A New Normal: Pedagogical Implications for Physics and STEM Teaching and Learning in the Post-Pandemic Era

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Abstract

When the pandemic hit, we were all faced with making many immediate changes and adjustments in terms of how we dealt with educating our students. At that time, we quickly moved to an online format, and this certainly posed many challenges for educators and students alike. These challenges involved more than just a change in the physical landscape of how we crafted the learning experience for our students. We also had to adjust how we assessed student learning; and, oftentimes this felt like we were doing it while trying to hit a moving target. As we reflect on these teaching and learning experiences during the pandemic, it is important and timely to pause and reflect on how these experiences may impact our classrooms going forward. In fact, some of these experiences may actually have produced encouraging outcomes and if so, we need to take the time to assess and evaluate how to translate them back into the learning environment of our classrooms going forward. One may even be able to argue that the online experience had a positive impact on learners that, for one reason or another, were not comfortable interacting in an in-person classroom. For these students, we might say that the online experience gave them a front-row seat and perhaps allowed them to engage more comfortably. For other students, the exact opposite might be the case. Additionally, with online learning there were also new issues with work-life balance for both educators and students. Sometimes this actually assisted the work-life balance in terms of offering more flexibility as well as more modalities for teaching and learning. Ultimately, we need to pause and ask ourselves how we measure the successes and failures in terms of both teaching and learning that occurred during the pandemic. This paper aims to provide some examples of these successes and failures as a catalyst for moving forward in the post-pandemic higher education landscape. More importantly, this paper will bring to light the challenges experienced in the online learning environment during the pandemic. With a focus on two introductory physics courses offered at American University both during and after the pandemic, this paper will address how the challenges experienced during the pandemic have now created new teaching and learning challenges as we have returned to in-person classes. We address these challenges by sharing some of the changes and modifications made to the teaching strategies designed to help alleviate them. By addressing these modifications and through a synthesis of these teaching and learning experiences, the goal of this paper is to showcase some of the pedagogical lessons learned and to provide suggestions and ideas in terms of how to incorporate them into our classrooms going forward in the post-pandemic era.

Introduction

In the pre-pandemic era, online teaching and learning had been a distance education option for various courses for many years. However, only a relatively small number of faculty at most traditional universities had received formal distance learning training and were actually teaching in an online platform. Oftentimes these courses were in one way or another a “specialty” course offering and were often taught in disciplines outside of STEM. For those courses that had successfully integrated digital platforms, online learning provided a carefully designed learning ecosystem [1]. One of the objectives of these learning ecosystems was to increase access to learning opportunities through the incorporation of synchronous, asynchronous, flipped

classroom and independent study activities designed to simulate the active learning environment, even in remote settings [2].

Naturally, prior to the pandemic many courses in STEM were designed and taught with the expectation of face-to-face interactions. The many physics and STEM laboratory-based courses are but one obvious example. These courses tend to rely heavily on the classroom presence of both faculty and students. However, during the pandemic, as all classes and laboratories quickly shifted to remote environments, the courses offered by physics and other STEM departments quickly became vulnerable to a host of new issues. Within the higher education community many faculty and students were naturally unprepared to deal with these new issues and the challenges they created. Of course, there were a few faculty and students that had a limited amount of experience with distance learning prior to the pandemic, but the vast majority did not. As a result of the pandemic, we observed a massive and almost instantaneous shift in the higher education paradigm, with educators and learners scrambling to adjust to the online teaching and learning environment.

Among several glaringly different strategies adopted in online classrooms during the pandemic, the large increase in technology use in both teaching and learning was a significant one. As such, the use of technologies such as smartphones and laptops have become ubiquitous in the post-pandemic era of higher education where teaching and learning methods advocate for a blended approach combining the technology used in remote learning with the face-to-face interactions of in-person classes [3 – 4]. Though several researchers have defined blended learning in different ways, blended learning can be commonly described as an instructional approach that integrates traditional classroom methods with online learning [5]. The pedagogical shift in the learning environment that we observed during the pandemic era needs to be carefully evaluated so that the strategies that enhance both teaching and learning are carried forward into future in-person classroom settings.

As we move into the post-pandemic era, there are many subtle yet significant undertones within the higher education learning environment that we feel need to be addressed and assessed. Moreover, numerous new questions have seemed to rise to the surface. Broadly, some important questions include:

- How do we build upon the successes and work to alleviate the failures observed in online learning going forward?
- What are the long-term pedagogical implications for both teaching and learning?
- How do these pedagogical implications overlap with topics that were already on the table prior to the pandemic such as diversity, equity, and inclusion (DEI), building community, issues involving student time management and multitasking, and the overall assessment of student learning?

At present, we are also beginning to see some of the longer-term learning fallout as students who have adjusted to the remote learning environment in the past few years suddenly find themselves back in the in-person classroom setting. Keeping the challenges these students are facing in our minds, we pose the following questions:

- What additional challenges are these students facing that are different from those faced by students in the pre-pandemic era?
- How do we uncover and address what these challenges are in order to better shape the learning experience to leave no student behind?
- Since the pandemic, there has been a resurgence of the phrase "we are dealing with a new normal." Is this just a cliché, or is there something more to this new normal?
- Moreover, what does this "new normal" really look like for STEM education, in general, and physics education, in particular?

In the following section we build upon the growing body of literature on these issues as we investigate questions such as these. In doing so, we will focus on the experiences of both students and educators with the aspiration of bringing their perspectives together to explore and learn about ways to enhance both teaching and learning in the post-pandemic era.

