Feynman, Lewin, and Einstein Download Zoom: A Guide for Incorporating E-Teaching of Physics in a Post-COVID World

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Abstract

Distance education has expanded significantly over the last decade, but the natural sciences have lagged in the implementation of this instructional mode. Recently, the abrupt onset of the COVID-19 pandemic left educational institutions fumbling with adapting curricula to distance modalities. With projected effects lasting into the coming academic year, this problem will not go away soon. Analysis of the literature has elucidated the costs and benefits of, as well as obstacles to, the implementation of e-learning, with a focus in undergraduate physics education. Physics faculty report that a lack of time for learning about research-driven innovation is their primary restriction to implementing it. In response, this paper is intended as an all-in-one guide of recommendations for physics lecturers and lab instructors to re-think their curricula to incorporate successful distanced educational practices moving forward, especially through the use of smartphones and social media. These technologies were chosen for their utility in supporting an effective transition to a virtual environment. Additionally, this paper can act as a resource for university administrators for developing infrastructure to adapt to the changing needs associated with new teaching modalities. Lastly, this paper concludes that, under the proper conditions, e-teaching is compatible with effective teaching of physics at higher levels.
I. INTRODUCTION

Despite much debate, no consensus has been formed in the literature as to a universal definition of e-learning.\textsuperscript{1-3} It is briefly defined for this paper as “technology-based learning in which learning materials are delivered electronically to remote learners via a computer network.”\textsuperscript{4} E-learning can be divided into two categories: asynchronous and synchronous. The former is commonly implemented through a combination of pre-recorded videos, email, and discussion boards. The latter is usually implemented through a combination of videoconferencing and chat platforms (Zoom, WebEx, Skype, etc.).\textsuperscript{5} Within the literature, “virtual” learning often refers to synchronous methods, whereas “online” refers to asynchronous.

From 2002–2016, distance enrollment at higher education institutions rose dramatically, averaging an increase of 18.5% per year, largely driven by e-learning. Meanwhile, on-campus enrollment dropped by 6.4% between 2012–2016.\textsuperscript{6-7} By 2011, however, although 31% of all higher education students were enrolled in at least one online course, less than 10% of institutions offering undergraduate physics courses had a single online section available.\textsuperscript{8} Its relative scarcity aside, online physics education follows the trend of growth seen in other fields.\textsuperscript{9} A few universities have housed online learning for decades, demonstrating its ability to thrive over time.\textsuperscript{10-13}

The COVID-19 pandemic profoundly impacted academic institutions, causing most US universities and high schools to shut down on-campus classes and ousting students from their dormitories before the scheduled end of the 2019–2020 school year. In an attempt to maintain instructional continuity, teachers turned to videoconferencing and recordings of lectures, labs, and office hour sessions. This change may be particularly detrimental to students within STEM subjects.\textsuperscript{14}

This pandemic may therefore act as a motivator for physics faculty and administrators to update curricula, adopt novel teaching modalities, and embrace research-based innovations. This change is not unreasonable; a survey of U.S. physics faculty found that 92% reported that their department encouraged improving instruction. Nearly half (48%) of the faculty reported that they themselves currently use at least one research-based innovation strategy in their teaching. Unfortunately, 53% of those answering replied that the principal reason for not using more research-driven innovations in their classroom is a lack of time (especially time to research and implement changes).\textsuperscript{15} Other studies have shown the same result.\textsuperscript{16} As a
response, the aim of this manuscript is to act as a brief, but thorough, guide for educators. It is intended to present an explanation for some of the above trends, a discussion on e-learning and its implementation, and specific guidance for implementing techniques and systems of e-learning in physics.

First, the benefits of, barriers to, and key factors for the implementation of physics e-learning will be discussed. These will give the reader some background on e-learning, while elaborating on some important related topics. Next, the effects of e-learning on inclusivity and demographic concerns such as household income and gender in science are discussed. Following, the smartphone will be introduced as an important educational tool for successful implementation of physics e-learning. A nearly ubiquitous device, the smartphone offers a wide range of sensors and substantial computational power to far-reaching audiences. It can be very useful for both doing science (data collection, analysis, demonstrations) as well as facilitating other technologies, such as social media. Applications of social media in the traditional and virtual classrooms are then presented, and their use examined in depth. Social media is of importance for improving a sense of community in virtual education. The smartphone and social media were chosen as innovative mechanisms whose use are often discouraged in the classroom, but for which proper implementation will yield improvements in electronic education. Other technologies for e-learning are then briefly introduced. The need for extensive institutional support to facilitate e-learning has been widely recognized and thoroughly researched. Consequently, a guide for informing administrators on the key factors for success in this implementation is presented. In all, it is the goal of this manuscript to act as a comprehensive but readable guide on the facilitation of e-learning in the physics community.

II. BENEFITS, BARRIERS, AND KEY FACTORS

E-learning has a well-documented array of benefits. Notably, it provides better access to education for a wider population, as well as opportunities for pedagogical improvements by instructors. It may be of use to reflect on the affordances of e-learning as instructors and students are forced into this learning environment due to the pandemic. Taking advantage of these facets, for example, through encouraging self-mediated learning (as will be discussed later), may help instructors deal with the changes in an auspicious manner.
On the other hand, e-learning also has its own pitfalls. These disadvantages lead to the reality that e-learning is plagued by low-retention rates. Nonetheless, approaches to mitigate the barriers to e-learning have been introduced, and will be discussed below.

