Teaching physics during COVID-19 pandemic: implementation and report of teaching strategies to support student learning

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Abstract
The COVID-19 pandemic presented several challenges to both teachers and students. The rapid shift to an online learning environment demanded the development of effective teaching strategies to support student learning. This work describes teaching strategies developed to teach physics during the COVID-19 period. The strategies included posting recorded lectures and live demonstrations, providing timely resources and feedback on student graded items, enhancing communication, providing additional interactive opportunities, offering extra help sessions and extra credit opportunities to students. Other factors that played a significant role for student success were faculty empathy, flexibility, and willingness to adjust teaching strategies. All students who completed the courses (without withdrawing) earned grades of C or better. Over a total of 12 physics class sections, grade distributions in Fall 2020 were better than those of Fall 2019. Only a handful of students received incomplete grades because they were directly or indirectly affected by the COVID virus. Even though student withdrawal rates were higher during the COVID pandemic, the teaching strategies adopted helped improve student grades across all sections.

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1. Introduction

The COVID-19 pandemic posed numerous unexpected global challenges for educators, learners, and institutions. The challenges included disruptions to curriculum, closing of schools, implementation of new teaching guidance, switching to online teaching, and lacking technological support [1–5]. Online teaching requires effort, technical knowledge, and training. Unfortunately, many university teachers generally lacked the pedagogical content knowledge (PCK) of the technical and administrative aspects of online platforms [5–9].

Institutions were forced to quickly rethink developing different teaching modalities to safely conduct instruction to protect all stake-holders from the virus [1, 4, 10]. Furthermore, institutions had to adopt to local, state, or regional regulations that are feasible, practical, acceptable, and consistent with the Centers for Disease Control and Prevention (CDC) safety guidelines [10]. Together, the COVID related challenges and new teaching regulations led to a rapid switch to mass-digitization of the learning process across the curriculum [11, 12]. Instruction modalities were either conducted synchronously or asynchronously. Regardless of the instruction modality, there were specific faculty, student, and technological challenges.

1.1. Faculty specific challenges

For faculty, the rapid transition from face-to-face (f-2-f) teaching to the use of technology for online teaching led to challenges associated with (a) using new online on-line platform(s), (b) developing teaching resources, (c) successfully engaging students in a virtual learning environment and (d) adjusting to the pedagogical shift to online teaching. The lack of faculty mentoring and support for online instruction exacerbated these challenges [13, 14].

1.2. Student related challenges

For students, the challenges were associated with (a) adjusting to the new online learning environment(s), (b) ability to psychologically maintain focus in the virtual learning environment and (c) new assessment formats. The online or virtual environment is devoid of the human-human connection and does not possess the full-range of tools and resources [15–18].

1.3. Technology challenges

For laboratory and technical courses that require hands-on experience, the virtual learning environment(s) are particularly difficult to implement [3, 19]. The implementation of any virtual learning modality for such courses requires careful planning and strategies to address some of the identified faculty and student challenges. This is particularly true where student-engagement is the hallmark of instruction as is the case at Georgia Gwinnett College (GGC) located in Lawrenceville, GA. GGC, founded in 2006, is an open-access, four-year liberal arts public institution in the University System of Georgia (USG). The college is committed to an integrated educational experience, and encourages new teaching pedagogy. The college currently enrolls close to 12,000 students and is labeled as the college with the most diverse student population (33% Black/African American, 17% Hispanic, 35% White, 10% Asian, and 5% other) in the USG system. Furthermore, the college provides extensive learning support and tutoring programs and places a strong emphasis on small class sizes to advance student success. Apart from the fact that a high percentage of GGC students are first generation students and need regular guidance and motivation, of many of the students:

(a) Are not equipped with good time management skills.

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Lack professionalism, require career counseling, and need personalized mentoring.
(c) Largest average work hours in the USG system.

These characteristics even made online learning more difficult for our student population. The need to develop effective pedagogical strategies and create learning environments that support student learning had never been greater during this COVID period. In a review study of 134 articles [20], Carrillo et al pointed out that there is the need for ‘a comprehensive view of the pedagogy of online education’. To the best of our knowledge, COVID-19-related faculty and student challenges have not been carefully addressed in teaching laboratory and technical courses. Also, no studies have been reported to address the specific teaching challenges of undergraduate physics during this COVID-19 pandemic. This paper presents (a) strategies developed and implemented in teaching introductory physics in hybrid and fully online formats and (b) results of the strategies on students learning during the COVID-19 pandemic period.

