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Teaching and Assessing College STEM Courses Online During COVID-19: Evidence-based Strategies and Recommendations

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Abstract

Since the devastating COVID-19 pandemic, most schools, colleges, and universities worldwide underwent a paradigm shift by transitioning to digital teaching and learning modalities. This phenomenon was essential to mitigate the contagion; however, the academic institutions needed to quickly come up with ways to ensure that the quality and rigor of education were maintained, especially the active and experiential learning required by undergraduate and graduate courses in science, technology, engineering, and mathematics (STEM). This paper highlights key approaches reported or proposed to effectively conduct college-level, in-person STEM courses online owing to the pandemic. These would range from synchronous versus asynchronous pedagogies to methods of teaching and assessing traditional face-to-face courses remotely, along with the application of cutting-edge technologies to uphold academic integrity. In addition, the analysis would help identify and bridge gaps among college students, faculty, and administrators in integrating instructional and evaluation tools for distance STEM education.

Keywords: Teaching and assessment strategies, college STEM courses, online learning technologies, distance education, COVID-19

Introduction

COVID-19 has been one of the most dreaded global disasters in recent times. After originating in the Wuhan province of China in late 2019, it rapidly spread to most other world nations. It was declared a pandemic by the World Health Organization (WHO) in March 2020. Among the various global sectors most affected by COVID-19 was education. As a result, most governments recommended prompt transition of in-person classes to remote online education, with efficient utilization of cutting-edge technology (Ortiz, 2020). The main purpose of this rapid transition to

online learning was to avoid contagion by maintaining social distancing, quarantine, or isolation, catering to individual health concerns of students, staff, and faculty. Teachers of traditional classes needed to undertake thorough workshops to familiarize themselves with state-of-the-art technical or electronic equipment, web/mobile applications, and other digital tools for successful teaching and assessment online, assisted by professional technical support. Technology permits easier access to the learning material; however, students in this digital age still depend on a structured learning environment and tools facilitated by an instructor to receive and process accurate information, particularly for experiential, active learning college-level courses in STEM.

Synchronous Versus Asynchronous Online Instruction

Synchronous, digital delivery of classes leverages videoconferencing and audiovisual recording via Zoom, Skype, Google Meet, Microsoft Teams, etc., with diverse options of breakout rooms, chatting, polling, reactions, and so on. Several institutions have mandated remote, synchronously scheduled office hours by faculty using Zoom, Microsoft Teams, Collaborate in Blackboard, and BigBlueButton (formerly, Conferences) in Canvas. Recorded lectures available asynchronously allow more flexibility for students at different time zones but reduce live interaction between students and faculty – a critical component of STEM courses, especially labs. Findings of recent studies about the quantity and quality of synchronous and asynchronous discussions relevant to course grades have been inconclusive; however, irrespective of the format, students have been reported to feel more connected to the online experience, express more significant levels of satisfaction, continue being motivated to engage, and are more successful in individual as well as group work (Watts, 2016).