In recent years, studies have identified some areas where e-learning may be specifically advantageous for physics teaching. For example:

1. mobile devices help to formulate an active learning setting and facilitate feedback loops between physics teachers and students;
2. student-led mobile technological use in the classroom correlates with physics achievement and interest;
3. the use of online learning systems can augment students' collaborative learning activities and knowledge construction through group interaction and
4. online synchronous learners in undergraduate introductory physics courses may pass at higher rates than in-person learners.

As previously mentioned, electronic instruction of physics faces specific barriers not found amongst teaching of the social sciences, humanities, and other natural sciences. Some specific disadvantages of physics e-learning include that:

1. e-learning is less applicable and less effective for science education that requires hands-on (e.g. laboratory) learning;
2. students often find it difficult to visualize physical phenomena, especially those in 3-D, through a screen;
3. teachers tend to have low competencies with technology to teach physics;
4. teacher-led technology use rarely engages students and may fail to facilitate students' knowledge construction in physics; and
5. students have higher withdrawal rates for online undergraduate introductory physics courses than in-person classes, possibly due to a lack of community.

With these many costs and benefits in mind, it becomes clear that certain components of e-learning are key to its success. These facets are well documented and extensively studied. The primary factors for successful and equitable e-learning include that:
1. professional training is crucial and has been shown to improve teachers’ acceptance of technology for physics instruction.\textsuperscript{22,29}

2. real-time tech support is essential to successful instruction.\textsuperscript{29}

3. participation in small-group collaborative learning correlates with deeper learning, development of learning, teamwork, and an increase in sense of community.\textsuperscript{30}

4. mechanisms including communication with lower-achieving students and improving overall performance in and experience with e-learning need to be developed to directly combat high dropout rates for e-learners,\textsuperscript{31} and

5. when considering hybrid/partial campus returns, household internet and technology availability, as well as difficult home situations, must be considered when selecting populations that will be allowed to return for on-campus instruction.

As colleges and universities prepare for integrating e-learning in their future curricula, success is dependent on the involvement of administrators, faculty, staff, and students. A general outline of the contributions of each is depicted in Fig. 1.

![Fig. 1. A graphical representation of support mechanisms for improving e-teaching and e-learning of physics at the university level (color online)](image-url)
III. ADDRESSING DEMOGRAPHIC CONCERNS

If e-learning is to be implemented equitably, economic concerns are the first and foremost problems that need addressing. The abrupt shift to an e-learning environment caused by COVID-19-induced closures generated significant difficulties for lower income families across the globe. Requiring children to study from home, unsupported by their learning institutions, may further exacerbate inequalities for those with fewer resources and less opportunity for parental support, especially for those students who may feel unsafe at home. For context, a substantial number of children in Europe live in homes with no access to internet (6.9%), insufficient heating (10.2%), no suitable places to do homework (5%) or no books of the appropriate reading level (5%). These issues are relevant in the US as well. Some (2.5%) children who attend public schools don’t live in stable residences. These stats are worse in certain areas like New York City, where 10% of students were homeless or had unstable housing last year. These cities are, of note, the most likely centers of COVID resurgences due to high population densities.

Data show that, similarly, home computer availability in the US scales with household income (from 75% to 96% by group). However, smartphone access is nearly ubiquitous amongst teens, shown to be nearly uniform amongst teens of varying gender, race, ethnicity, and socioeconomic background. Smartphone use may therefore be helpful in addressing educational inequality. Smartphones also have utility in addressing other demographic differences, such as empowering visually and hearing impaired students. The smartphone is evidently a key tool to improving physics education in the wake of COVID-19, and will be addressed more thoroughly in the following section.

It is well known that sex and gender inequality is rampant in the sciences, especially in physics. Although the percent of female scientific authors increased substantially from 12% in 1955 to 35% in 2005, both physics and math still had female representations of 15%. Additionally, within the classroom, female students have less successful learning and identity formation experiences than males.

Gender differences can also be found in the use of technology for e-learning. Although it has been shown that there is no difference in scientific literacy across genders, males may show better performance in science practices because of their base of prior knowledge related to technology formed from daily activity. Consequently, gender should play a role in
the design of blended learning systems. In a study of 1,290 university students, perceived usefulness and playfulness were been identified as key drivers for the adoption and use of these learning systems, and gender-dependent variations were identified. Other studies have shown the significance of perceived usefulness, perceived ease of use, and attitude towards computer use in behavioral intention of computer use. One such study identified gender differences in the influence of computer-based teaching ability on perceived usefulness and ease of use, as was ascribed to males’ higher computer self-efficacy. Clearly, gender has an effect on technology acceptance, which, in turn, affects its use in e-learning. Educators must communicate with their students to identify deficiencies in technological aptitude and comfort before electronic course instruction. They should utilize feedback loops to continuously address the needs of underrepresented and disadvantaged students.

In order to achieve wide success in implementation, it is important that educators address differences in demographics, especially considering how education, age, household income, race, and gender affect users’ acceptance of the technology. Feedback loops and support structures must be implemented and backed by the educational institutions, as teachers rarely have the resources or time to both develop their own structures and implement them within the classroom. Lastly, when considering partial campus returns, household internet and technology availability, as well as difficult home situations, must be considered in selecting populations that will be allowed to return for on-campus instruction. These actions will assist in making science education more accessible for the general public and addressing inequality in the sciences.