2. Methods

2.1. Course design of physics courses in regular face-to-face setting

GGC does not have a physics major so the majority of students enrolling in introductory physics courses are biology, chemistry, pre-engineering, or exercise science majors who perceive taking physics as only a pre-requisite or graduation requirement [21–24]. At GGC, physics courses are intentionally structured to address some of these perceptions by including relevant hands-on projects, lab activities, and specific examples to make the subject matter relevant to students’ area of study.

Also, all laboratory class sizes at GGC (including physics) are limited to a maximum of 24 students and taught in a studio-style setting, where lectures and laboratory activities are combined in 2 weekly 2 h and 45 min sessions. The classroom set-up (figure 1) is comprised of six work stations with four students assigned to each. A typical GGC studio-style physics class is comprised of lectures, problem-solving, and laboratory (hand-on-activity) sessions. Lecture is immediately followed by a group problem-solving session, and a laboratory activity. During the problem-solving session, students at each station work on a set of problems that are developed specifically to address concepts covered in the lecture unit. The laboratory activity, following the problem-solving session, is designed to further elucidate concepts covered in the lecture period. The time distributions for the lecture, problem-solving, and laboratory activities sessions vary and depend on the topic being covered. Such integrated high impact practices (HIP) promote a learning environment for effective student engagement, team-building skills, collaboration and free-exchange of ideas.

2.2. Adjustment to online modality as a result of COVID

The integrated F2F format described above is not easily transferable into online format without compromising the HIP of the learning experience [20]. To maintain some of the HIP associated with the traditional F2F, deliberate effort was made in the course design phase to include some of the features from the Community of Inquiry (CoI) framework of ‘creating a deep and meaningful (collaborative-constructivist) learning experience through the development of three interdisciplinary elements of social, cognitive, and teaching presence’ [25, 26]. Figure 2 shows the strategies implemented to improve student’s learning.

2.3. Implementation

The strategies were implemented in both the hybrid format (HF) and fully online (FO) Principles of Physics I course. The HF comprised of 70% virtual and 30% face-to-face instruction. The FO format was completely 100% virtual (lab and lecture) conducted in a synchronous manner. Both class formats met twice a week for a duration of 2 h and 45 min and described in detail below.

2.3.1. HF: online instruction (70%). During the HF online sessions, students and instructor met synchronously using an online learning management system via Blackboard (Bb) Collaborate. A conscious effort was made on the first day of
class, to communicate the details of the delivery method by pointing out its advantages and to get students on-board (appendix available online at stacks.iop.org/PED/56/065030/mmedia). Assessment strategies adopted included (a) giving reading quizzes at the beginning of class (b) timely grading of student assignments and updating grade book weekly, and (c) requesting frequent feedback and questions. The class exams were conducted in an in-person format.

2.3.2. HF: face to face lab (30%). The F2F component was an in-person attendance to conduct lab activities in two separate groups (A and B) cycling out of class to meet CDC distancing guidelines. The hybrid F2F lab shown in figure 3, requiring students to complete (a) an out-of-lab (independent) activity related to the laboratory activity and (b) an in-lab activity to collect data and answer specific questions. During the time of group A’s in-class lab activity, group B was required to be working on out-of-lab portion of the lab and vice versa. A 5 min switch over time was built into the design to allow for class transition from Group A to Group B.

2.3.3. FO: lecture component (70%). The lecture instruction is a replica of the method used for the HF. Figure 4 shows the schematic of FO format.

2.3.4. FO: online labs component (30%). Each lab comprised of (a) review of the significance of the specific lab activity, (b) data collection process, and (c) analysis of the data to draw conclusions. Some of the methods used for the FO labs included employing online interactive simulations (PhET and Aviary Physics), live lab sessions conducted by instructor, and recorded
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Figure 2. Strategies implemented to improve student’s learning.