Literature Overview

In this section, an overview of the literature related to teaching and learning issues and strategies both before and during the pandemic is synthesized. As a backdrop we will highlight some issues pertaining to teaching and learning that have been a concern of most educators for a long time. These include issues related to teaching and learning modalities, building community, DEI, and overall issues related to the assessment of student learning. It is important to acknowledge these issues as they simply did not go away during the pandemic when students and faculty were struggling to navigate the new online landscape. Throughout the remainder of the paper we will address emergent themes this research suggests with the aim of teasing out teaching and learning lessons (and hopefully successes) that our pandemic experiences may be pointing to.

One of the primary tenets of effective teaching is to enhance student learning. Within the realm of physics education research, it has been well documented that teaching strategies that promote active learning lead to enhanced learning outcomes (LO). More traditional teaching methods that place the instructor as the only one really active in the class have long been shown to place students in a position of passive learning [6]. More importantly, passive learning rarely leads to those enhanced learning gains we all desire. Many long-standing and seminal pieces of literature show that more traditional classrooms where students are merely "lectured to" and are expected to read the book outside of class often lead to students acquiring new material while oftentimes enhancing their misconceptions about the material being studied [7 – 11]. Designing approaches that serve to provide opportunities for the learner to actively engage with the classroom material has long been the aim of educators [12 – 14]. This knowledge has been echoed in recent times within digital learning environments. In fact, as Lohr, et al. have described, students become more cognitively engaged and retain learning material more effectively when they move from passive to active, from active to constructive, and from constructive to interactive activities in digital learning [15]. However, as constructive and interactive digital learning activities require the most amount of preparation time and effort by the instructor, passive digital learning activities are inherently chosen by educators.

An inherent part of online classrooms during the pandemic was the increased utilization of technology by both teachers and learners. With the increased use of smartphones and laptops

during the pandemic came a heightened perception on the part of many students that multitasking was, in part, the way to handle the new demands the online environment presented. While some students might feel that multitasking allows them to accomplish more in less time, research has shown that this perception is unfounded [16]. In fact, Baron has suggested that for most cognitive tasks, one cannot concentrate on two or more things at once and expect to perform and complete them as well as if each task had been accomplished separately. Baron further made the argument that "a cascade of multitasking studies continues to indicate that one of the major issues is interruption. The intrusive stimulus breaks our concentration on the initial task at hand, and performance on that task degrades." [16, p. 218]. Gazzaley and Rosen described a form of multitasking they term "media multitasking" [17]. They define media multitasking as being accomplished, not by one's brain performing two tasks at once, but instead by very quickly switching from one task to another. These researchers indicate this is something that everyone (and not just the younger generation) does. In fact, they described a recent study that followed a group of younger adults and a group of older adults that wore biometric belts embedded with eyeglass cameras for over 300 hours of free time. It was observed that the group of younger adults switched tasks on average 27-times per hour while the group of older adults switched tasks about 17-times per hour. Gazzaley and Rosen concluded that the more often we switch tasks the more harmful it is to our real-world performance.

As the pandemic ensued, a growing body of research within the STEM literature base grew rapidly, particularly at ASEE conferences. Much of this research focused on changes that were being made to the teaching and learning process as a result of the move to online learning during the pandemic. With a focus on teaching modalities during the pandemic, Fadda, Rios, and Vinay showed that faculty preferred a remote virtual synchronous modality because it was deemed the closest one could come to the in-person teaching and learning experience [18]. In addition to disruptions within the classroom environment, many faculty members experienced the stresses of trying to convert hands-on interactive laboratories into a robust online experience. Javaid, Wittenmyer, Henriquez, and Pritchett, for example looked at the grade distributions of their students [19]. They found no statistical difference in overall laboratory grades following implementation of an online laboratory experience. Regarding overall lessons learned related to teaching and learning during the pandemic, Azemi, Ma, and Goomey, found that interventions that served to make the online experience more interactive were found to be the most impactful [20].

A case study on the effects of Covid-19 on higher education by Karimi, Yazdanpour, and Lewis revealed that all academic levels, to some degree had been impacted by the pandemic [21]. This same study found, however, that female students experienced a greater mental impact. In a paper relating the pandemic effects on gender and science as a profession, McCullough found similar results [22]. She noted that the stresses and decreased productivity in the sciences have disproportionately affected female scientists. A study by Vican, Andreasen, Doty, and Cook suggested that their initial findings show that female faculty member scholarship productivity declined during the pandemic at a rate that was higher than their male counterparts [23].

In the next two sections, we present a brief discussion of some teaching and learning strategies often used both before and after the pandemic. Following that discussion, we will present a general discussion of some of the teaching and learning experiences in two introductory physics

classes from American University before and after the pandemic. We will also share a synthesis of how pedagogical modifications were made in these classes in spring 2023 to help address some of the perceived learning challenges students were facing as they returned to an in-person learning environment. It is our hope that by calling attention to these issues as we are experiencing and dealing with them in real-time, that this will help shed some light on potential future transformations of the teaching and learning paradigm.

Common Teaching and Learning Strategies Before the Pandemic

In the pre-pandemic era, courses offered in in-person classroom settings mostly incorporated lecture-based teaching. Certainly many of us continue to strive for more interactive-based teaching and learning approaches. In fact, many of us have been successful in using a number of approaches to increase learner activity during in-person classes. For example, the use of clickers via various polling systems have increased in popularity in the past couple of decades. Some of us have also utilized techniques such as just-in-time teaching, flipped classroom approaches, and team-based problem solving in our classes. However, traditional lecture-based teaching remains a predominantly non-interactive method of teaching, and does not yield substantial learning benefits and many teachers opted for expository and evaluative forms of interaction with students rather than creating opportunities for students to actively express their viewpoints [24]. Undoubtedly, several physics courses as well as other STEM courses involve a laboratory component. It is easy to think that the lab-based experiences provided to students are perhaps enough to address our concern for interactive and activity-based learning. Once the pandemic hit, a concern that emerged was that we were being forced through the online platform to revert to less active learning approaches in our classes.