IV. SMARTPHONES AS EDUCATIONAL TOOLS

Especially over the last decade, as digitalization became prevalent in the world, cell phones rapidly became an infrastructure for distraction within the classroom. However, when teachers permit their use, smartphones can be effectively transformed into a transparent part of the infrastructure of learning. They are able to facilitate the use of social media and learning management systems within and outside of the traditional “classroom,” and effectively complement other technologies used in the classroom. Some researchers have advocated for smartphone use within teaching, arguing that smartphones offer benefits of “rich contents deliverability, knowledge sharing, and dynamic learning activities where students
can expect to experience multiple channels of interactions in learning.” A comprehensive list of the advantages of smartphone use integrated into class includes that:

1. mobile learning use encourages independent and collaborative learning;

2. mobile learning engages reluctant learners by removing some degree of formality from the experience;

3. mobile learning use increases attention span and self-esteem;

4. students have extensive experience with smartphones already;

5. smartphones allow flexibility in the time and place of use;

6. smartphones can empower visually and hearing-impaired students;

7. smartphones distract less than laptops; and

8. as of 2018, 95% of US teens aged 13-17 and rising had access to smartphones, with no dependence on household income.

As previously discussed, e-learning is often less effective for science education that requires hands-on learning. It is especially important, for this reason, that new modalities and technologies are explored and embraced for pushing physics education. Mobile devices have been shown to connect teachers and students to formulate an interactive learning setting for feedback loops between teachers and students. A survey of students focused on the multiple uses of smartphone sensors for teaching physics fundamentals displayed the comfort with smartphones found amongst young people. Additionally, it has been demonstrated that smartphone use, if implemented properly, can raise interest levels in physics classes and curiosity of content, while simultaneously bearing no distractions and no dependence on gender, self-concept, or experimental experience. In this manner, smartphone use as an experimental technology can be used to help inspire less interested and lower achieving students.

Smartphones are especially oriented towards successful use in laboratory settings due to their multitude of high precision sensors and analysis tools. As described by Kolb, “many teachers are discovering that a basic cell phone can be the Swiss army knife of digital learning tools.” Such sensors include sound meters, accelerometers, magnetometers, proximeters,
gyroscopes, photometers, cameras, GPS, and barometers. These sensors are integrated into the everyday functioning of the device and its applications. In order to access them directly, a multitude of physics toolbox and lab function apps have been developed. These include the Physics Toolbox Sensor Suite, phyphox, Sensor Kinetics, Sensors Toolbox, and Sensors Pro. The former four are available as free apps (some with premium versions), while the latter is paid.

An especially useful function of these sensors and smartphones for physics education lies in the teaching lab. Table I contains a host of smartphone-based lab experiments that can be used in undergraduate (and high school) introductory physics labs with little other equipment. These experiments are particularly relevant for planning post-COVID, on-campus/small group learning, where smartphones can be used to limit the use of shared data collection and analysis equipment. Using smartphones—devices with which students are already familiar—for data collection can also help increase their interest in and comfort with experiments. Table II contains a similar list, but specifically geared towards smartphone-based lab experiments that can be conducted outside of the lab and/or at home due to their lack of need for other specific equipment. These experiments should be adapted to the course such to cover the learning goals outlined in the AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum. A process for operationalizing such a transition has been laid out with the goal of aligning lab instruction with AAPT learning goals.

These thorough lists demonstrate the wide-ranging capabilities of such a ubiquitous and common device. Authors have found much success with this implementation of smartphones as educational tools in the lab. For example, it has been shown that smartphone experiments “may be more effective in improving students’ understanding of acceleration with respect to traditional ‘cookbook’ and real-time experiments,” with the most significant improvements seen with regards to students’ own critical deductive thinking capability in designing their own experiments. In order to carry out this approach, teachers are encouraged to adapt the POE method (predict-observe-explain) for smartphone-based experiments—predict the results of an experiment, collect data with smartphone sensors, and explain the resulting phenomenon theoretically. By allowing students to utilize this method in association with familiar smartphone technology, improvements in conceptual understanding of underlying phenomena can be achieved.
Certain smartphone sensors may be advantageous for use in lecture sections as well. For example, the slow motion camera has been used for qualitative demonstrations of center of mass rotation, the Doppler effect, a frustrated Newton’s cradle, the falling chimney effect, and tautochrones. The smartphone can be paired with external sensors like a thermal imaging camera to demonstrate phenomena such as work and energy transfer within the body. Additionally, pairing smartphones with a smart student response system can effectively promote active physics learning in the classroom.
As with all other experimental equipment, however, smartphone usage must be regulated for successful use in classroom settings. It is important to be conscious of these guidelines for successful smartphone implementation in e-learning:

1. Especially for younger students, the instructor must be explicit in establishing proper rules of using smartphones before teaching.51

2. Apps used for data collection and analysis should be free, easy to use, intuitive, open-source, and allow for processing and exportation of data as needed.139

3. Instructors should have sufficient professional training on the technical use of smartphones, as has been shown to increase instructor acceptance of the technology.22

4. In order to combat a degradation of students’ professional communication skills, oral
conversations (for synchronous settings) or presentations (asynchronous) should be integrated into the course setting.[7][8]

5. Instructors should utilize smartphones for a combination of data collection and analysis within demonstrations/experiments, as well as for social media to facilitate discussion and self-regulated active learning, as will be explored in the next section.

