How Have STEM Courses 'Adapted' to Online Learning During a Pandemic?

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Abstract of Thesis

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Higher education STEM courses are typically taught face to face as many aspects of the class require hands-on experiences. However, these courses were forced to transition to emergency online learning delivery in the middle of the Spring 2020 semester because of the COVID-19 pandemic. This pandemic shut down higher education and impacted courses learning outcomes, particularly those in the STEM fields. This paper outlines the literature on pedagogy and how this is applied to online learning before and after the emergency online transition. The thesis also considers the stressors associated with this transition and provides case studies of how some STEM courses transitioned their courses online. I also provide a personal experience in transitioning ANTH 1001 labs to an online format at George Washington University during the Spring 2020 transition.

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Chapter 1: Introduction and Literature Review

Introduction

Over time higher education has become more inclusive to students who are seen as "non-traditional" because they are older or come from backgrounds which are traditionally underrepresented in higher education. These and other students benefit from the flexibility of online learning because they can access it from anywhere and work around their busy schedules. This online learning modality also costs less per credit hour than in person courses on campus (Porter and Graham, 2016). However, the STEM fields are slower to adapt to this online learning modality as many instructors believe that there are hands on experiences in person that are difficult to replicate in an online environment (Lashley and McCleery, 2020; Qiang et al., 2020). This mindset was forced to change when the COVID-19 pandemic spread to the United States as all courses, including STEM courses, were forced to adapt to emergency online learning. This paper seeks to review the literature on STEM online learning, specifically with regard to the pedagogical response STEM instructors in this field used to transition their courses online during the pandemic.

COVID-19 Information

During March of the Spring 2020 semester, universities transitioned to emergency online learning due to the pandemic outbreak. This outbreak was caused by SARS-COV-2, also known as the Coronavirus Disease 2019, or COVID-19, which mainly impacts the respiratory system (Fauci et al., 2020). COVID-19 originated in the city of Wuhan, China and quickly spread across the globe as it spreads from person to person by airborne

droplets or contact (Fauci et al., 2020; Li et al., 2020). Because of how quickly COVID-19 was spreading, restrictions were put into place in the United States, and across the world, that included social distancing, quarantine, stay-at-home orders, and the use of face masks in public (Li et al., 2020). These restrictions made it impossible for college students to attend classes as normal, so they were transitioned to online courses in the middle of the Spring 2020 semester. During 2020 approximately 3,358,814 people died from the coronavirus (Ahmad et al., 2020), with the number continuing to grow every day, as of the submission of this thesis. The shift to online learning has undoubtedly saved lives but this transition was not easy pedagogically or mentally.

Pre-COVID Online Learning Practices

This section aims to describe the types of online learning and why students might choose to take these courses over traditional face-to-face courses before the COVID pandemic. Online learning can be defined as the use of online platforms to facilitate learning at a distance; this includes blended learning, fully online courses, and massive open online courses also known as MOOCs (Toven-Lindsey et al., 2015). Blended learning is a type of online education that has a face-to-face component as well as an online learning component. Blended learning is popular among the sciences as it allows students to do their lectures, or equivalent, online and participate in labs in small groups face-to-face (Porter and Graham, 2016). Another kind of online learning is fully online courses where all aspects of the class are facilitated through an online video platform such as Zoom, Blackboard Collaborate, or Microsoft Teams. These kinds of courses allow for students to access class from anywhere as long as they can access the internet.

MOOCs take fully online learning to extremes, typically enrolling hundreds of students at a time in asynchronous learning (Toven-Lindsey et al., 2015). This fully asynchronous aspect of MOOCs differs from other fully online courses, which typically emphasize synchronous learning, though they may have some asynchronous aspects.

Online learning offers an innovative flexible learning environment and at a lower cost than traditional face-to-face courses which makes it a good alternative to traditional learning (Porter and Graham, 2016). These can be important factors for those who are not considered “traditional learners" as they are often returning students or those who got a later start on school. This flexibility and lower cost is important to these non-traditional students as most of them have families, are working part or full time, or other obligations which they are juggling at the same time as their course work (Porter and Graham, 2016). Those who choose to take online courses typically take them because they provide greater levels of flexibility allowing students to balance external commitments, like family and work obligation, that typical face-to-face learning could not work around (Crawford-Ferre and Wiest, 2012; Redmond et al. 2018). As online learning has become more popular, universities are also coming to recognize the value that online learning courses hold, as well as courses that incorporate online learning aspects such as blended learning. It is thus logical to predict that blended and online learning will become more widespread in higher education in the years to come (Porter and Graham, 2016).

Online Learning Pedagogy

To provide an overview of different pedagogical approaches and how these strategies can be utilized in online learning environments, this section aims to define and

discuss them. Different pedagogical approaches to teaching, in person or online, can be described as either objectivist or constructivist approaches (Toven-Lindsey et al., 2015). Objectivist pedagogy assumes that learning occurs through information presented from the instructor directly to the learner (Kundi and Nawaz, 2020). Constructivist pedagogy asserts that learning occurs through the interaction of students to create, or construct, their own knowledge (Kundi and Nawaz, 2020). Objectivist approaches are common in MOOCs and can be defined into two further categories of objectivist-individual approach and objectivist-group approach to teaching (Toven-Lindsey et al., 2015). The objectivist-individual approach assumes one objective reality focusing on the transmission of knowledge, emphasizing instructional sequence and individual mastery (Toven-Lindsey et al., 2015). This approach is found in traditional face-to-face courses and some online courses as it involves the transfer of knowledge directly from an expert to student (Kundi and Nawaz, 2020; Toven-Lindsey et al., 2015). The other objectivist approach is the objectivist-group approach in which learners are working on collaborative activities that allow them to form a greater sense of community through social interaction seen as associated with positive course outcomes (Toven-Lindsey et al., 2015). While this approach is similar to objectivist-individual approach, in that there is a one-way transmission of content from the professor to the student, the objectivist-group approach encourages student interaction through group activities (Kundi and Nawaz, 2020; Toven-Lindsey et al., 2015).