Common Teaching and Learning Strategies During the Pandemic

During the pandemic, educators were in that under-recognized group who had to work on meeting students' needs while still maintaining the quality of education, which was further complicated by the evolving nature of the regulations posed by academic institutions during the pandemic. Educators had to quickly transition into a remote learning environment, create lecture plans that would utilize the technology at hand, while still trying to grasp the understanding of the platforms in which they were expected to teach. As a result, synchronous classes often had issues in the form of disruption, technological challenges. Many instructors chose to opt for asynchronous classes as it provided them with more control of the environment. However, asynchronous classes also meant the least amount of engagement with students, since instructors did not have enough time to prepare active learning activities that should usually be accompanied with asynchronous learning.

In immediate terms, instructors struggled with the need of ensuring a smooth continuation of content delivery and timely completion of course requirements for students to achieve degree objectives. However, the longer-term impact of the pandemic on teaching practices was the utilization of technology in a way that ensured engagement and not distraction from achieving the learning objectives during class. The use of "Zoom" classrooms became prevalent during the pandemic and they perhaps encouraged students to be more expressive in the chatrooms. On one hand, we have seen that in the "Zoom" classroom, all students had the chance to "sit in the front row" and engage in a level that is comfortable for them. As such, we saw an up-rise of students

using the chat rooms, even those students who would remain quiet in an in-person classroom. However, at the same time, it was easier for students to just switch off their camera and completely disengage from the classroom. Moving forward, one of the challenges will be to preserve the essence of those increased chatroom discussions and ensure that they are translated to the in-person classroom. We also saw use of apps such as Discord in engaging students in academic settings, which were, up until the pandemic, considered mostly for video gaming purposes.

To further highlight some major changes in the higher education paradigm during the pandemic, in lecture-based classes, students expressed the ability to re-watch lectures, attend classes on time and see and hear instructors better from the comfort of their home as part of advantages of online classrooms [25]. On the other hand, it was especially difficult for first year college students to make that transition from high school if their learning experiences were online, as that limited the level of interactions and collaborations they could avail. Also, in situations where opportunities for collaborative work or grade incentives were not provided, students lacked the self-motivation to keep up with the demands of the coursework. Having a structure in asynchronous classes by scheduling students to attend classes and submit assignments at regular intervals is essential towards overall student success [26]. Moreover, for online learning/blended learning to be successful, it has to be kept in mind that not all students have access to the technology/devices used in classrooms [27].

The pandemic also exacerbated learning inequity among students as many students were now faced with juggling their time between study and other roles they had to fulfill in terms of part-time jobs, care-giving etc. As a result, many instructors faced issues with inattentive students. Among issues that instructors dealt with, the primary ones that they highlighted were: struggling with visual attendance and engagement related issues, and lack of virtual class etiquette [28]. Several instructors also struggled to find the balance between showing compassion in this ever-evolving situation, while still ensuring that students met the course requirements.

As a back-drop to our discussion, in the following section we showcase the modifications to the teaching and learning landscape in two introductory courses at American University in spring 2023. While we all have our own personal pandemic-related teaching and learning experiences, we feel it is very important to pause to address how meeting the course learning outcomes can be achieved in the post-pandemic landscape. Examples of the modifications made to ensure achievement of the learning outcomes will be provided. In addition, issues related to assessment of student learning will also be shared. As we share the modifications made in these two courses, we aim to address two questions from the introduction: *What additional challenges are these students facing that are different from those faced by students in the pre-pandemic era? How do we uncover and address what these challenges are in order to better shape the learning experience to leave no student behind?*

Post-Pandemic Modifications to Teaching and Learning in Introductory Physics

In this section we focus on modifications to the teaching and learning experience made in two introductory physics classes offered at American University in spring 2023. We chose these classes as they were also offered during the pandemic. As a result, the modifications made were

informed by pre-pandemic experiences. The two physics courses comprise a part of the university's general education core of courses. The first class was a 100-level course entitled Physics for the Modern World. Physics for the Modern World is a classified as a Habit of Mind course in the Natural Scientific Inquiry portion of the general education core of courses. This course is a first-level algebra-based physics course with a laboratory component. The second course was a 200-level algebra-based course entitled Light, Sound, Action. This course is also part of the university's general education core of courses and is classified as a Quantitative Literacy II (Q2) course. The only requirement to take both of these course is that students must have first taken a Quantitative Literacy I (Q1) course. It is quite common for students in these courses to have taken a fairly low-level algebra course to meet the Q1 requirement.

Both courses consist of non-majors representing a wide range of majors on campus and the students range from freshmen to seniors. Because of the diversity in both courses in terms of year in school, some current students were in high school when the pandemic hit and courses went online. A few were seniors in high school when courses went online and continued their education online during their freshmen year. The remaining students were in college at the time courses went online.

A general overview of each of these courses is provided in the following subsections. This overview includes a presentation of the learning outcomes for each course along with strategies developed to achieve the learning outcomes. In the final subsection, we describe the sometimes subtle, yet very intentional changes made to the teaching and learning landscape within these courses post-pandemic with the aim of continuing to achieve the learning outcomes for each course. We also share experiences and observations regarding the overall assessment of student learning.

Physics for the Modern World

Physics for the Modern World is a more traditional lab-lecture type of course where students attend two 75-minute classes and one 2.5-hour laboratory session each week. The topics covered in Physics for the Modern World focus on basic mechanics. This includes such things as systems of measurement, motion concepts, Newton's Laws, momentum, energy, rotational motion and fluid mechanics. These topics are typical of many first-semester courses whether they are algebra-, trigonometry-, or calculus-based.

Many of the laboratory activities the students perform correspond to the broad topics covered in the course. During most of the activities emphasis is placed on building students' skills in working with Excel spreadsheets. This has been very popular with the students as they know these skills are important, yet they haven't had the opportunity for any formal spreadsheet instruction prior to taking Physics for the Modern World.