Figure 3. Schematics of the hybrid format (HF).
videos of experiments. The live labs were conducted by the instructor and broadcasted to students. In the video format, recorded video links were embedded into the lab worksheet that allowed students to see how the experiment, and data collection was conducted. After the data collection, students were sent to breakout groups to share their opinion with their group members, analyze results and draw conclusions. For students to have the full range of lab experiences, they were also taught how to analyze data using PASCO capstone software. Exams were also conducted using online tools via Respondus Lockdown browser and monitor (RLDB + monitor), requiring them to take exam in front of their computer webcam.

3. Results and discussions
This section presents the benefits of the implemented strategies and reports the impact on student learning.

3.1. Resources
The weekly resources (pre-lecture reading assignments, pre-recorded lectures and course documents, etc) posted in D2L provided students with timely weekly resources for reviewing at their own pace to prepare for class. Weekly quizzes were used to consistently evaluate student knowledge and understanding of material. These weekly quizzes also helped faculty to determine areas of misconception and to re-adjust teaching strategies to address student difficulties. Finally, we gauged the pace/content of online course delivery/material and adjusted the content accordingly. The content delivery adjustment was carefully done to still cover enough materials to prepare students for future courses.

3.2. Encouragement
The pre-lecture reading assignments and class attendance/participation extra credit motivated students to come prepared for each class. With these incentives, we saw increased student’s participation and engagement. We implemented weekly help sessions that were not mandatory, but designed for students who either needed extra help or had specific questions.

3.3. Engagement and collaboration
Online live demonstrations, breakout sessions, and problem-solving sessions, were used to engage students and promote collaboration. For example, during the problem-solving sessions,
students and instructor worked on problems together using the whiteboard feature of Bb collaborate. This collaborative activity allowed students to be active participants of the learning process rather than passive learners by asking questions and contributing to discussions. The breakout rooms of Bb collaborate were used to encourage student interaction with each other in virtual small group settings. Attendance was conducted at the beginning of each class and also at random periods during the class to keep students engaged throughout the virtual sessions. This action was necessary to prevent students from virtually signing into class and walking away from their computers.

3.4. Enhanced communication

Enhanced communication was used to remind students of important due dates, make new announcements, check on students who missed class, and provide updates relevant to student progress, and for feedbacks. The chat feature of Bb collaborate allowed us to keep students in the virtual lecture format to freely express themselves (difficulty, concerns, and ask questions). Student comments allowed faculty to adjust teaching methods to best serve the needs of students. Also, the chat feature of Bb collaborate was used to check on student understanding of concepts by asking them to post their answers to multiple choice conceptual questions. In cases where a response is not seen from a student during the allotted question discussion time, the instructor will send a chat message to the specific student for feedback.

3.5. Other advantages and learning impact

The HF lab structure provided the following advantages of (a) providing the same learning experience for all students in the class, (b) covering the same subject matter for all students at the same time, and (c) maintaining consistency in addressing student’s difficulty. The hands-on experience during the labs and working in groups helped students to overcome some of their individual learning challenges and promoted their understanding of physics concepts. For the FO lab sessions, the interactive simulations, instructor live labs, and videos challenged students to think intuitively using in-built simulation tools to test hypothesis, and learn through exploration and discovery.

3.6. Survey and evaluation

3.6.1. Student survey and results. At the end of the semester, a survey was conducted to understand challenges that affected learning and gauge strategies that worked for the students. This study was carried out in accordance with the principles outlined in Georgia Gwinnett College’s (GGCs) ethical guidelines and the approval identification number for the study is IRB#: 17343. No participant in this study was under the age of 16, no identifying individual data was used, and consent was obtained from all students who completed or participated in the survey. Two questions were asked of each student:

Q1. What were the challenges that affected your process of learning during COVID-19 pandemic?
Q2. What teaching strategies helped to improve your learning experience in physics?

Tables 1 and 2 summarizes the key responses of Q1 and Q2, respectively. Students indicated that the small break-out sessions helped with student-to-student engagement. Also, students responded that the instructor additional help sessions were very helpful by providing avenue to freely ask questions, receive immediate feedbacks, and be able to express ideas without feeling rushed. The help sessions addressed students’ feeling of not getting immediate feedback on worked out physics problems.