Constructivist approaches to learning are more popular in online learning settings as these approaches challenge students to develop their own understanding of the course material by utilizing their problem-solving skills and participating in meaningful

discourse (Crawford-Ferre and Weist, 2012; Kundi and Nawaz, 2020; Toven-Lindsey et al., 2015). This constructivist learning approach should provide a collaborative learning environment, student-centered approach, increased student-faculty interactions, project-based learning, and challenging course assignments (Kim and Bonk, 2006; Maor, 2003; Robinson and Hullinger, 2008). To challenge students in this constructivist format instructors should strive to elicit prior knowledge, create cognitive dissonance of what they know and what they are going to learn, challenge students to apply knowledge with feedback, and reflect on learning (Mbati and Minnaar, 2015). Constructivism, like the objectivist approach, can be broken down into two categories as well, the constructivist-individual approach and the constructivist-group approach (Kundi and Nawaz, 2020; Mbati and Minnaar, 2015; Toven-Lindsey et al., 2015).

The constructivist-individualistic approach assumes that students construct knowledge independently through interaction with the subject and combining different sources of information (Kundi and Nawaz, 2020; Toven-Lindsey et al., 2015). The constructivist-group approach takes the stance that knowledge is socially constructed, thus this teaching strategy encourages a higher degree of collaboration among students (Kundi and Nawaz, 2020; Toven-Lindsey et al., 2015). This strategy suggests that the collaborative approach in a social learning environment is essential to any educational experience and can be facilitated through activities that encourage reflective thinking, peer-learning, and joint construction of knowledge (Maor, 2003). Incorporating these constructivist teaching strategies into online learning requires instructors to have a strong understanding of pedagogy and technology (Maor, 2003; Mbati and Minnaar, 2015).

Implementation of learning strategies

In order to implement teaching strategies instructors must understand factors that contribute to the success of online courses, such as the time it takes to plan and organize online courses, effort it takes to facilitate these courses, an increase in teaching presence, and an increase in social presence (Baran and Correia, 2014). Thus, this section will go over these factors as well as strategies for professors to incorporate these learning techniques into their courses. There are five elements of engagement that are considered to be crucial from a social constructivist perspective: social engagement, cognitive engagement, behavioral engagement, collaborative engagement, and emotional engagement (Redmond et al., 2018). Social engagement is seen to be as important as intellectual engagement in online learning environments where social interaction can be low, if not intentionally incorporated into the curriculum (Redmond et al., 2018). This social interaction can be easily facilitated through asynchronous and synchronous group discussions in class or an online discussion board to also promote individual and group learning (Baran and Correia, 2014; Redmond et al., 2018).

Successful online teaching is the result of a complex balance of personal, pedagogical, contextual, and organizational factors (Baran and Correia, 2014). Teaching online requires that professors have a strong understanding of course content and can translate this to online learning platforms while also incorporating social interactions (Baran and Correia, 2014). In order to create successful online courses teachers need the support of their professional community as well as the support from their universities (Baran and Correia, 2014). Through this support instructors are empowered to teach in a new challenging environment that they might not otherwise consider (Baran and Correia,

2014). These factors imply that student cognition is not individualistic, like objectivist approaches imply, rather that their learning is rooted in social and cultural interaction as the meaning and student-centered learning can help the individual obtain a deeper understanding of course content (Toven-Lindsey et al., 2015). Due to the success of student-centered learning, it can be understood that the constructivist approach would be more effective for an online learning environment.

In order to facilitate learning through the constructivist approach teachers are challenged to be engaged with the learning process but not dominating the discussion, as this would limit opportunities for student collaboration and this constructivist approach utilizes students' social interactions (Mbati and Minnaar, 2015; Redmond et al., 2018; Toven-Lindsey et al., 2015). Without these social interactions students can become disconnected from the class and in the end retain less knowledge from the course (Mbati and Minnaar, 2015). It is important to note however, that student-instructor interaction can benefit students as well, with regards to feedback, but not when instructor interaction is in the way of students' social interactions (Toven-Lindsey et al., 2015). Instructors get in the way of social interactions when they dominate discussions or other areas of course work that require student interaction. These social interactions of students can also be facilitated through group projects or peer tutoring that can solicit different perspectives and idea sharing to aid in a collaborative learning environment (Robinson and Hullinger, 2008). Another way that students can be engaged with course material is through multimedia content that can be delivered synchronously or asynchronously (Crawford-Ferre and Weist, 2012).

By introducing multimedia content like videos, presentation slides, video lectures, and website exploration, students can be challenged to think critically while also providing a different mode of delivery (Crawford-Ferre and Wiest, 2012; Huda et al., 2016). Providing students with these different modes of delivery and allowing them to think critically keeps them interested and involved in course content which then supports higher content retention, as students find it more enjoyable (deNoyelles and Reyes-Foster, 2015). Changing the role of the professor, or expert, to a co-learner with their students and providing them with the tools to become responsible for their own learning will enhance their learning outcomes (Maor, 2003). An example of when an instructor would do this is by assigning topics to groups and having them come to class prepared to teach their peers about it (Maor, 2003).

Two examples of studies utilizing constructivist techniques are the use of data available online (Huda et al., 2016) and the use of word clouds in online discussions (deNoyelles and Reyes-Foster, 2015). Using data in course curricula allows students to learn techniques associated with analyzing data to improve their decision-making skills, knowledge-based discoveries, and facilitate their own learning (Huda et al., 2016). The use of data also supports learning by helping students distinguish between reliable and unreliable data sources as there are many different resources for data. Students may need help at first identifying reliable sources so instructors should set time aside in class to go over this concept or provide a document outlining how to find reliable sources. Briefly, important aspects of a reliable source are if the work is original, current, and comes from a credible source such as reputable journals, government agencies, or universities.

Students also gain the ability to extract value from large volumes of data and provide higher student engagement with learning (Huda et al., 2016).

The next example is the use of word clouds in online discussions, which take the most frequently used words and randomly display them by size based on the frequency that they appear in the discussion board text (deNoyelles and Reyes-Foster, 2015). The use of word clouds promotes critical thinking and student engagement as a positive relationship was found between critical thinking, engagement, and peer interaction (deNoyelles and Reyes-Foster, 2015). Word clouds can be utilized to promote reflection and defining main ideas of the text. When students analyzed the word clouds produced in discussions, a t-test revealed that these students had higher scores on critical thinking than their peers who did not analyze the word clouds (deNoyelles and Reyes-Foster, 2015).