The learning outcomes for all Habits of Mind courses within the Natural-Scientific Inquiry portion of the general education core were established by the university's general education committee in tandem with input from faculty. The learning outcomes are presented in Table 1 and are consistent across all courses within this area of general education core.

Table 1. Natural-Scientific Inquiry Learning Outcomes

LO	In this course, you will cultivate the following Habits of Mind:
1	Describe, evaluate, and communicate experimental results using appropriate technical, qualitative, and quantitative skills.
2	Analyze and interpret data or theories about natural phenomena, using pertinent scientific terminology, principles, and theories.
3	Synthesize theory, observation, and experimentation to understand the natural world through laboratory simulation, or field experience.
4	Assess science-related content in popular discourse, daily life, or scholarly research.

To achieve the learning outcomes in Physics for the Modern World, students are exposed to a range of activities including formal homework assignments, short quizzes, in-class writing activities, weekly laboratories, a final exam, and a various in-class community building opportunities. These activities are synthesized in Figure 2 as they relate to each LO.

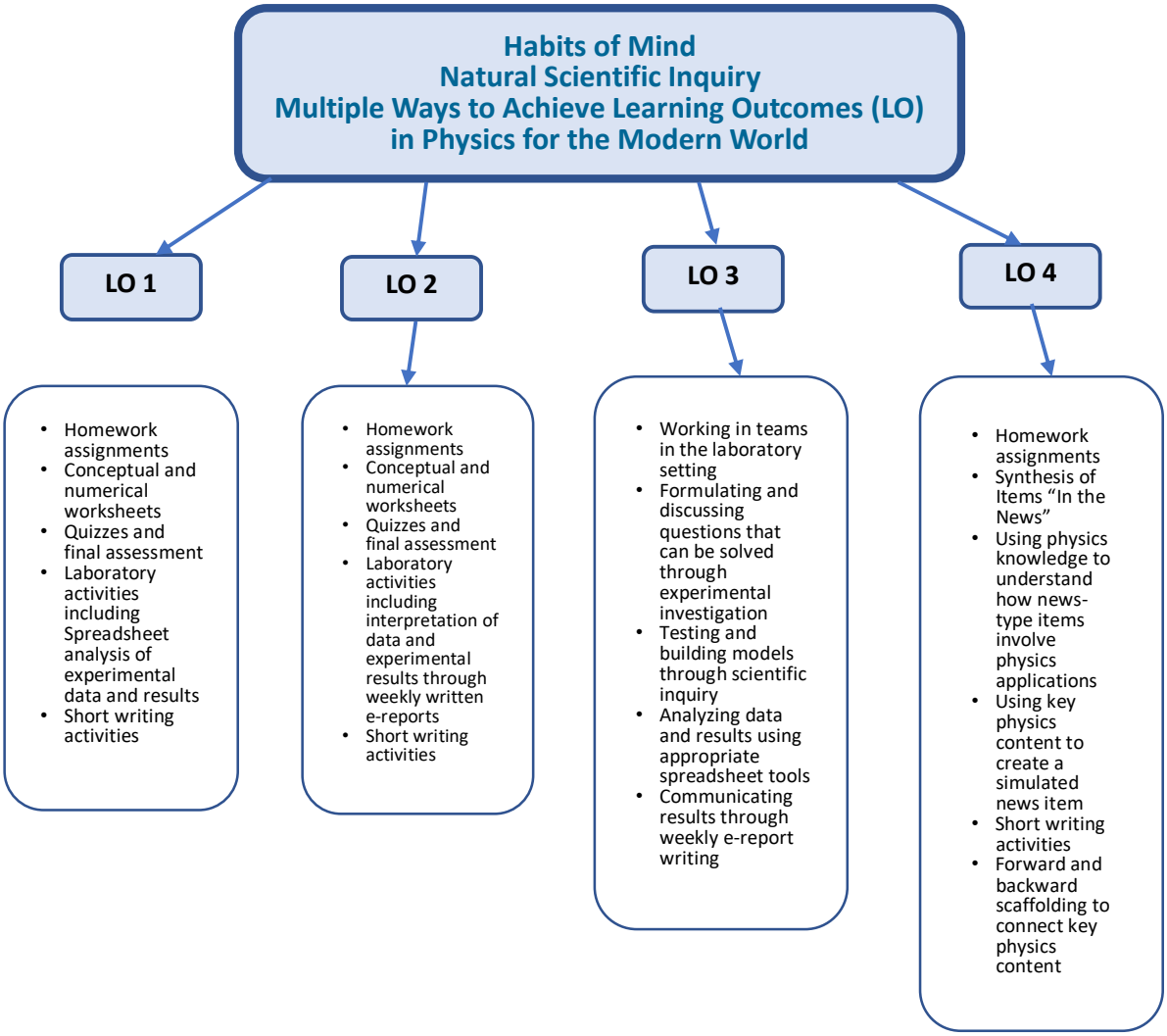

Figure 1.
Opportunities and Experiences Designed to Support Habits of Mind Learning Outcomes

Table 2 shows the weighting of each activity in terms of the students' course grade. One aim in the design of these activities is to allow students multiple ways to demonstrate their learning in the course. In addition, using a variety of activities also allows several ways to achieve the LO for the course.

Table 2. Determination of Final Grade in Physics for the Modern World

Activity	Percent of Final Grade
Homework	21%
Quizzes	21%
Writing Activities	15%
Laboratory	18%
Community Building	10%
Final Exam	15%

In the next subsection we present the learning outcomes and grade distribution for the less-traditional Light, Sound, Action course. In addition, a discussion of some of the unique features of the course is also shared.