V. INTEGRATING SOCIAL MEDIA IN “THE CLASSROOM”

The pervasive global spread of social media (SM) presents an intriguing opportunity for conversations about and collaborative analysis of physics topics inside and outside of the traditional classroom. SM comprises an array of online tools through which users can quickly create and share content digitally—e.g. Twitter, Facebook, YouTube, and Wikipedia. The integration of SM within the learning environment can be influential in offering students self-agency of their own learning and career planning. Despite these positive outcomes, most universities continue to rely on more conservative, established learning management systems and environments, perhaps due to FERPA compliance concerns. This prevents capitalization of the extensive potential inherent in social networks in collaboration and the associated skills that students bring into the classroom.[10]

This hesitation to adopt SM is not ubiquitous. In a survey of 459 secondary teachers in the Netherlands, almost all teachers used SM for classes. Teachers in the natural sciences used SM at a level insignificantly different from those in social sciences and humanities, but they tend to use it least often for the facilitation of self-regulated learning.[11] On the other hand, Italian university faculty demonstrated lower levels of adoption of SM (41% using at least one tool on a monthly basis). Younger faculty used SM more than their colleagues, particularly Twitter—though it was concluded that age differences require further investigation. Math, computer science, and natural science faculty used SM less than those in humanities and social sciences.[12] This leaning may be explained by the lack of content relevant to the sciences on these sites.[13] The dearth of relevant content is attributed to a main trend in consuming rather than producing digital resources.[14] Science faculty, as a result, tend to prefer blogs/Wikipedia and Youtube/Vimeo information sources to promote collaborative learning, rather than Facebook/Twitter type communication SM channels.[14]

Many specific examples have been offered to demonstrate the effectiveness of SM within
the classroom. One principle of high-impact online education is faculty/teaching assistants providing timely feedback to students outside of class.[145] This task can be assisted through SM communication channels. WhatsApp has been shown to assist high school physics teachers in relating with students in a personal manner, allowing extensive availability of the teacher to students and students to each other. In turn, this permits teachers to identify problems that are not recognized during the traditional class hours.[146] In this regard, WhatsApp has been demonstrated to be extremely useful as a pedagogical resource.[147] Other similar messaging apps including Slack, Discord, and Google Hangouts can replace WhatsApp with similar functionality. Overall, SM helps teachers share information, questions, and insights to promote curiosity in physics.[148]

Perhaps of most importance, SM can be used as a tool to promote a sense of community within the classroom. A lack of community is often blamed for the high withdrawal rates of online learning.[149] Microblogging (i.e. Twitter) has been shown to combat this flaw, strengthening virtual learning community sense within higher education.[150] Classroom-specific Twitter threads can be used to connect with students and parents, provide classroom updates, and facilitate academic conversations in a manner familiar to students.[151][152] Similarly, the use of Facebook groups for sharing ideas and support, asking questions, and participating in discussions has been shown to promote a virtual student learning community.[153] Integration of SM, therefore, especially through inclusive technologies such as the smartphone, can be key to battling low retention rates in virtual education during the COVID-19-induced closures.

There are, however, some concerns with SM that instructors are encouraged to be mindful of when using it in the classroom:[36][132][143][147][148][154][155]

1. Not all students have smartphone access (although, in the U.S., ~95% do).

2. Cultural/Social—Teachers show reluctance because:
   - there is a perceived erosion of traditional roles and difficulties in managing relationships with students;
   - teachers fear privacy threats and inappropriate chatting content; and
   - language barriers, discrimination, and misunderstandings can undermine SM use.

3. Pedagogical—Teachers show reluctance because:
• many instructors perceive of face-to-face teaching as more effective;

• instructors often feel that direct relations with students are indispensable for results; and

• perceived usefulness is an important motivator for SM usage, but teachers often rate low in this category.

4. Administrative/Institutional (elaborated in final section)—Teachers show reluctance because:

• there is a need for financial investment in technical infrastructure to innovate teaching practice and educational services; and

• institutional support for advising and guiding faculty would increase self-efficacy and correct their lack of digital competency.

Research on innovative practices is crucial to adapting to changing learning environments. Inter- and intradepartmental sharing of effective practices can assist in the re-thinking of pedagogies to adapt traditional teaching methods to the emerging needs and technologies available. Together, these changes could shift attitudes from resistance to a welcomeness in using SM to assist and improve physics teaching in higher education.

VI. OTHER NOVEL AT-HOME TECHNIQUES

Smartphones are a promising way to do physics at home, but other technologies can be used in complement with them or replace them for various e-learning tasks for which smartphones are unsuitable. For example, the use of experimental kits provides students the opportunity to conduct physics right on the kitchen table, and can be instructor-provided or student-assembled. Such kits have been implemented in the classroom for massive open online courses (MOOCs), in open universities, for in-class demonstrations, and for experimental distance learning. Kits can even be paired with smartphones as data collection and analysis devices to increase student comfort with the experiments.