While the second example is an asynchronous technique, students in Crawford-Ferre and Wiest's (2012) study found that students perceived online classes with synchronous communication as being higher quality than courses that only utilize asynchronous communication. As long as the asynchronous communication is paired with synchronous portions of the course, then students' perception of the course will be that it is of higher quality. Online learning methods have a lot to contribute to student learning outcomes, as they contribute to student ability to write clearly, think critically, and analyze quantitative problems (Robinson and Hullinger, 2008). However, speaking skills, such as class presentations and discussion, are not as developed in online learning as they are in face-to-face courses (Robinson and Hullinger, 2008). This lack of

contribution to speaking skills can easily be incorporated into these online learning environments with presentations and synchronous discussion based courses.

Benefits to online learning

Online learning does not need to only be considered an alternative mode of learning, as it has the ability to produce similar skill outcomes as face-to-face instruction; thus, this section outlines some of the benefits associated with online education to produce these outcomes. We now know that online education can be as effective as traditional instruction, as learning opportunities in online courses can stimulate higher levels of thinking (Kim and Bonk, 2006). These higher levels of thinking go beyond knowledge comprehension and require students to synthesize their knowledge and evaluate based on their own experiences (Kim and Bonk, 2006). These learning opportunities that stimulate higher levels of thinking include, but are not limited to, online discussion forums and online mentoring (Kim and Bonk, 2006; Robinson and Hullinger, 2008). These asynchronous networks allow the learner more time to think critically and reflect on their learning while different channels of communication promote thought processes and learning communities advance students' thinking strategies (Robinson and Hullinger, 2008). One of the top benefits to online learning is the development of computer skills as students are highly engaged with various technologies that facilitate their learning (Robinson and Hullinger, 2008).

The development of these transferable technological skills is critically important for preparing students in higher education for their careers after graduation. Thus, it has become imperative that students get the chance to develop technological skills through

online learning environments (King and Boyatt, 2014). In a study conducted by Robinson and Hullinger (2008), more than 70% of students acquired some job-related skills in an online learning environment and 80% of students reported that online learning helped them develop these skills to solve complex problems. The students in this study were engaged in online discussions and shared their ideas by responding to others which promoted their writing, critical thinking, and communication skills; these students were also reported to be more engaged in higher levels of analysis, synthesis, judgements, and applications of knowledge (Robinson and Hullinger, 2008). Because these students were able to utilize an online learning environment, they developed skills that will help them in the future. In person courses are capable of implementing some aspects of online learning into their face-to-face courses in order to capitalize on this skill-building learning outcome.

The role of professors in the online learning environment

Although there are many benefits of online education, it also comes with increased complexity, requiring professors to fulfill a number of different roles in this environment. This is because, while the students hold responsibility to engage academically, ultimately it is the instructor that must create a course that promotes interaction, participation, and communication (Robinson and Hullinger, 2008). This section strives to describe how professors' roles in the online learning environment can be used to promote student learning outcomes and how instructors can accomplish this. In order to create a course with a student-centered approach, the professor plays the role as the facilitator for promoting productive online discussions that inspire reflective thinking

(Crawford-Ferre and Wiest, 2012; Maor, 2003). The most demanding role in online learning environments is the role of facilitator, because it is the facilitator's responsibility to monitor and evaluate the student-peer interactions in discussions to assess their understanding of the course material (Maor, 2003).

This demanding role of the facilitator has four different "hats": the social hat, managerial hat, technical hat, and the pedagogical hat (Maor, 2003). This social hat is involved with student support, interpersonal communication, and creating a positive learning environment to keep students engaged as it is important to be able to harness emotion while teaching (Maor, 2003; Redmond et al., 2018). The managerial hat and the technical hat are similar in that the managerial hat is involved in designing course activities and learning outcomes, while the technical hat is the guidance of this technology to support students, but without the managerial hat the professor would not be able to help the students (Maor, 2003). The fourth hat, the pedagogical hat, is the one involved with promoting interactive and student-centered learning (Maor, 2003).

These different "hats" professors must metaphorically wear creates more work, as they have to create course work in an online environment on top of aiding students in adapting to this online learning space (Crawford-Ferre and Wiest, 2012; King and Boyatt, 2014). Although students may have previous experience with online learning environments, and the technology and learning platforms used, this experience and knowledge may vary (King and Boyatt, 2014), so it may be helpful to provide students with an orientation to familiarize them with the course features (Crawford-Ferre and Wiest, 2012). In an online learning environment, students can be very demanding as they

expect that they have access to resources anytime and anywhere, including the professor (King and Boyatt, 2014).

Professors are less likely to transition their courses online if they have no support from their peers and little to no training in online pedagogy or technology (Crawford-Ferre and Wiest, 2012). Instructors need training in technology just as much, if not more, than their students to be able to effectively teach online. Without this additional training, it is possible that professors do not feel motivated to transition their teaching to an online learning platform. Instead of being able to see the useful teaching opportunities online learning provides, the lack of support from universities, the time it takes to develop online curricula, lack of knowledge about pedagogy and technology can all become barriers to the adoption of online learning (King and Boyatt, 2014). Universities should be taking responsibility for providing this kind of training for their instructors, as universities are responsible for deciding courses that are going to be offered online (Maor, 2003).

Training for instructors should include technological, pedagogical, and examples of opportunities that online course technologies provide for student learning outcomes (Baran and Correia, 2014; Maor, 2003; Mbati and Minnaar, 2015). These trainings should not treat technology as a separate entity from pedagogy, instead they should incorporate both to support instructors in making quality online courses (Baran and Correia, 2014). Faculty already have busy schedules and adding online courses to this list will just lay more responsibilities on instructors, but if they have the universities support as well as professional support from those in their field of study, the quality of these online courses will greatly increase (Baran and Correia, 2014). These resources may help instructors, but

overall instructors report that online courses do take more time to teach than traditional courses (Crawford-Ferre and Wiest, 2012). It is also challenging to facilitate and have useful online discussions if students do not ultimately want to participate meaningfully in the coursework because in the end students hold the final responsibility in their education (deNoyelles and Reyes-Foster, 2015; Maor, 2003; Redmond et al., 2018).