Light, Sound, Action

Light, Sound, Action is less traditional in its design and is taught in a modified workshop format as students explore topics related to sound and waves, electricity and magnetism, and light, color and optics. Each week students attend one 75-minute class period where material is presented in a fairly traditional lecture format. However, students are often tasked to work on small problems individually or with a partner. In addition, students attend one 150-minute workshop style class.

The learning outcomes for all Q2 courses within the general education core were established by the university's general education committee in tandem with input from faculty. The learning outcomes are presented in Table 3 and are consistent across all courses within this area of general education core.

Table 3. Quantitative Literacy II Learning Outcomes

	In this course, you will develop the following skills and knowledge:
1	Translate real-world questions or intellectual inquiries into quantitative frameworks.
2	Select and apply appropriate quantitative methods or reasoning.
3	Draw appropriate insights from the application of a quantitative framework.
4	Explain quantitative reasoning and insights using appropriate forms of representation so that others could replicate the findings.

To achieve the learning outcomes in Light, Sound, Action students are exposed to a range of different classroom and laboratory activities. These activities include formal homework assignments, a number of short quizzes, several in-class writing activities, a laboratory activity each week, a final exam and a number of in-class community building opportunities. These activities are synthesized in Figure 2 as they relate to each LO.

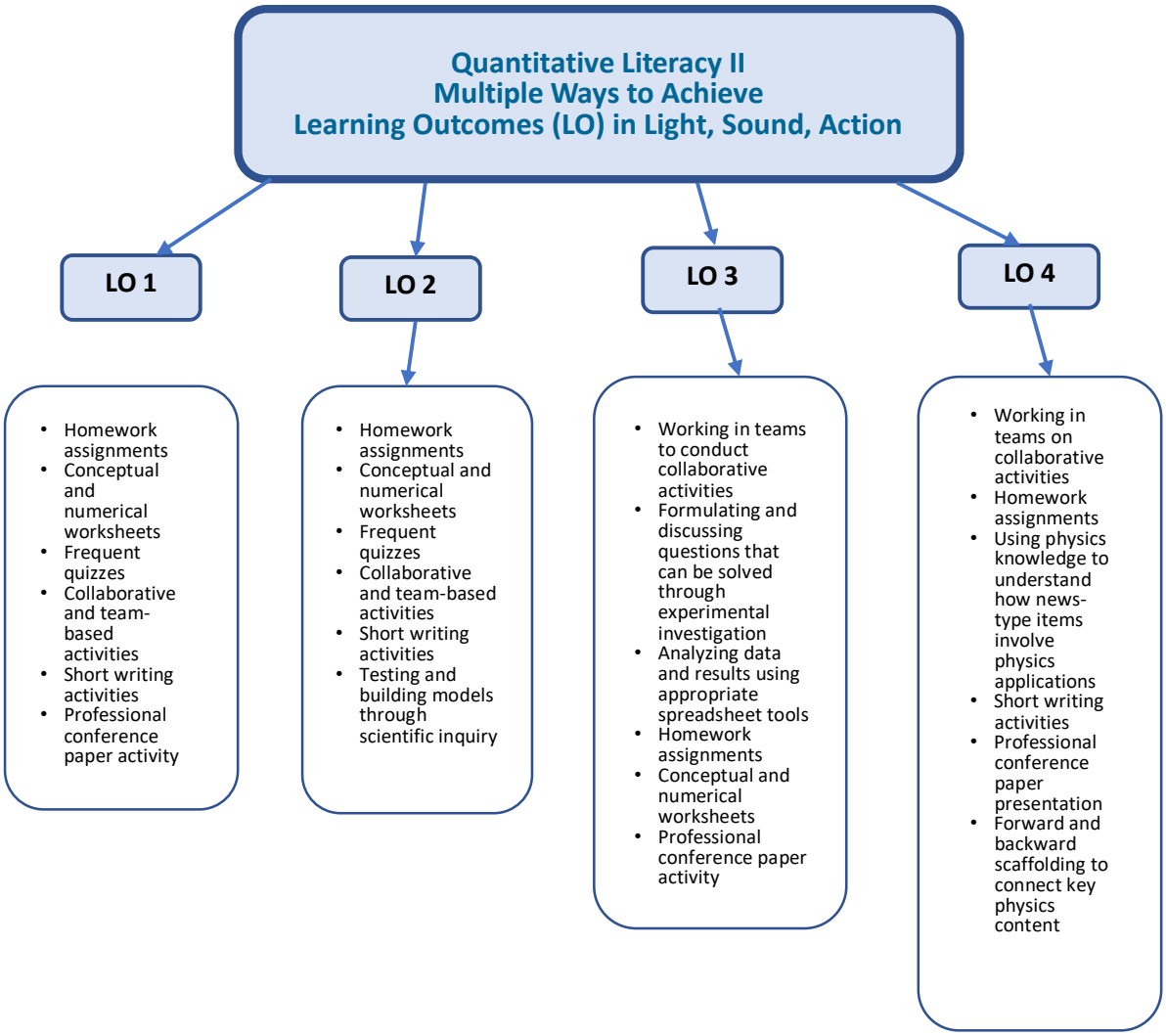

Figure 2.
Opportunities and Experiences Designed to Support
Quantitative Literacy II Learning Outcomes

During the workshop sessions students have a number of opportunities to actively engage with the course content through collaborative, team-based activities. These collaborative activities are often referred to as "collabs." To facilitate building community, new teams are formed for each activity conducted. As new teams are created, students are often given an opportunity to win a small physics prize, which they appreciate. Some of the collaborative activities students perform involve such topics as standing waves on strings, determination of the speed of sound, electrostatics, electric circuit design, motor building, and a variety of activities related to light and color.