Given a lack of physical laboratory equipment, experiments can also be conducted remotely. Virtual and remote labs have been around since commercialized internet became prevalent across the world, and their use has expanded significantly through today. One
such facility is FARLabs, centered at La Trobe University, which allows users to remotely access lab technologies for real-time experiments. There are many other such sites. Remote experiments can be used to teach many aspects of physics; for example, radioactivity and electronics. Such lab access provides clear financial advantages over physical analogs, as well as pedagogical benefits, and can find much use in the physics classroom during this pandemic and moving forward.

For instructional demonstrations of concepts and simple experiments, online resources such as simulations can be extremely useful. Simulations have been used in the physics classroom for many years, and much research has been conducted on successful approaches for their use. Two such simulation bases are the PhET project developed by the University of Colorado and PhysClips of the University of New South Wales. Many simulations and other resources can also be found on The Physics Source at AAPT’s ComPADRE site. The simulation approach can be especially advantageous for instructors struggling with the extra preparation time required for online courses.

Lastly, an often overlooked resource by instructors is video instruction akin to Khan Academy. Whereas YouTube videos might be used intermittently, embracing and encouraging the consistent use of Khan Academy can fill gaps in student knowledge, or act as a support system for a physics class. Lists of similar online resources can be found readily. As this is adopted by more instructors during the wake of COVID-19, researchers need to investigate and debate the advantages and disadvantages of such a platform for learning in more detail.

VI. RECOMMENDATIONS FOR INSTITUTIONAL ADMINISTRATORS

Whereas this manuscript is specifically motivated to assist and guide physics educators in shifting to online learning, effective recommendations for an institution must be wide-ranging. Value in pandemic-induced e-learning will depend on educational institutions realigning and embracing the necessary structural changes associated with it. Such changes are outlined below.

1. Online mental health and medical services should be expanded. It was found that 20–35% of the 2,530 surveyed students and workers at a Spanish university reported moderate to severe symptoms of anxiety, depression, and stress after COVID-19 school
closures. Similarly, nearly half (46%) of Australian children and young people studying at home are “vulnerable to adverse effects on their educational outcomes, nutrition, physical movement, social, and emotional wellbeing.” Universities (and other educational institutions) are recommended to:

- expand the availability of online counseling services; and
- encourage faculty to embrace technology as a means to focus attention on student experiences and enrich learning.

2. Direct financial investment into e-learning should be a priority. An analysis of blended learning at one university showed that student satisfaction was best predicted by the sufficiency of university resources. Another study showed that the top faculty-identified needs for successful e-learning are multimedia development support and real-time help desks. Universities are recommended to:

- make expenditures related to internet access necessary for hybrid approaches,
- engage in hiring or contracting of support staff for IT and
- ensure proper teacher compensation (important for quality online instruction).

3. Pedagogical research, data collection, and evidence-based practices focused on e-learning should be expanded. Student feedback can be motivated by effective communication mechanisms integrated into a student’s online learning space, and has been shown to be of great value in improving blended course quality. Universities are recommended to:

- integrate easy-access course feedback into virtual learning management systems;
- “close the [feedback] loop;” that is, organize a system to analyze feedback data, identify problem points, delegate responsibility for addressing them, and report back to the students on resulting actions, and
- adopt a hiring and promotion process that factors in teaching achievement through student feedback. This will help incentivize research-driven innovation and teaching practices in the classroom.
4. Teacher training capabilities for multiple modes of e-learning should be expanded. Training is essential to the effective delivery of electronic physics instruction, and has been demonstrated to lead to instructors’ enthusiastic acceptance of mobile technology for teaching.

As learning institutions plan for resuming education during the coming school year, these matters are critical to their success and continued operations. Faculty should encourage the use of these recommendations to administrators, citing the criticality of such matters for the success of education under circumstances induced by the pandemic.

VIII. CONCLUSIONS

The COVID-19 pandemic thrust learners and educators across the world into a new environment, in which e-learning became the foremost method of education across the globe. As the community is unsure about how this pandemic will persist, it is of paramount importance to embrace e-learning in physics education. Firstly, demographic concerns were addressed, including technology’s association with income and gender differences in physics. Consideration of demographics is key to the equitable implementation of e-learning. It was proposed that adopting research-driven innovation will help teachers adapt curricula to the changing needs of students in the wake of the pandemic. An extremely suitable technology for e-learning is the smartphone (mobile learning). The smartphone was explored in its capacity as an educational tool, identifying the advantages of its use in the classroom and its range of sensors and apps for use in the laboratory. Nearly 70 examples of smartphone-based lab and at-home introductory physics experiments were identified and sorted by subject for review by instructors. Following, a guide for the use of social media as a classroom tool was presented. While smartphones and social media are key for some aspects of e-learning, other technologies like remote labs and experimental kits can complement their use effectively. These alternatives were touched upon briefly. Lastly, a guide for institutional administrators, which highlights the criticality of online mental health/medical services, financial investment in e-learning, pedagogical research initiatives, and teacher training, was offered. This manuscript should be utilized by the physics community, and educators as a whole, for guiding the execution of fruitful electronic learning practices.
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1 V. Singh and A. Thurman, “How Many Ways Can We Define Online Learning? A Systematic Literature Review of Definitions of Online Learning (1988-2018),” Am. J. Distance Educ., 33 (4), 289–306 (2019).