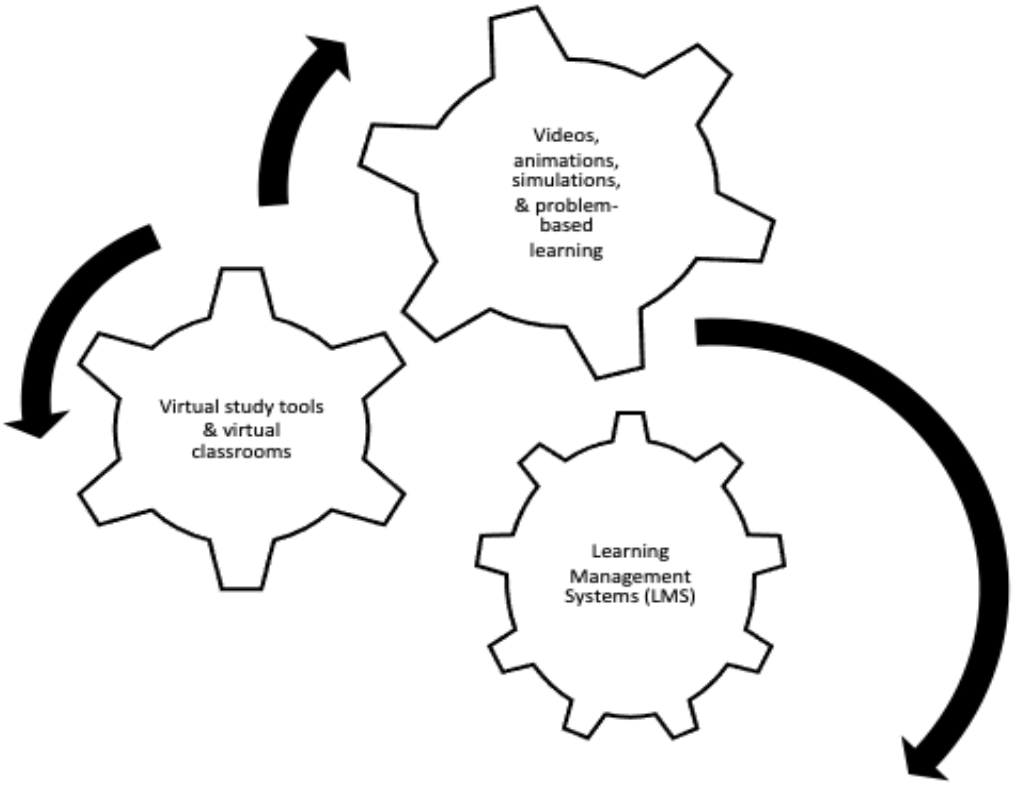
Online Teaching Methods

Learning Management Systems (LMSs), such as Canvas, Blackboard, and Moodle, are online systems used to post course content, taped class sessions, study guides, announcements, individual or group assignments, and grades in a timely and organized manner. Further, the LMS, along with discussion boards, help provide students the opportunity for constructive criticism, interactive learning, and feedback from the instructor and peers. These can be coupled with virtual study tools permitting revision, practice, and self-assessment, viz. Pearson's Mastering series or McGraw Hill's Connect, to name a few, come integrated with the course textbooks. These also provide three-dimensional illustrations, simulations, and modeling virtually, adding value to active learning in experiential courses across STEM disciplines. For example, Mastering Anatomy and Physiology contain numerous resources covering animal dissection videos with highlighted and labeled structures, stained histological images, physiological exercises, dynamic study modules, and review questions with answers to help students grasp the subject matter. Other e-learning tools include open education resources (OERs), such as (a) YouTube videos, (b) animations, and (c) online problem-based learning (PBL), which are supported by regular communication via email or even social media groups/pages, have the capacity of enhancing information-based e-pedagogy to pique students' motivation, interest, and application in the physical or life sciences, even from a distance.

Short case-based learning activities have been proposed as a possible approach to teaching online Biochemistry laboratories (Thibaut & Schroeder, 2020). Nonetheless, for a General Chemistry course during the drastic mid-semester transition in Spring 2020, the author, rather than adapting to entirely new strategies for online teaching, restructured earlier experiences with interactive chalkboards to conduct synchronous sessions and asynchronous recorded videos (Ranga, 2020).

An innovative way to foster learning and engagement for students could be by developing virtual classrooms on digital platforms like Second Life, which offers a comprehensive, highly structured, instructor-led, and easily navigable educational method promising improved student learning outcomes (De & Cavanaugh, 2020). Interestingly, an earlier report had indicated that virtual worlds and games could be leveraged to present STEM subjects to students through socially oriented, engaging activities (August et al., 2011). In this study, August et al. developed a virtual science museum and education center that enables virtual practice with fundamental engineering concepts and transforms an entertainment-based platform into a vehicle for computer science and electrical engineering content. This strategy empowers students with autonomy and offers immediate feedback, and was designed to draw diverse audiences to computer science and engineering disciplines. As figure 1 demonstrates, various teaching methods in STEM education conducted online can be combined to promote a more rewarding and engaging student experience.

Figure 1
Online Teaching Methods in STEM



Note: Combination of various digital tools to promote students' learning and engagement in college STEM education.