In lieu of a final exam, students experience all aspects of writing a professional conference paper. This includes submission of an abstract, a first draft for instructor review, a second draft for peer review, and a final camera-ready paper. On the last day of class, students present their papers at an in-class conference. Developed by one of the authors, this course has become an

anchor for students pursuing an applied physics minor. Because the course has no prerequisites other than a Q1 math prerequisite, for most of the students, this course serves as their first ever physics course. This is a bit unusual as most second-level physics courses require the first-level course as a pre-requisite. There are times when covering certain material where the instructor needs to provide a mini lesson on a topic from the first-level course. For example, when talking about sound waves, the topics of energy and power are quite important. So a mini discussion on energy taken from the first-level material is often presented. Table 4 shows the weighting of each of the activities in terms of the students' overall course grade.

Table 4. Determination of Final Grade in Light, Sound Action

Activity	Percent of Final Grade
Homework	22%
Quizzes	24%
Collaborative Activities	10%
Conference Paper	20%
Conference Paper Peer Review	6%
Conference Presentation	10%
Community Building	8%

In both courses, prior to the pandemic homework assignments were submitted in paper format. The in-class writing assignments were done on paper as well. These activities were then scored by hand by the instructor. Exams and quizzes were taken during class and completed with pencil and paper. During the pandemic all of the assessments needed to transition to an online format, and through that experience a number of lessons were learned. Some of the modifications to the teaching and learning experience in these introductory physics classes post-pandemic come from lessons learned during the pandemic and are synthesized in the following subsection.

A Syntheses of the Post-Pandemic Modifications in Introductory Physics

Most of us that taught online during the pandemic experienced a wide-range of challenges that led to real concerns about the quality of the content we were presenting. Many questions naturally arose as to how and if the online delivery platforms were possibly impeding student learning. These challenges, questions, and concerns were exacerbated in courses that had laboratory or activity-based components. This was certainly true in both Physics for the Modern World as well as Light, Sound, Action. And of course, questions related to the assessment of student learning using an online platform quickly emerged as well. Returning to the in-person classroom environment post-pandemic has also caused us to ask some new questions about how we deliver course content and assess student learning as we strive to achieve the learning outcomes for our courses. The difference is that we now have some lived experiences to draw on now as we strive to make use of what we learned teaching during the pandemic.

In both Physics for the Modern World and Light, Sound, Action, some modifications to the course delivery and assessment methodologies have been made post-pandemic. A description of some of these modifications is presented in the discussion that follows. Important to note is the

fact that the learning outcomes for these courses cannot be changed as they are set by the university's general education committee. However, how material is presented and assessed to continue to meet the learning outcomes has recently been changed.

Post-pandemic the author at American University continues to use Zoom to record all the lectures. Students continue to express how valuable it is to be able to go back and re-watch a problem being solved or review a discussion topic. Doing so also provides additional resources for students who occasionally miss a class due to family obligation or illness.

One example of a change in delivery of the course material has been implemented in both introductory physics courses is the use of video demonstrations in class. During the pandemic the author at American University made video recordings of every demonstration she normally uses in class. These video recordings have now become an integral part of the in-person classes. Students are still shown the actual demonstration during class away from the computer screen. However, in tandem with the live video, the video recording of the demonstration is also shown to them. Because the lecture is being recorded, students can go back and watch the demonstrations and associated discussions as many times as they like. For some students, this seems to be invaluable.

As is well-known, mathematics is the language of physics regardless of the mathematics level of the course. One observation the author at American University has made is that for some students, their math skills seem to have waned during the pandemic. In fact, many students have informally suggested that taking a math course during the pandemic was especially challenging for them. Because students need to complete their Q1 math requirement prior to taking both introductory courses, it is likely they did so during the pandemic. Perhaps this is one reason for the perceived decline in math skills of the students in these course. To deal with this issue the instructor has found that it is necessary to take class time to teach students some remedial math skills that they should have obtained when taking their Q1 requirement. While this was sometimes the case prior to the pandemic, the need to explain remedial math skills to students has definitely increased since the return to in-person classes.

Perhaps one of the more significant modifications to the in-person physics classes post-pandemic is the continuation of the use of online assessments in both physics classes. While classes are occurring in-person now, students are still submitting their homework and laboratory activities online in Physics for the Modern World. In Light, Sound, Action students are submitting their homework and collaborative activities online. Based on the experiences in the physics classes at American University, there have been several advantages that have emerged with online assessment. These advantages were centered around the ease with which more robust feedback could be provided to the students. There is also a significant time-saving component in terms of how long it takes to assess and score the students' work.

Quizzes are also being administered online in both physics courses since the pandemic. Prior to the pandemic these were done on paper during class. Students now take the quizzes outside of class during a preset time window. This has been very popular with the students and the instructor has noticed no negative impact on student performance. There has also been no perceived increase in plagiarism with the online assessments.

An additional advantage to online assessment is it is much easier to support students who have special accommodations regarding their learning needs. For example, some students are given extended time when taking assessments. Prior to the pandemic this meant students had to make an appointment to take a quiz or exam with student services. This often meant that a student would take the quiz or exam in another location to receive the extended time and hence they would not be in attendance when the quiz or exam was given in class. In some ways, this calls unnecessary attention to those students, especially in smaller classes as other students likely know the reason why some classmates are not there. And having special learning needs that require special accommodations should be kept personal and confidential and is something that online assessments do very nicely. It is very easy to set the time according to a students' individual needs using the Canvas online learning platform.

A number of short writing assignments are also done in Physics for the Modern World. Prior to the pandemic these were done on paper during class. Students now complete their writing assignments online through the course learning platform during class and this is proving to be very effective. Oftentimes these short writing assignments are given at the start of a new topic of study to try and tease out students' preconceptions. Students do not lose points for incorrect use of physics on these short writing activities. Instead, they are used to stimulate course discussion and help students engage with the topic right from the start.