Faculty under stress

Online instruction can be extremely stressful for instructors and this section strives to explain how this stress can be mitigated by instructors' peers and universities. Faculty are more concerned about time and effort it takes for online courses and without support from the university this can be very stressful for instructors (Baran and Correia, 2014; Kim and Bonk, 2006). Typically, in online courses instructors have limited interaction with their peers and this can be very intellectually and socially isolating without support from their community, which can add more stress to faculty (Baran and Correia, 2014; Crawford-Ferre and Wiest, 2012). Suggestions to combat this includes the faculty forming a collaborative professional community to work together and develop programs, which would also provide psychological and emotional support for instructors to help alleviate some of the stressors associated with online instruction (Baran and Correia, 2014; Crawford-Ferre and Wiest, 2012). Different courses will need different kinds of support. This would mean that practices will be unique depending on the needs of the instructors. One common practice is pairing a senior online instructor with a new instructor and building a mentoring relationship; another is peer observation which provides an opportunity for feedback and suggestions on their courses (Baran and

Correia, 2014). Online instruction is stressful for faculty as well as students but there are ways in which instructors' peer communities can support each other to provide a positive and beneficial experience.

Chapter 2: Transition to COVID-19 emergency online learning

The COVID-19 pandemic has disrupted education and had the potential to shut down learning in higher education institutions (Bidwelle et al., 2020), but faculty adapted quickly and were able to continue higher education courses despite the challenges they faced. In this section the difficulties of this emergency online learning transition and the stressors associated with these demanding challenges are outlined. Faculty reported they modified their courses to meet the needs of students, while considering pedagogy, to the best of their abilities (Bidwelle et al., 2020), as most universities transitioned suddenly to having a majority of courses online (Qiang et al., 2020). This is an incredibly difficult task, as professors were required to do this in a very short amount of time in the middle of the Spring 2020 semester (Qiang et al., 2020).

The pandemic quickly shut down the country and the transition to emergency online learning impacted everyone, but not everyone was impacted equally (Aubrey et al., 2020). The inequality of COVID impacts was related to the various roles students and professors alike play outside of the classroom in relation to their families and jobs. Everyone was suddenly forced to play all of their roles from home and this level of impact varied from person to person. This unequal impact provided a unique challenge for professors as they attempted to adjust to new platforms as did their students. Some students found themselves unable to participate in courses because of bad connectivity and needing access to the material asynchronously (Reynolds et al., 2020). Thus, instructors also had to determine ways that they could produce high-impact learning

experiences able to be facilitated through online learning platforms while adjusting and being flexible during this new normal (Reynolds et al., 2020).

These adjustments proved to be especially difficult for the instructors who teach in the STEM fields, as many courses require hands-on experience as an important part of their learning outcomes (Lashley and McCleery, 2020; Qiang et al., 2020). This significant slow down, or outright cessation, of research and laboratory activities at universities has forced instructors to reconsider how learning is approached in the sciences, and more specifically in applied sciences like ecology and evolutionary biology courses who relied heavily on hands on experiences in the lab or the field (Lashley and McCleery, 2020; Qiang et al., 2020). With COVID-19 restrictions in place, in-person laboratories are not available for students to attend and it is expected that this will have impacts in learning outcomes of students in the years to come (Richter et al., 2020). With no real answer to when the pandemic will be "over", professors are making hard decisions about their courses while also dealing with the added stressors that the pandemic has caused everyone.

Feelings on the pandemic emergency online learning transition

COVID-19 forced education to move to an online delivery format causing mixed reactions among students and instructors. This section strives to describe some of what students and professors were, and continue to feel, during this time. Students anxieties were heightened with concerns about future employment, as the unemployment rate skyrocketed, and these unexpected changes in course modality impacted student motivation (Villanueva and Zimmerman, 2020; Wang et al., 2020; Qiang et al., 2020).

There is also the possibility that online learning caused increased feelings of isolation among students as learners, having limited interaction with their peers (Evans et al., 2020). The student's home life also greatly impacts their ability to perform in their classes as some students may be balancing many different priorities such as roommates, children, or family members (Reinholz et al., 2020).

This has led to students becoming depressed and distant in their online courses and reports of depression and anxiety among graduate students doubled during the pandemic, especially among those who are low-income and minority students (Woolston, 2020). Although mental health issues have risen among students and continue to do so, it is increasingly more difficult to access these mental health resources during the pandemic (Woolston, 2020). These signs of depression were most common among students in the physical sciences as they have either lost access to their labs or lost the opportunity to participate in class laboratories (Villanueva and Zimmerman, 2020; Wang et al., 2020; Woolston, 2020). In light of this, it makes sense that student participation dropped once classes moved online, but professors were able to adjust to these challenges and implement new strategies so that participation increased (Reinholz et al., 2020).

However, students were not the only ones who felt the effects of the pandemic, professors also felt profound impacts. In a normal situation, professors could be trained in online instruction, but this would take time and preparation that instructors did not have going into emergency online learning (Bidwelle et al., 2020; Fujita, 2020). Thus, many professors became overwhelmed with remote instruction techniques as they were expected to maintain high-quality course content with more work, no training, and a short transition period (Bidwelle et al., 2020; Fujita, 2020). The online learning response to

COVID-19 is not representative of what online learning is supposed to be and instead is more of a “pedagogical triage” (Bidwelle et al., 2020) in the disrupted semester transition to salvage learning for the rest of the semester. In ecology and evolutionary biology courses, female faculty, assistant professors, those who did not have access to a private room, and instructors that care for one or more children at home were more dissatisfied with their work-life balance than others during the pandemic (Aubrey et al., 2020).

Professors teaching courses with field activities and laboratories were impacted by the pandemic and many professors had to remove or reduce the learning outcomes associated with them (Barton, 2020). A majority of respondents to Barton’s (2020) study reported that their field learning outcomes for ecology and evolution courses were impacted by the pandemic. These impacts are perceived as having negative effects for the upcoming semesters as instructors had to remove or redesign much of their course material and ecology and evolution professors feel that lab and fieldwork can “make or break” a research program (Aubrey et al., 2020; Barton, 2020). More than half of the respondents to Aubrey et al. 's (2020) survey reported that they spent more time mentoring and teaching during the pandemic because of the loss of resources. Despite the challenges professors faced during the pandemic they made considerable progress in implementing new teaching pedagogy even under these challenging circumstances (Reinholz et al., 2020).

