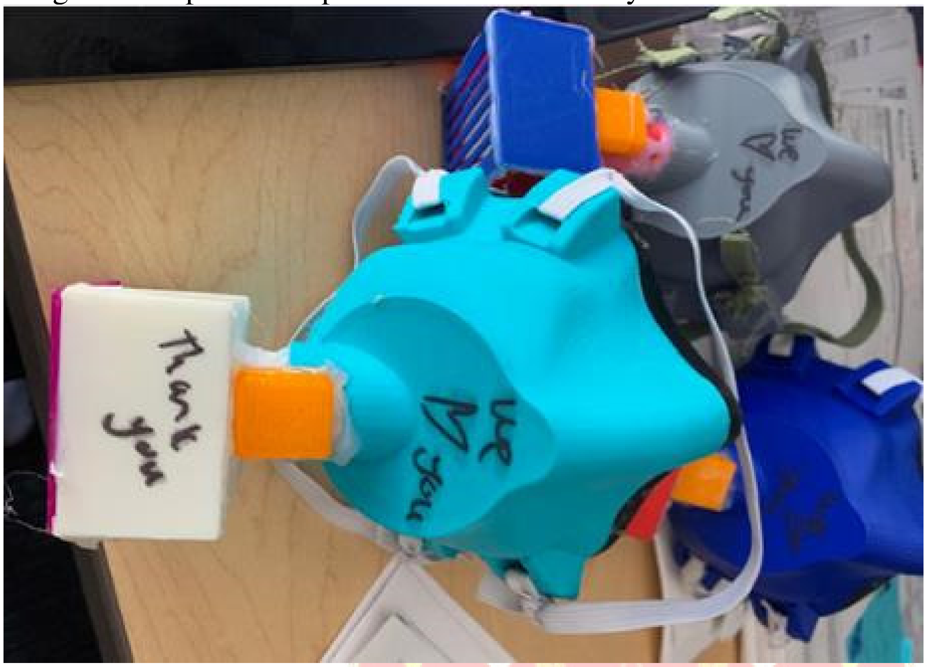

Image 5. Citadel student activities for collaboration across South Carolina for producing 3D-printed N95 masks