It has thus far been the experience at American University, that using the online Canvas platform for homework assignments, lab activities, writing assignments etc. has an added benefit for the instructor in that it has substantially cut down on the time the instructor spends grading, without compromising grading quality. For many assignments and activities, grading time has been cut by a third or even a half what it was prior to the pandemic. Less time spent grading also translates into more time spent coming up with new classroom lessons and activities.

In the section that follows we pull together some of what we learned from the teaching and learning experiences in the introductory physics courses at American University. We also offer some recommendations and share some of our own personal experiences and insights in terms of the lessons we learned during the pandemic and what those lessons mean for teaching and learning going forward. These recommendations also tie in to three of the questions posed in the introduction: *How do we build upon the successes and work to alleviate the failures observed in online learning going forward? What are the long-term pedagogical implications for both teaching and learning? How do these pedagogical implications overlap with topics that were already on the table prior to the pandemic such as diversity, equity, and inclusion (DEI), building community, issues involving student time management and multitasking, and the overall assessment of student learning.*

The Return to Teaching and Learning Post-Pandemic

As we transition into the post-pandemic era, and students return to their brick-and-mortar classrooms, one of the most important questions that the higher education community is faced with is how to reimagine learning environment in a way that blends the utilization of technology and engagement that we saw in remote learning with the in-person classrooms. The return to face-to-face interaction and perhaps more collaborative environments now give us a little pause

as we aim to blend our online experiences to improve future teaching and learning experiences. While blended learning may seem like the "holy grail" in this new era in higher education, it requires careful planning and making modifications to the traditional classroom practices that we were used to in the pre-pandemic era.

One of the key changes that we suggest that instructors should consider in their teaching strategies is the utilization of online tools in in-classroom settings. For instance, use of Zoom polling and other apps in classrooms instead of clickers not only reduces the chances of germ transmission, but there are also many more options to create questions and engage a class when using different synchronous polling software like Poll Everywhere. Additionally, this can create added scope and depth for in-person active learning activities by blending them with the embedded component of engagement through the utilization of online platforms. Also, instead of using traditional assignments that students would turn in class, use of jamboards and discussion board posts in the learning platforms may ensure continuation of the collaborative environment as well as enhancing student engagement, even outside of the brick-and-mortar classroom.

Students continue to remind us that they appreciated the fact that some of the courses they took during the pandemic were recorded. This allowed them time to look back and review the course content and to try and clarify points that were not clear during the lecture. Hence, continuing to record classes conducted in an in-person setting could be another way of ensuring that students have access to the content even if they miss a class. As we have all discovered, we still have students that miss classes for traditional illnesses like the cold or the flu. But we are also seeing students still getting Covid and this often puts them out of class for a week or more. Provisions for students to attend class via Zoom while they are ill and/or allowing them to view the class recordings when they are feeling better ensures that no student gets left behind. Doing so also speaks well to providing a more equitable and inclusive classroom going forward.

To provide an example of Zoom use in the return to in-person classes, the author at American University has noticed, both through direct observation of students in the classroom and through informal discussions with students outside of the classroom, that students are still struggling with issues related to lack of motivation and focus as well as time management. This lack of focus may also be connected to an increase in "media multitasking" that the pandemic experience may have inadvertently caused [17]. Despite evidence to the contrary, during the pandemic, multitasking became ubiquitous for students during remote learning, as they now had less pressure of maintaining a classroom etiquette and also were at times juggling with several responsibilities.

Since the return to in-person classes, the author at American University has continued to use the Zoom platform in all of her in-person classes. In addition to reducing barriers to time management on students' end, the Zoom platform allows for contactless polling and provides an easy mechanism to record lectures. The lectures can then be posted on the course's Canvas site, which is the learning platform used at this university. Informal feedback from the students suggests that they appreciate knowing that they have the opportunity to go back and review the lecture material. This has certainly been a positive lesson learned as a result of our online teaching experiences during the pandemic.

During the pandemic many of us experienced challenges as a result of issues we had with technology. Hence, we feel it is especially important that students' access to technology should be carefully evaluated before instructors adopt a blended approach in classrooms. Although most institutions offered some form of training to provide faculty and staff with tools to reduce barriers into the transition to the online environment during the pandemic, almost little to no consideration was given to consider the training and/or preparation our students needed to make the leap to learning in a completely remote environment. Some institutions offered some technology-related resources during the pandemic, but very little focused on actual training. In addition, the author at American University found that students who had technology issues often found it challenging to access these resources. For example, for students taking classes outside of the U.S., many students had to log into Zoom using a VPN connection. This caused some students to miss class and/or have very poor online connections. As we continue to make the transition back to in-person learning, care must be taken to ensure that students are fully equipped to utilize the blended learning environment. To reduce barriers in accessibility, devices and technology chosen for use in learning in a blended teaching environment should be carefully selected to ensure all students have access to the technology. Also, training, such as workshops could be conducted prior to the beginning of the start of classes to ensure students are familiar with the technologies and platforms to be adopted and utilized within the classrooms.

During the pandemic, several changes in assessment and lenient grading policies were incorporated to accommodate for the change in education setting and students' personal situations [29]. In terms of grading, many universities opted for qualitative scales (such as pass/fail system) during the pandemic. In fact, in spring 2020 when the pandemic first hit, many universities provided students with a pass/fail option a bit later in the term than they normally would have. While this expanded pass/fail option was not in place for long, we need to think about the impact it had in terms of exacerbating issues of motivation and lack of focus that students believed were issues for them during the pandemic. As we continue to move into the post-pandemic era, we assume that a return to more quantitative grading will become the predominant mode of assessing student progress again. We further assume that universities have returned to the use of their traditional rules in terms of restricting the pass/fail options for students. As we migrate back to the brick-and-mortar classroom, evaluating students' performance in terms of their coursework would be another challenge that the instructors face. Perhaps the pandemic has helped us to expand our repertoire of assessment techniques. Our suggestion is to incorporate not only summative, but also more formative assessments into the course content, so as to reduce issues related to grading leniency, but at the same time also provide students with a chance to learn without worrying about earning a high grade.