2 J. L. Moore, C. Dickson-Deane, and K. Galyen, “e-Learning, online learning, and distance learning environments: Are they the same?,” Internet High. Educ., 14 (2), 129-135 (2011).

3 S. Guri-Rosenblit, “‘Distance education’ and ‘e-learning’: Not the same thing,” High. Educ., 49, 467–493 (2005).

4 D. Zhang, J. L. Zhao, L. Zhou, and J. F. Nunamaker, “Can e-learning replace classroom learning?,” Commun. ACM, 47 (5), 75–79 (2004).

5 S. Hrastinski, “A study of asynchronous and synchronous e-learning methods discovered that each supports different purposes,” EDUCAUSE Q., 31 (4), 51–55 (2008).

6 J. E. Seaman, E. I. Allen, and J. Seaman, Grade Increase: Tracking Distance Education in the United States, Wellesley, MA: The Babson Survey Group (2018).

7 E. I. Allen and J. Seaman, Sizing the Opportunity: The Quality and Extent of Online Education in the United States, 2002 and 2003, Needham, MA: Sloan-C (2003).

8 A. M. Reagan, “Development of a Fully Online Undergraduate Physics Laboratory Course,” AAPT Winter Meeting, Jacksonville, FL (2011).

9 A. M. Reagan, “Online Introductory Physics Labs: Status and Methods,” J. Wash. Acad. Sci., 98 (1), 31–46 (2012).
10 G. Kortemeyer, “Lessons from (almost) 25 years of hybrid and online physics courses at Michigan State University,” EdMedia + Innovate Learning, Washington, DC (2017).

11 R. Lambourne, “Laboratory-based teaching and the Physics Innovations Centre for Excellence in Teaching and Learning,” Eur. J. Phys., 28 (3), S29–S36 (2007).

12 R. Lambourne, “Einstein at a distance,” Eur. J. Phys., 26 (6), S135–S140 (2005).

13 N. D. Adams, “Teaching Introductory Physics Online,” ERIC, ED478781 (2003).

14 E. J. Sintema, “Effect of COVID-19 on the performance of grade 12 students: Implications for STEM education,” Eurasia J. Math. Sci. Tech. Ed., 16 (7), 1–6 (2020).

15 M. Dancy and C. Henderson, “Pedagogical practices and instructional change of physics faculty,” Am. J. Phys., 78 (10), 1056–1063 (2010).

16 C. Henderson and M. H. Dancy, “Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics,” Phys. Rev. Spec. Top.-Phys. Educ. Res., 3 (2), 1–14 (2007).

17 V. Arkorful and N. Abaidoo, “The role of e-learning, advantages and disadvantages of its adoption in higher education,” Int. J. Instruct. Technol. Distance Learn., 12 (1), 29–36 (2015).

18 A. F. Mayadas, J. Bourne, and P. Bacsich, “Online education today,” Science, 323 (5910), 85–89 (2009).

19 G. Packham, P. Jones, C. Miller, and B. Thomas, “E-learning and retention: key factors influencing student withdrawal,” Educ. Train., 46 (6/7), 335–342 (2004).

20 C. A. Murphy and J. C. Stewart, “On-Campus students taking online courses: Factors associated with unsuccessful course completion,” Internet High. Educ., 34, 1–9 (2017).

21 A. Rosenthal, “The Trouble with Online College,” New York Times, Feb. 19, 2013. Retrieved from https://www.nytimes.com/2013/02/19/opinion/the-trouble-with-online-college.html

22 X. Zhai, M. Li, and S. Chen, “Examining the uses of student-led, teacher-led, and collaborative functions of mobile technology and their impacts on physics achievement and interest,” J. Sci. Educ. Technol., 28, 310–320 (2019).

23 C. Zhu, “Student Satisfaction, Performance, and Knowledge Construction in Online Collaborative Learning,” J. Educ. Technol. Soc., 15 (1), 127–136 (2012).

24 E. K. Faulconer, J. C. Griffith, B. Wood, S. Acharyya, and D. Roberts, “A Comparison of Online, Video Synchronous, and Traditional Learning Modes for an Introductory Undergraduate Physics Course,” J. Sci. Educ. Technol., 27, 404–411 (2018).
25 A. Badia, D. Martín, and M. Gómez, “Teachers’ Perceptions of the Use of Moodle Activities and Their Learning Impact in Secondary Education,” Technol. Know. Learn., 24, 483–499 (2019).

26 P-C. Sun, R. J. Tsai, G. Finger., Y-Y. Chen, and D. Yeh, “What drives a successful e-Learning? An empirical investigation of the critical factors influencing learner satisfaction,” Comput. Educ., 50 (4), 1183–1202 (2008).

27 H. M. Selim, “Critical success factors for e-learning acceptance: Confirmatory factor models,” Comput. Educ., 49 (2), 396–413 (2007).

28 X. Zhai, M. Zhang, and X. Zhang, “Understanding the relationship between levels of mobile technology use in high school physics classrooms and the learning outcome,” Brit. J. Educ. Technol., 50 (2), 750–766 (2018).

29 A. S. Chow and R. A. Croxton, “Designing a Responsive e-Learning Infrastructure: Systemic Change in Higher Education,” Am. J. Distance Educ., 31 (1), 20–42 (2017).