Best pedagogical practices seen in pandemic pedagogy

To address the sudden shift in content delivery many professors were forced to quickly adapt using new learning techniques to lessen the impact that this emergency

online learning transition will have on learning outcomes. Many practices outlined in this section are also seen outside of pandemic learning, however this section describes what kinds of solutions are seen during this time and how these have become increasingly important. Most traditional students are a part of the Millennial and Gen Z generations, who use technology on a daily basis as "digital natives" and were able to adjust to online learning using multiple online platforms without too much distress (Evans et al., 2020; Qiang et al., 2020). This rapid transition is unprecedented, and the innovations developed by instructors came with a steep learning curve requiring a lot of work, more than recording lectures and posting power point slides online (Woolliscroft, 2020). If instructors were to just merely distribute their current material to students in an online learning environment it could lead to a less interactive classroom as this approach does not engage most students and this is ineffective to promote deeper learning (Evans et al., 2020; Qiang et al., 2020). Students who watch recorded lectures are more likely to become distracted and uninterested in learning course material (Evans et al., 2020). Thus, being able to promote engagement and learning in online learning platforms requires additional, or different, ways that instructors can support students such as online office hours, discussion board monitoring, and TA support (Richter et al., 2020).

Instead of delivering lecture content in one long recording, content should be re-designed to 5–7 minute engaging videos that focus on one or two concepts at a time, used alongside other learning tools like quizzes, case studies, interactive technology, or discussion (Evans et al., 2020). This framework is utilized to maintain as much social interaction with students as possible with their peers as well as instructors interaction which can be developed through the use of student names, breakout rooms, and re-

establishing the norms and expectations for the online classroom (Evans et al., 2020; Reinholz et al., 2020). These group activities give students the opportunity to receive support from their peers and build their academic confidence but are more difficult to execute online, however instructors have demonstrated that this can be done (Qiang et al., 2020).

Online classroom active learning strategies need to be deliberate in their implementation because online learning requires instructors to create course content that enables student social interaction and participation and this only happens with careful consideration of pedagogical practices (Evans et al., 2020; Richter et al., 2020). These instruction techniques seen in pandemic pedagogy typically utilize the constructivist-social approach which is defined as students interacting with others to construct their knowledge (Toven-Lindsey et al., 2015). Some instructors already had elements of active learning incorporated into their in-person courses (Fujita, 2020) but this is still a challenge to transition them to be effective in an online environment as well. During the immediate pivot however it is important to note that instructors were more focused on getting course content out to their students (Fujita, 2020) as they had little time to prepare for this transition. But after the immediate reaction instructors were able to incorporate more active learning strategies into the subsequent semesters courses.

In general, it is also important in an online learning environment that students are able to make meaningful connections in their courses between what they are learning and their career goals; this is because they then maintain a higher level of interest in the course (Wang et al., 2020). This is defined by Wang et al. (2020) as “meaning making” and is important for students to feel that the class has meaning as this will also improve

participation among these students and their view of online learning would be more positive. Meaning making has become increasingly important for pandemic pedagogy to maintain student engagement as students can easily become disengaged from online course material. But not all instructors are able to create meaning, especially with courses that are satisfying a general education requirement as it is more difficult for meaning making to occur in these courses. This is because most students in these courses are taking the course to check a box and not because it is for their major; this would be easier for meaning making as it would directly relate to their future goals.

Meaning making is a difficult task to accomplish and with the difficulties seen in transitioning lab-based courses online, it is also especially difficult during this time for STEM courses because they are typically hands-on classes (Qiang et al., 2020). Important strategies for biology instructors to promote participation in their courses are calling students by their name, use of breakout rooms, and alternative modes of participation for students such as chats and polls (Reinholz et al., 2020). Another strategy is to cut course content as this might also allow for instructors to create a less stressful environment with less work while also presenting leading questions that initiate some self-learning (Qiang et al., 2020). This is a good solution in the short term but in the coming years the content that was cut could become important for students whose courses are prerequisites for others, so instructors should still be mindful of what course content they choose to exclude.

Instructors should keep in mind that the content they do deliver should include important aspects of online learning, as discussed earlier, which are the social, cognitive, and teaching presence as these are interrelated and can support learning outcomes

(Reinholz et al., 2020). This is grounded in the social constructivist viewpoint and the social presence in online learning classrooms refers to the degree of social connection and interaction in that students can build and maintain relationships in this space (Reinholz et al., 2020). This cognitive presence is defined as the opportunities available for students to explore, reflect, and construct meaning in their own ways and instructors can support this by providing meaningful learning opportunities for students like discussion, problem solving, and individual reflection (Reinholz et al., 2020).

This would be difficult for lab-based courses to re-create the in-person learning environment and it is suggested that simulations might be useful for these courses instead (Reinholz et al., 2020). Simulations can be anything from an online laboratory program that describes an experiment process and outcome visually or an online laboratory space that students can interact with and perform labs together in. These "skill based" courses are important to prepare students for higher levels of education, whether that be the rest of their undergraduate years, or graduate school and or their future careers (Villanueva and Zimmerman, 2020). As mentioned earlier, meaning making is important for student interactions with course content but if professors cannot make these connections, then it becomes difficult to encourage student participation which also influences social interactions between students. It is clear that pedagogy during the pandemic plays a huge role in the learning outcomes for the course, as always, but during this time more of an emphasis is needed on these practices because of the added stressors.

Chapter 3: Case Studies

Pedagogy should be considered carefully when designing an online course as there are many ways to implement these learning strategies. Some techniques work better than others for specific courses so each one will be different. During the transition to emergency online learning this was difficult for professors to consider as they had to quickly adapt during the Spring 2020 semester. The following semester, Fall 2020, was also online and the break gave professors some more time to consider pedagogical practices to use in their courses. This section presents several case studies from professors who transitioned their STEM courses during the pandemic and what practices they utilized to do this. I also present a case study that I participated in transitioning the material for a laboratory section of a course during this time.

Qiang et al. 2020

The first course example is by Qiang et al. (2020) from the University of Southern Mississippi, where they transitioned a chemistry course for online learning during the Spring 2020 semester. During this course, the instructors attempted to create a less stressful environment for their students by providing a slightly lighter workload for them (Qiang et al., 2020). The homework assignments' purpose was to supplement the content missed from the cut material by attempting to initiate some self-learning in students with leading questions (Qiang et al., 2020). During the first two weeks of the course's online transition, Qiang et al. (2020) wanted to maintain undergraduate research by having students engage in research group meetings and attending scientific webinars. However,

they soon realized that these do not provide the full research experience. In an attempt to adapt further, Qiang et al. (2020) explained to their students that this unprecedented time is an important learning opportunity and that rapid, or unexpected, change can happen at any time during their careers, and they need to be able to adapt. This is an extreme teaching moment but still very relevant for those students who are in STEM careers, as there are many opportunities where things do not go as planned. Thus, the chemistry course turned to literature review, experiments, and computational tools to challenge their students during emergency online learning (Qiang et al., 2020).