Online Assessment Strategies

Educational evaluation is a widely studied and discussed topic in higher education. According to Archer (2017), assessing learners in higher education can help support the students' learning process, implement accountability, and gain advancement and certification (Archer, 2017). In addition, the rapid shift to distance learning caused by the pandemic forced the integration of online assessment applications and experiences in STEM education (Díez-Gutiérrez & Gajardo Espinoza, 2021). Online assessments can demonstrate gains in student understanding and use data visualization and critical thinking comparable with face-to-face mentoring, discourse, argumentation, conceptual interactions, and training students for research. For instance, Course-based Undergraduate Research Experiences (CUREs) with bioinformatic foci have noted increases in student confidence and interest in science and a better understanding of life science concepts (Harvey et al., 2014; Makarevitch et al., 2015).

Novel strategies of assessment with established learning outcomes for a research-oriented CURE termed as Biochemistry Authentic Student Inquiry Lab (BASIL) include students' hypothesizing and testing of the role(s) of enzymes with unknown function by combining computational and wet-lab experiments (Irby et al., 2018; Kim, Haughton, et al., 2020; Kim, Muchintala, et al., 2020). However, this project also noted that as a result of the COVID-19-based shift to online instruction, students learned more about bioinformatics experiments and concepts than about their wet-lab counterparts, being unable to perform the wet lab techniques in person and having to rely solely on virtual learning to master critical laboratory-skills (Kapil, De, et al., 2021; Kapil, Gonzalez, et al., 2021; Kapil, Pathak, et al., 2021). Therefore, online assessment strategies need to be leveraged to complement or supplement in-person courses to ensure holistic and practical post-COVID-19 college education in STEM.

Digital video recordings are commonly used in higher education to assess students' learning skills (Henderson & Phillips, 2015). In addition, video assessments have been used in several life science-related programs; namely, nursing (Lewis et al., 2020), surgical education (McQueen et al., 2019), and laboratory classes (Speed et al., 2018). Another recent study demonstrated peer-video blogs as an innovative and powerful assessment approach, highlighting the usefulness of integrating peer assessments, video assessments, and social-media blogs (Luyegu & De, 2020). On the other hand, mobile phones allow distance learners to learn fun and for teachers to communicate and share relevant material (Churiyah et al., 2021). Further, socio-biologically relevant, cost-effective, yet user-friendly mobile science applications with real-world relevance have increased interest and learning among undergraduate science students (De & Nethi, 2020; Nethi & De, 2020). Additionally, mobile science apps have been proposed as a novel way of attracting teenage girls to STEM (De & Nethi, 2019; Nethi & De, 2019).

These strategies could be incorporated as powerful online assessment tools in STEM higher education. Both formative and summative assessments frequently involve students' written reports submitted via the LMS or afore-mentioned academic e-platforms on Pearson, Wiley, McGraw Hill. These assessments also include oral presentations of projects conducted by videoconferencing. The use of rubrics is essential to assess the integrity and reliability of the assignments. In addition, rubrics are helpful to grade the quality of the student's work.

Additionally, the rubric can guide students to mark the criteria of what students need to demonstrate through the assessment task (Grainger, 2021). In addition, the use of rubrics is vital to assess the integrity and reliability of the assignments. Rubrics are helpful to grade the quality

of the student's work. Additionally, the rubric can guide students to mark the criteria of what students need to demonstrate through the assessment task (Grainger, 2021). Figure 2 summarizes the different online assessment tools that can be used in STEM undergraduate education.