30 J. E. Brindley, L. M. Blaschke, and C. Walti, “Creating Effective Collaborative Learning Groups in an Online Environment,” Int. Rev. Res. Open. Dis., 10 (3), 1–18 (2009).

31 J. K. Njenga and L. C. H. Fourie, “The myths about e-learning in higher education,” Brit. J. Educ. Technol., 41 (2), 199–212 (2010).

32 M. S. C. Thomas and C. Rogers, “Education, the science of learning, and the COVID-19 crisis,” Prospects, (2020).

33 W. Van Lacker and Z. Parolin, “COVID-19, school closures, and child poverty: a social crisis in the making,” Lancet, 5 (5), E243–244 (2020).

34 A-C. Guio, D. Gordon, E. Marlier, H. Najera, and M. Pomati, “Towards an EU measure of child deprivation,” Child Indic. Res., 11, 835–860 (2018).

35 Federal Data Summary: School Years 2015–16 through 2017–18, Greensboro, NC: National Center for Homeless Education (2020).

36 M. Anderson and J. Jiang, “Teens, Social Media & Technology 2018,” Pew Research Center (2018).

37 D. M. Coca and J. Slisko, “Software Socrative and Smartphones as Tools For Implementation of Basic Processes of Active Physics Learning in Classroom: An Initial Feasibility Study With Prospective Teachers,” Eur. J. Phys. Educ., 4 (2), 17–24 (2013).
J. Huang, A. J. Gates, R. Sinatra, and A-L. Barabási, “Historical comparison of gender inequality in scientific careers across countries and disciplines,” P. Natl. A. Sci. USA., 117 (9), 4609–4616 (2020).

Z. Hazari, G. Sonnert, P. M. Sadler, and M-C. Shanahan, “Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice,” J. Res. Sci. Teach., 47 (8), 978–1003 (2010).

A. Pramuda, Mundilarto, H. Kuswanto, and S. Hadiati, “Effect of Real-time Physics Organizer Based Smartphone and Indigenous Technology to Students’ Scientific Literacy Viewed from Gender Differences,” Int. J. Instr., 12 (3), 253–270 (2019).

A. Padilla-Meléndez, A. R. del Aguila-Obra, and A. Garrido-Moreno, “Perceived playfulness, gender differences, and technology acceptance model in a blended learning scenario,” Comput. Educ., 63, 306–317 (2013).

K-T. Wong, T. Teo, and S. Russo, “Influence of gender and computer teaching efficacy on computer acceptance among Malaysian student teachers: An extended technology acceptance model,” Australas. J. Educ. Tec., 28 (7), 1190–1207 (2012).

M. Moran, M. Hawkes, and O. El Gayar, “Tablet personal computer integration in higher education: Applying the unified theory of acceptance and use technology model to understand supporting factors,” J. Educ. Comput. Res., 42 (1), 70–101 (2010).

B. Pynoo et al., “Predicting secondary school teachers’ acceptance and use of a digital learning environment: A cross-sectional study,” Comp. Hum. Beh., 27 (1), 568–575 (2011).

C. M. Y. Rasimah, A. Ahmad, and H. Zaman, “Evaluation of user acceptance of mixed reality technology,” Australas. J. Educ. Tec., 27 (8), 1369–1387 (2011).

T. Teo, “Factors influencing teachers’ intention to use technology: Model development and test,” Comput. Educ., 57 (4), 2432–2440 (2011).

B. Šumak, M. Heričko, M. Pušnik, and G. Polančič, “Factors Affecting Acceptance and Use of Moodle: and Empirical Study Based on TAM,” Informatica, 35, 91–100 (2011).

C. E. Porter and N. Donthu, “Using the technology acceptance model to explain how attitudes determine Internet usage: The role of perceived access barriers and demographics,” 59 (9), 999–1007 (2006).

T. Ott, “Mobile phones in school: From disturbing objects to infrastructure for learning,” Ph.D. thesis, Gteborgs universitet, 2017.
A. Buchholz, B. Perry, L. Beck Weiss, D. Cooley, “Smartphone Use and Perceptions among Medical Students and Practicing Physicians,” J. MTM., 5 27–32 (2016).

M. Anshari, M. N. Almunawar, M. Shahrill, D. K. Wicaksono, and M. Huda, “Smartphones usage in the classrooms: Learning aid or interference?,” Educ. Inf. Technol., 22, 3063–3079 (2017).

J. Attewell, “Mobile technologies and learning: A technology update and m-learning project summary,” London: Learning and Skills Development Agency. (2005)

L. Kolb, “Adventures with cell phones,” Educ. Leadership, 68 (5), 46–55 (2011).

D. K. Duncan, A. R. Hoekstra, B. R. Wilcox, “Digital devices, distraction, and new student performance: Does in-class cell phone use reduce learning?,” Astr. Educ. Rev., 11 (1), (2012).

J. A. Sans et al. “Smartphone: a new device for teaching Physics,” 1st International Conference on Higher Education Advances, Valencia, Spain (2015).

K. Hochberg, J. Kuhn, and Andreas Müller, “Using Smartphones as Experimental Tools—Effects on Interest, Curiosity, and Learning in Physics Education,” J. Sci. Educ. Technol., 27, 385–403 (2018).