3.6.2. Student grade distribution. We examined grade distributions across 12 sections of Principles of Physics with 161 unduplicated students for only AY 2019 and 2020 fall semesters as shown in figure 5.

In both the HF and FO classes for these sections, all students who completed the course (without withdrawing), successfully passed the...
Table 1. Challenges that affected student learning process during COVID-19 pandemic.

| Challenge                           | Learning effect                                      |
|-------------------------------------|------------------------------------------------------|
| Adjustment to online format         | Making learning physics concepts difficult           |
| Remote nature of instruction        | No hands-on experience or immediate feedback (FO)    |
| Human-human interaction             | Students felt isolated and lost motivation to learn  |
| Technology challenges               | Sharing technology with siblings                     |
| Learning environment                | Distracting family members, lack of focus or interest|
| Connectivity and technical difficulties | Missed classes, quizzes, added layer of learning difficulty |
| Lack of peer-to-peer interaction    | Lack of exchange of ideas and support                |
| Feedback from distance Student-Teacher engagement | Limited questions, expressing ideas, getting extra help, and showing worked out problem solving by hand. |
| LockDown Browsers for exams         | Added stress, connectivity uncertainty, anxiety      |

Table 2. Implemented strategies that impacted their learning during COVID-19.

| Instructor implemented strategies                  | Impact on student learning                                           |
|-----------------------------------------------------|------------------------------------------------------------------------|
| Pre-lecture recordings                              | Familiarized with material before class time.                        |
| Live recorded lectures                              | Allowed replaying lectures at their own pace on concepts and problem solving. |
| Education videos/animations                         | Clarification of difficult concepts and an additional source of learning. |
| All content available on D2L                       | Helped to access and review material at own pace, and stay on track with assignments/due dates. |
| Reading quizzes                                     | Allowed to constantly review concepts                                |
| Graded feedbacks on quizzes, classwork, labs and homework | Helped them to have a better understanding of content and be prepared for exams |
| Use of special Bb collaborate features (Break-Out Sessions) | Peer-to-peer interaction and exchange of ideas                      |
| Use of Bb whiteboard feature for problem solving    | Enabled to follow steps used in solving problems in real time         |
| Effective Instructor Communication                  | Helpful on keeping class informed on important due dates, announcements, reminders, assignment directives, etc. |
| Flexibility in turning in assignment                | Lessened anxiety, stress level, provided support, motivated          |
| Weekly help session                                 | Provided a platform for extended discussion with instructor           |

course with grades of C or better. The overall grades across all the 12 sections of the Principles of Physics I in the Fall of 2020 were higher compared to grades from 2019 sections. The authors attribute these grade improvements in the Fall of 2020 compared to Fall of 2019 to the strategies developed and implemented. We used data from 2019 and 2020 of students’ background preparation such as math SAT scores and averaged GPA’s, and prior physics knowledge to ensure that no hidden confounds affected or skewed the grades from Fall 2020 compared to those of 2019. Additionally, since the strategies implemented were only in the Fall of 2020, it is reasonable to assume that the final grade differences we observe may be due to the effectiveness of the strategies. Even though, student grades improved, the withdrawal rate in Fall of 2020 was 20% compared to 9.2% in 2019. These withdrawal results are consistent with what we expected because of learning difficulties during the COVID period. Our strategies were specifically directed to improving student...
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Figure 5. Grade distribution for AY 2019 and 2020 (Fall ONLY) across all 12 sections.

4. Conclusions
The COVID-19 pandemic presented many challenges to both faculty and students in lab courses. We successfully designed and implemented teaching strategies for lab science course in a hybrid and fully online formats. The strategies included several pedagogical techniques such as conducting online live demonstrations, posting recorded lectures, providing additional tutoring/help sessions, awarding participation credits, utilizing online breakout sessions, and modified labs to enhance student learning. All students who completed the course (without withdrawing), successfully passed the course with grades of C or better. Additionally, grade distributions improved across all sections in the Fall of 2020 compared to grade distributions from Fall of 2019. Students who were unsuccessful in the courses were students who stopped coming to class or were directly or indirectly affected by the COVID virus. Furthermore, we observed that the implemented strategies increased participation, improved attendance, and promoted effective communication.

Data availability statement
All data that support the findings of this study are included within the article (and any supplementary files).

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