Online Academic Integrity Tools

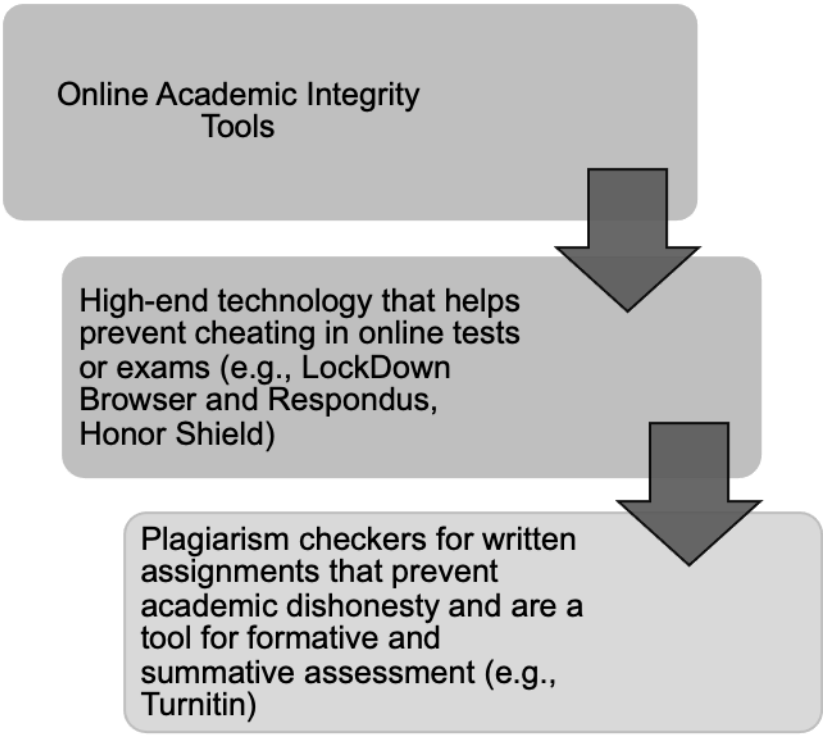
Academic integrity has become a severe problem for higher education institutions, particularly with all the technology available for the students that allow them to cheat on exams and commit plagiarism in written assignments (Goodsett, 2020). Academic integrity is based on five pillars: honesty, trust, fairness, respect, and responsibility and courage (https://www.turnitin.com/blog/what-is-the-difference-between-academic-integrity-and-plagiarism). Due to the complex nature of online exams and other types of online assessments, educators are encouraged to critically analyze digital technologies' roles when designing their assessment practices (Allan, 2020). Further, Allan remarks that the literature on online exams in higher education demonstrates a worry about how these assessments can be administered securely and most efficiently.

Modern, high-end technology integrated with an institution's LMS can deter student cheating during online exams and other online assessment formats. For example, tools such as Lockdown Browser and Respondus Monitor can be used to lock down the student's test-taking device such as laptop, computer, smartphone, or tablet. Lockdown Browser is a client application that can be installed on a computing device. It is a browser used to take exams through the LMS. In addition, if an exam requires Respondus Monitor, Lockdown Browser could access the Respondus Monitor web application before the test starts. The student would perform a webcam check and other options as determined by their professor. The instructor is able to proctor the assessments by video-recording on the LMS (https://web.respondus.com/accessibility-lockdown/). Alternately, faculty may prefer to schedule separate video-recording sessions (e.g., via Zoom, Microsoft Teams, etc.) that enable students' live, virtual proctoring during an exam. Apart from that, reasonably tightened timing of each assignment and every question in the assignment, allowing no more than one attempt per question and a single sitting to complete the entire assignment, reinforced by giving a different set and sequence of questions, can be controlled on most online testing platforms, and are often undertaken to prevent cheating by students. Another effective tool to safeguard and support test and exam integrity is *Honor Shield*. This online tool allows the instructor to upload the exam, set the exam timeframe, and safeguard the test (https://www.chegg.com/honor-shield?utm_source=IHE&utm_medium=display&utm_campaign=honorshield_IHE_standalone_email).

Plagiarism is often discussed with matters encompassing academic integrity; hence, both terms are used interchangeably sometimes. Plagiarism is an act of academic dishonesty and misconduct (https://www.turnitin.com/blog/what-is-the-difference-between-academic-integrity-and-plagiarism). Turnitin is a universally used online plagiarism detection software that covers the following areas: (a) check for similarities against a central content database, (b) show textual manipulations to bypass integrity-checks, (c) identify plagiarism in students' assignments, and (d) verify originality of students' work (https://www.turnitin.com/products/originality). The results can identify matches with existing sources and can be used for formative and summative

assessments to help students learn to avoid cheating and improve their writing scrupulously. Further, Turnitin can be integrated into the institution's LMS. In addition to Turnitin, there are other plagiarism detection checker sites. Figure 2 presents a summary of the online academic integrity tools discussed in this section.

Figure 2
Online Academic Integrity Tools



Note: Adapted from (De & Arguello, 2021).