In the following section we focus on setting the stage for turning the lessons we have learned during pandemic into action items for the future. Using the experiences of the students in the two introductory physics classes focused on in this paper, we also provide suggestions related to the last two questions posed in the introduction: *Since the pandemic, there has been a resurgence of the phrase "we are dealing with a new normal." Is this just a cliché, or is there something more to this new normal? Moreover, what does this "new normal" really look like for STEM education, in general, and physics education, in particular?*

Setting the Stage for the Future: Putting What We Learned to Good Use in Terms of a Transformation of Teaching and Learning

We begin setting the stage for the "new normal" with a focus on building community. Building community is something that closely ties in with DEI. Providing a classroom where all learners feel welcome and valued is essential to providing the most conducive learning experience possible. As we learned through our experiences working with students pre- and post-pandemic, the lack of a sense of community can be perceived as one of the negatives of their online learning experiences during the pandemic. Conversely, we should note that for some of the introverted students, the online platform may actually have been beneficial in the sense that it gave them a front row seat and allowed them to feel less anxious about contributing to class discussions, etc. But for many students and faculty, the online experience posed many challenges in terms of building community. Many of us who taught during the pandemic know all too well the issues related to encouraging students to turn their cameras on during online classes. Going to class became like looking at a graveyard of tiny little black rectangles on our computer screens. It was very challenging to try and build community while not being able to look into the eyes of our students. In fact, this is why many of us became teachers in the first place—to be able to look into the eyes of our students as well share with them some interesting aspect of our course topics—only to see that all-important lightbulb go off through their eyes and facial expressions. Not being able to have this experience was incredibly challenging as an instructor.

Many of us did our best to provide fun activities in our online classes during the pandemic, such as using Kahoot! Learning Games [30]. These online games did not take a lot of time but may have served to increase engagement in our online classes during the pandemic. At American University, one author made use of picture and recipe sharing as a way to begin each class session. In fact, this was something she had started prior to the pandemic and it became a daily way to help motivate the students while simultaneously building community. Students were also given three community building (CB) points for simply attending class. Unlike participation points, students earned CB points for simply attending class, making it a much more equitable way to help students feel included in the classroom. Students could earn two extra CB points for sharing a picture or recipe. In fact, recipe sharing became quite popular (perhaps because students had more time during the pandemic to engage in activities like cooking) that a module was even set up to share them on the course's Canvas site. This author is still utilizing these community building strategies in her in-person classes post-pandemic.

Our recommendation is that the need to focus on community building strategies remains high in the post-pandemic learning environment and that simple strategies like picture or recipe sharing can go a long way in that regard. These may also help improve the connections between faculty and students, foster a sense of belonging and perhaps even lead to increased use of office hours.

One concern we have is how students made use of office hours both pre- and post-pandemic. As faculty, we know how important it is for students to take advantage of office hours. It is often a struggle with in-person classes to get students to come to office hours. Other than personal experiences, it is not clear how many students took advantage of online office hours during the pandemic. But interestingly, for the author at American University, many students in the past two semesters continue to request for online office hours during Zoom. So many students have

asked for this that she is now offering office hours both in-person and on Zoom and sometimes both. In addition, she has noticed an uptick in spring 2023 of students making use of her in-person office hours. Perhaps our experiences using Zoom have provided us with a new tool going forward for assisting our students efficiently and possibly just as effectively, if not more so, outside of class.

Not having to commute during the pandemic may have had positive implications for some students. We think that many of the faculty felt this way as well and as we move into the post-pandemic era more of us are settling into a hybrid approach and working from home on days when we are not physically in the classroom. The added benefit is that both students and faculty get more done. And, in some cases a hybrid approach is actually more equitable for both the faculty and student. We feel that the continuation of some classes being continued to be offered online provides additional flexibility for students to have more options when selecting future classes. The option to take some classes remotely may perhaps provide a more equitable and inclusive option for some learners.

Summary

The broad aim of this paper was to take a look at the strategies adopted during online teaching-learning during the pandemic and to understand how that would shape the higher education landscape in physics and STEM going forward. To achieve this, we highlighted some major challenges and benefits observed in online classrooms during the pandemic and contrasted those with the typical strategies that were in place prior to the pandemic. Our goal was to alleviate the issues while preserving the advantages of online learning when moving forward into the brick-and-mortar classrooms post-pandemic. In addition, we aimed to provide a lens to the intersection of pedagogical implications moving forward with DEI, community building, learning assessment and issues involving students' engagement and time management.

We also provided a synthesis of experiences with the online learning environment during the pandemic. In particular, using the two introductory physics classes focused on in this paper as a back-drop, we also discussed some of the pedagogical lessons learned during the pandemic. These lessons helped inform our recommendations on strategies that might be utilized to adopt a blended teaching and learning approach to help preserve what worked in the online classrooms with the more traditional approaches of in-person classrooms. Our suggestions include:

- Focusing on building community through classroom and after class activities and adopting various online tools to help with the tasks.
- Continuing to offer hybrid class and office hour options as a way to provide a more equitable and inclusive option to learners.
- Choosing technology and platforms used in class more prudently and offering training to students to familiarize them with the platform as a way to encourage students' success.
- Considering the modification of assessment and grading policies to include both summative and formative assessments.

It is our hope that the insights and suggestions we have shared will provide us a clearer window into how teaching and learning might be enhanced in the post-pandemic higher education landscape of the future. By listening to the real-life experiences shared by the students, we also offered ideas and strategies to help adapt to a more hybrid approach. We hope these ideas and

strategies may also serve to inform what the "new normal" will really look like for STEM education, in general, and physics education, in particular.

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