A literature review was chosen because this would allow students to build up significant background knowledge on a topic that the student needs (Qiang et al., 2020). In order to do this, the question for the literature review needed to be specific to lead students in the right direction for their research while also allowing them to create their own questions (Qiang et al., 2020). The example given by Qiang et al. (2020) is "What are the main factors to consider for fabricating a polymer solar cell device with high efficiency?", which is specific enough for students to know what their goal is, while also forming their own questions about the topic to answer. Overall, the literature review was found to be effective to engage students and interest them in the topic at hand (Qiang et al., 2020).

This course also utilized experiments while students were at home through virtual experiments posted in the Journal of Visualized Experiments, that has a step-by-step protocol section for the procedure paired with a video (Qiang et al., 2020). Students enjoyed these experiments as they could watch a procedure and understand what to expect after each step (Qiang et al., 2020). The only difficulty with this is that if students

do not have the right materials at home, it could be hard for them to perform the task unless they are learning enough through just watching the video. Lastly, this course utilized computational tools like Python and MATLAB that students chose to learn based on what would be most beneficial for them in the future (Qiang et al., 2020). Learning a computer language from the ground up can be extremely difficult to do alone, however there are many resources available online to do so (Qiang et al., 2020). In the class, those who liked this activity already had an interest in learning these strategies, while other students disliked this activity because these programs have a steep learning curve that can be difficult to get over without the help of an instructor (Qiang et al., 2020). This course example utilized a more constructivist-individual approach, as students were completing these assignments by themselves and creating their own knowledge. One way that they could include more social learning would be to have groups of students learn and teach each other different computational tools for a deeper understanding of the subject. This group work could be done in or outside of class to provide students with a more constructivist-group approach to their learning.

Reynolds et al. 2020

In an Ecology course at Duke University, Reynolds et al. (2020) transitioned the course "Ecology of Human Health" to an online delivery by utilizing writing assignments to meet similar learning outcomes as their in-person course. When news spread of the coronavirus, Reynolds et al. (2020) explained that they adjusted the course to discuss zoonotic disease, age structure, metapopulations, and super spreaders. The course originally discussed the general link between human health and the environments they

lived in, so this pivot was not out scope for this class (Reynolds et al., 2020). Reynolds et al. (2020) believed that writing intensive courses are the easiest for science faculty to adopt for online learning. Writing assignments can promote conceptual learning and deepen student engagement with the subject and their peers (Reynolds et al., 2020). The flexibility and ability to be designed to prevent cheating and plagiarism are major benefits to this modality (Reynolds et al., 2020), as professors can use websites like Turnitin (https://www.turnitin.com/) that check for these. Turnitin is a useful website because it will go through submitted papers and pull out the percentage of plagiarism in each paper.

However, writing assignments still require a considerable amount of time spent grading. Reynolds et al. (2020) recommends strategies for professors to write effective writing assignments as well as strategies for managing the workload of these types of assignments. Important aspects of a good writing assignment are inherently challenging topics, which should be knowledge-transforming questions rather than a knowledge-telling question (Reynolds et al., 2020). For example, a knowledge-telling question would be a question that students could easily answer directly from what they are learning like, how do vaccines work? Whereas a knowledge-transforming question would be taking prior knowledge in addition to what they learned to come up with an answer. An example of this could be, how would someone go about creating a vaccine and what goes into this process? This second question requires a lot more information to answer and can transform student knowledge by providing them with an overall better understanding of vaccines. The difference between the two is that transformational writing is one that utilizes what students already know and what they have learned to make an informed

decision, whereas knowledge-telling writing is more of a summary of information (Reynolds et al., 2020). Writing assignments should also include detailed guidelines for students as this will explain who their audience is, the genre, and how the assignment will be assessed as all these are important to promote deeper learning in students (Reynolds et al., 2020).

Lastly, it is important that these writing assignments receive high-quality feedback not only from the professor but also through peer review (Reynolds et al., 2020). Utilizing peer review in the course also takes some of the weight of grading off the professors shoulders, as well as promoting a deeper understanding of the prompt as students also get to see how their peers interpreted the question, while giving and receiving feedback (Reynolds et al., 2020). Professors will still have to grade the assignments themselves and cannot solely rely on peer feedback. However, it is stressed by Reynolds et al. (2020) that science faculty should not strive to teach writing skills and should instead focus on the learning outcomes of the topic for grading. The learning outcomes that students should meet can be included in the rubric as this is a document meant for the breakdown of how students papers will be graded. This is important because it directly allows students to see what they are being graded on. If professors feel they lack the writing expertise, for the prompt and rubric, instructors should consult with experts in this area (Reynolds et al., 2020). These experts hold different positions at different universities but typically referred to as Writing Centers (Reynolds et al., 2020), or some variation of this. Reynolds et al. (2020) implemented a kind of objectivist-group approach to writing assignments in their ecology course and found that these assignments promote deep engagement in their students through writing, feedback, and revision.

Villanueva and Zimmerman 2020

In another upper-level chemistry course transition, Villanueva and Zimmerman (2020) collaborated remotely in order to transition their course online to have a constructivist-group approach. In order to accommodate the changing schedules and the added workload on students, Villanueva and Zimmerman (2020) held shorter synchronous classes each week. This simulated a normal week for students while also allotting time for students to spend on the work outside of class as well (Villanueva and Zimmerman, 2020). They chose to take a guided inquiry (GI) approach as they have proven to be useful in the chemical sciences and promotes concept discovery through analyzing data (Villanueva and Zimmerman, 2020). This GI approach engages students by encouraging the use of critical thinking skills, application of previous knowledge, and concept discovery through data analysis without large amounts of faculty facilitation (Villanueva and Zimmerman, 2020).

The assignment for this course asked students to use data generated from the beginning of the course, when students were in person and created synthetic systems, and literature research to conclude about the environmental impacts their synthetic modifications would have (Villanueva and Zimmerman, 2020). The students were encouraged to work with their laboratory groups to complete the assignment, but each student needed to have a copy of the calculations (Villanueva and Zimmerman, 2020). Overall students reported that they had a difficult time writing about what they "expected to see" in their systems since they had to reference what they literature said instead of finishing their experiments in class (Villanueva and Zimmerman, 2020). This course

utilized collaboration from the instructors to the students because Villanueva and Zimmerman (2020) collaborated as co-teachers to transition the course online and students were able to work together to complete the assignment. Collaboration is important for the success of online courses, as discussed previously, and this course was able to utilize that well.