A collaborative test of 15 web-based text-matching systems showed that while specific systems can help detect some plagiarized content, they cannot find all plagiarism and, at times, identify even non-plagiarized content as problematic. The selection of the best proctoring tools depends on a thorough comprehension of how the technology works and concerns about each method for monitoring online interactions. Adopting the best approach to ensure academic integrity should be based on the topics/material being tested and how comfortable both students and faculty are with the technology used (Foltýnek et al., 2020). According to Lancaster and Cotarlan (2021), students have been using file-sharing sites that offer "homework help" for exams and assessment in a way that is not permissible by universities (Lancaster & Cotarlan, 2021). As a result, Lancaster and Cotarlan recommend that educational institutions put interventions to minimize the risk to academic standards owing to such sites, primarily because increased online teaching and assessment could continue post-COVID-19. Interestingly, Guerrero-Dib et al. (2020) conducted a research study to investigate the relationship between academic integrity and ethical behavior in the workplace; the results revealed that students who report being involved in acts of

academic dishonesty also report being involved in dishonest actions in other contexts (Guerrero-Dib et al., 2020).

Discussion

This article provides a comprehensive review of required published methods of effective teaching and assessing college STEM courses online and proposes potential future approaches that may be considered to achieve that aim, building up on our presentation of the topic at the Florida Distance Learning Association 2021 Virtual Conference (De & Arguello, 2021). On the other hand, the new drive to shift online could be seen as a chance to evaluate our future plans for design and delivery of STEM curricula, for example, Anatomy (Evans et al., 2020). Virtual classes have little to no negative impact on student learning or test scores (White et al., 2010). Distance learning and online assessments are particularly relevant and perhaps the only alternative to traditional classroom instruction during such pandemics. Effective implementation of this would ensure public health and safety without compromising the expected learning goals, rigor, or efficacy of education.

During recent times, all three main stakeholders of college STEM education (i.e., students, faculty, and institutional administrators) have faced multifarious challenges. Moreover, these stakeholders have been efficiently employing digital tools for teaching and evaluating college STEM courses would be an essential solution to overcome the hurdles (Arguello et al., 2020; De & Arguello, 2020). Those barriers aggravated and combined with newer challenges as COVID-19 adversely impacted education and research in healthcare and STEM worldwide (Autore & De, 2021; Autore et al., 2020; Autore et al., 2021; Hallett et al., 2021; Hallett & De, 2020; Hoang & De, 2021; Hoang et al., 2021). The United States Department of Education continuously seeks better solutions for at-risk students to persist and complete higher education in STEM. Besides, it is concerned about students with limited access to college STEM academia and struggling because of financial, medical, or location barriers. Transforming the way vital STEM courses are taught in times of crisis like this could significantly contribute to meeting the growing national and global demands of skilled practitioners in the STEM workforce and professionals specializing in disease prevention and health promotion.

Conclusion and Significance

In the wake of the recent Coronavirus Infectious Disease 2019 (COVID-19) pandemic, schools, colleges, and universities had to undergo a paradigm shift by rapidly transitioning to internet-based classes. The present article encapsulates key reported methods of effectively teaching and assessing college-level courses in science, technology, engineering, and mathematics (STEM) online while suggesting other approaches. Though the COVID-19 pandemic is still ongoing, this paper lays a foundation for developing or implementing ways to harness synchronous or asynchronous methods of effective pedagogy, assessment, and anti-plagiarism in college STEM education run online. Furthermore, it helps to identify which online practices should be sustained or improved upon. Analysis of evidence-based STEM higher educational practices and recommendations reported to promote student engagement and conceptual learning in college during the pandemic underlines the significance of adaptability and flexibility of teaching and

assessment approaches in STEM, simultaneously maintaining academic rigor and integrity. Furthermore, this analysis shows the impact of fostering an integrated learning environment, combining various online and in-person tools to augment active, experiential education in STEM. The holistic review could drive standardized adoption of evidence-based or recommended strategies of e-pedagogy and assessment across academic institutions and curricula to improve post-COVID-19 content, delivery, and quality of higher education in STEM as well as other disciplines.

Competing Interest

The authors declare that there is no competing interest involved with this article.

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