Lashley and McCleery 2020

At the University of Florida (UFL) Lashley and McCleery (2020) reformatted two ecology courses, Wildlife Habitat Management and Wildlife Techniques, to an online delivery format. Before the pandemic, most ecology and evolutionary biology courses at UFL were face-to-face lectures and labs that met weekly in a lab classroom setting, outdoors, or small field trips. With COVID-19 these different lab experiences were not possible and forced the instructors of these hands-on courses to rethink how this is done. The strategy implemented by Lashley and McCleery (2020) allows for students to learn concepts related to ecology in a mostly online environment.

By utilizing a constructivist-group approach short 10-minute asynchronous videos, synchronous discussion, and short intense, in person, field experiences were used to supplement weekly labs (Lashley and McCleery, 2020). Lashley and McCleery (2020) believe that it is more important for ecology and evolution students to experience these concepts in person rather than online. They recommend that these experiences occur over a 1- to 2-week time period and have students tested for COIVD-19 and remain on site for the duration of the experience (Lashley and McCleery, 2020). This is a better, and COVID safe, option to weekly lab meetings in person in their opinion and provides

students with the hands-on experiences that they need (Lashley and McCleery, 2020). This is a solution that, if students could block out time to participate in these labs and get tested, provides a great option for students and instructors. However, this is unrealistic for a lot of schools and students due to money and time constraints with different schedules, so this option is not for everyone.

Richter et al. 2020

This next example is a collaborative effort between the authors at different universities teaching ecology courses (Richter et al., 2020). They state that they actually planned their courses to be available in an online delivery years ago, 2015-2016, which made them very prepared for this online transition (Richter et al., 2020). These courses are typically large introductory courses with 150-400 students made up of mostly second year students with some previous biology experience (Richter et al., 2020). The instructor's goal was to provide a way that was simple to implement but still maintains the original learning outcomes for the courses (Richter et al., 2020). They also wanted to provide students with an opportunity to connect with their surroundings that they normally might not have the chance to do (Richter et al., 2020).

Students in the course were encouraged to explore and collaborate with their peers around campus or other settings in nature to inspire curiosity about the environment around them to incorporate data collection and aspects of citizen science into the curriculum (Richter et al., 2020). While out in the “field” students were expected to collect data on different organisms they came across by identifying and recording the information to see if it matched up with their hypothesis of what they would find (Richter

et al., 2020). This constructivist-group approach allowed students to go through the scientific inquiry processes while also getting experience in the field (Richter et al., 2020). This seems to be a better option than the previously mentioned intensive lab course as this would allow students to social distance themselves when meeting outside of class at an agreed time. Students could also do this solo instead of a pair, if they were worried about COVID-19, and still have a rich learning experience. This might have been difficult to implement in the new school year with new students as they did not need to move close to the university but again, if implemented for single students instead of pairs this would still work.

Personal experience - ANTH 1001 GWU

When classes were stopped and forced to move online because of COVID-19 during the Spring 2020 semester, I was a part of a two-person team at George Washington University (GWU) that was planning on redesigning the current labs for the ANTH 1001 Intro to Biological Anthropology course. This team was made up of the Department Lab and Academic Programming Coordinator, Marli Richmond, from the Center for the Advanced Study of Human Paleobiology (CASHP) and myself, a master's student in the Human Paleobiology program. Previously the course had a face-to-face lecture and an in-person laboratory section once a week that utilized hands-on experiences to deepen understanding of the lecture material. When COVID-19 forced learning to move online, we pivoted what we were doing to adapting what was left of the labs for the spring 2020 semester, this allowed for the lecturer to focus on adapting the lectures and teaching assistant's (TA's) to continue to facilitate labs without the transition

of these labs becoming an extra burden on either of them. The material for the online labs were offered asynchronously and students would work on them alone, which takes on a more objectivist-individual approach rather than a constructivist-group approach.

The Spring 2020 labs were more of the "pedagogical triage" (Bidwelle et al., 2020) discussed earlier, this is because it was more important at the time that students were able to complete all course content from the last five of fourteen labs for the semester than how it was being delivered. Even with the given time constraints, we were able to transfer content from the current labs to online labs using reading and response, interactive websites, and online 3D models. Reading and response was used for most of the transfer of knowledge and interactive websites were used for a virtual "field trip" and 3D models for bones and stone tools. In the original design of the course students would take week 13 of the lab classes to go to the Smithsonian in DC and explore the Hall of Human Origins to answer questions for the lab. This was no longer possible due to the pandemic shutting down the museums and school so an online "field trip" was substituted for this lab. The lab was limited to what was available for students online which was the interactive human family tree and an interactive timeline of human evolutionary ancestors. This made the outcomes of the lab narrower as the original lab provided more opportunities for a deeper understanding of human evolution whereas this online lab gave a more general overview due to the nature of what was available.

After the spring semesters labs were completed, we then began transitioning the Summer 2020 semesters labs to online labs. The summer labs were adapted differently than the spring labs, as the summer labs covered the entire course content whereas the spring labs only covered the last five labs content. The summer course was also shorter than the typical semester and required us to condense 14 labs into 6, so the previously

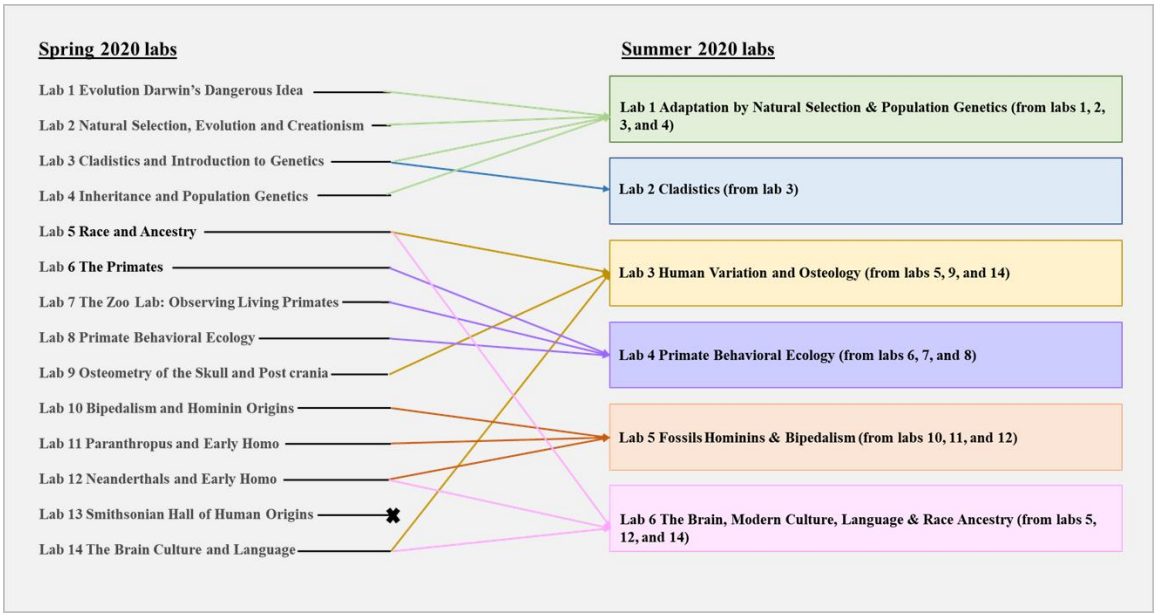

Figure 1: List of labs from the Spring 2020 and how their learning outcomes were split into the 6 Summer 2020 labs

made spring labs could not be used again. We did this by combining the labs that had similar topics and taking the most important learning outcomes for the labs and creating the content and questions from there. For example, labs 10-12 were combined as they discussed various aspects of human evolution and labs 6-8 were combined to discuss primates and their behavior. A more detailed explanation of how the labs were divided from the original lab design to the shorter summer labs is given in Figure 1. These summer labs were offered asynchronously and still utilized reading and response as well as the interactive websites for 3D models. New elements were also included in these labs

like TA videos which were used to give students context about the labs before they completed them.

More problem-based learning was also included, as opposed to only reading and responding to prompts. These new additions required students to think critically to make a decision based on the knowledge they gained from the labs. Lastly, more calculations were included in these labs than the previous semester, however this could be more due to what course content was being covered rather than an actual reflection of course delivery from one semester to the next. This is because the full summer course offers opportunities for calculations throughout the curriculum, but during the spring semester there was only one opportunity for this. In the end these labs had no social aspect except for the opportunities for TA feedback and TA office hours. In the future an aspect of social learning should be included to further students interaction and understanding of the course content. The following Fall 2020 semester I was not involved in making the labs, however, they had to also start from the beginning for these. No one was sure how long the emergency online learning would last and neither of the previous sets of labs would work for the full fall semester of online labs. However, there was an increase in quality and design of the

Problem based learning example question from Lab 6:

"The results of experimental archaeology tool-making studies present an interesting opportunity for us to consider the role of communication in human evolution. Based on your cumulative knowledge of hominin behavior (Intra and Inter-continent migration; tool making; hunting and foraging; group cooperation and care; personal adornment etc.) what inference can you make about how and when our ancestors began to formulate and use verbal communication strategies? Please use your opinion to answer this question."

labs from the spring 2020 to summer 2020 because of the time allowed for the design of course content; so, it is expected that Fall 2020 labs will also increase in quality.

Going forward, I would recommend that social aspects be included like a group project and or synchronous presentations to promote more social learning aspects in the course. This course would be difficult to do synchronously, unless the TA's were to lecture on the material students were required to read. Although this might become an extra burden on TA's, as this was not part of their job prior to the beginning of the pandemic. Incorporating a group project or student presentations would strengthen the learning experience of this course and add more social learning to the lecture portion of the course could be useful in supplementing the lab's lack of social interaction. An example of this would be breakout rooms for the lecture because the intro course is too large for a regular discussion thus, labs should also strive to incorporate more social aspects into the curriculum.

Future directions

Going forward professors should strive to learn as much as they can from this emergency online learning experience. There are useful things that can be learned from online courses that can be utilized in the in-person courses as well. Online courses create unique learning experiences and require innovation for learning outcomes to be met in this modality. It is important for future courses to continue to utilize technology in their curricula because more and more technology skills are needed for jobs after graduation. Courses should strive to utilize various learning strategies to keep students engaged and interested in what they are learning, as well as allowing them to gain important skills.

Instructors should also, if not already in place, set up communities that they can rely on for support in pedagogy, technology, and general social support. This provides professors with the support and resources they need especially during the pandemic when instructors were forced online instead choosing to do so.

This emergency online learning experience can also be used to conduct research on how effective the online delivery for higher education is. Previously, students in online education were a highly self-selected group, largely comprising “non-traditional” students. The pandemic has eliminated the self-selection bias typically seen in studies that strive to compare online learning to in person classes. This is when students get the opportunity to choose to take the online course versus the traditional in person course and they end up choosing the modality that would most benefit themselves and this bias could skew the outcome of the study if significant. However, COVID-19 has provided a unique opportunity in that everyone was forced online so this bias is not prevalent in these courses. It would make the most sense to utilize the data from the 2020 Fall and Spring run of courses as Spring 2020 was the emergency transition and is most likely not representative of the best teaching practices as well as student performance. This could be because of many different factors as this was an unprecedented and stressful time for everyone. Future studies should strive to compare in person versus online learning to determine how they are being received and if students are receiving the same, or more, skills as in person courses.

Conclusion

In the end, lab-based courses adapted well to the emergency online learning transition. By utilizing online tools many professors were able to salvage their learning outcomes and produce meaningful online courses. The constructivist-social approach, although labor intensive, was a commonly implemented pedagogy for the online STEM courses discussed. This approach provided students with rich and interesting material. It is important to keep students engaged and interested in online learning as it is very easy for them to become disconnected from the task at hand and become distracted and uninterested. Technology played an essential role during this time and it should be expected that it will continue to be an important part of course design moving forward. This is because transferable skills are essential for students to learn in higher education for their future careers. Professors should thus take these online activities discussed in this paper and utilize them in, not only their online courses but also, their in-person classes. By utilizing different pedagogical practices, it allows students to gain a skill they may need after their time in higher education. Now that it has been proven that courses can be implemented online it should be expected that this may have accelerated the wider implementation of online learning across more degrees. This is because these online courses can reach a wider audience and provide opportunities for students that they normally might not have access to. With many earning degrees during this emergency online learning time, it would be difficult to argue against utilizing online learning going forward.

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