R. Vieyra, C. Vieyra, A-M. Pendrill, and B. Xu, “Gamified physics challenges for teachers and the public,” Phys. Educ., 55 (4), 1–7 (2020).

J. Kozminski et al., AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum College Park, MD: AAPT (2014).

N. G. Holmes and E. M. Smith, “Operationalizing the AAPT Learning Goals for the Lab,” Phys. Teach., 57, 296–299 (2019).

U. Pili, R. Violanda, and C. Ceniza, “Measurement of g using a magnetic pendulum and a smartphone magnetometer,” Phys. Teach., 56, 258–259 (2018).

S. Kapucu, “A simple experiment to measure the maximum coefficient of static friction with a smartphone,” Phys. Educ., 53 (5), 1–3 (2018).

A. Çoban and M. Erol, “Teaching and determination of kinetic friction coefficient using smartphones,” Phys. Educ., 54 (2), 1–5 (2019).

C. Baldock and R. Johnson, “Investigation of kinetic friction using an iPhone,” Phys. Educ., 51 (6), 1–6 (2016).

D. Lopez, I. Caprile, F. Corvacho, and O. Reyes, “Study of a variable mass Atwood’s machine using a smartphone,” Phys. Teach., 56 182–183 (2018).
W. Namchanthra et al., “Analyzing a torsion pendulum using a smartphone’s sensors: mechanical energy conservation approach,” Phys. Educ., 54 (6), 1–8 (2019).

T. Pierratos and H. M. Polatoglou, “Study of the conservation of mechanical energy in the motion of a pendulum using a smartphone,” Phys. Educ., 53 (1), 1–5 (2018).

P. Vogt and J. Kuhn, “Analyzing collision processes with the smartphone acceleration sensor,” Phys. Teach., 52, 118–119 (2014).

S. K. Ayop, “Analyzing Impulse Using iPhone and Tracker,” Phys. Teach., 55, 480–481 (2017).

J. C. Sanders, “The effects of projectile mass on ballistic pendulum displacement,” Am. J. Phys., 88 (5), 360–364 (2020).

L. Seeley and E-H. Shin, “Colliding without touching: Using magnets and copper pipe fittings to explore the energetics of a completely inelastic collision,” Am. J. Phys., 86 (9), 712–717 (2018).

U. Pili, “A dynamic-based measurement of a spring constant with a smartphone light sensor,” Phys. Educ., 53 (3), 1–3 (2018).

U. Pili and R. Violanda, “Measuring a spring constant with a magnetic spring-mass oscillator and a telephone pickup,” Phys. Educ., 54 (4), 1–3 (2019).

J. A. Sans, F. J. Manjón, A. L. J. Pereira, J. A. Gomez-Tejedor, and J. A. Monsoriu, “Oscillations studied with the smartphone ambient light sensor,” Eur. J. Phys., 34 (6), 1349–1354 (2013).

J. C. Castro-Palacio, L. Velázquez-Abad, M. H. Giménez, and J. A. Monsoriu, “Using a mobile phone acceleration sensor in physics experiments on free and damped harmonic oscillations,” Am. J. Phys., 81 (6), 472–475 (2013).

R. Jaafar, S. K. Ayop, A. T. Ismail, K. K. Hon, A. N. M. Daud, and M. H. Hashim, “Visualization of Harmonic Series in Resonance Tubes Using a Smartphone,” Phys. Teach., 54, 545–547 (2016).

J. A. Gómez-Tejedor, J. C. Castro-Palacio, and J. A. Monsoriu, “The acoustic Doppler effect applied to the study of linear motions,” Eur. J. Phys., 35 (2), 1–9 (2014).

R. Pörn and Mats Braskén, “Interactive modeling activities in the classroom—rotational motion and smartphone gyroscopes,” Phys. Educ., 51 (6), 1–7 (2016).

A. Shakur and J. Kraft, “Measurement of Coriolis Acceleration with a Smartphone,” Phys. Teach., 54, 288–290 (2016).
79. M. S. M. N. F. Gomes, P. Martín-Ramos, P. S. P. da Silva, and M. R. Silva, “The ‘spinning disk touches stationary disk’ problem revisited: an experimental approach,” Eur. J. Phys., 39 (4), 1–10 (2018).

80. P. Klein, A. Müller, S. Gröber, A. Molz, and J. Kuhn, “Rotational and frictional dynamics of the slamming of a door,” Am. J. Phys., 85 (1), 30–37 (2017).

81. N-A. Goy et al., “Surface tension measurements with a smartphone,” Phys. Teach., 55, 498–499 (2017).

82. M. Wei et al., “The study of liquid surface waves with a smartphone camera and an image recognition algorithm,” Eur. J. Phys., 36 (6), 1–8 (2015).

83. M. R. Silva, P. Martín-Ramos, and P. P. da Silva, “Studying cooling curves with a smartphone,” Phys. Teach., 56, 53–55 (2018).

84. J. Rayner, “Using a Cell Phone to Investigate the Skin Depth Effect in Salt Water,” Phys. Teach., 55, 83–86 (2017).

85. F. G. Tomasel and M. C. Marconi, “Rolling magnets down a conductive hill: Revisiting a classic demonstration of the effects of eddy currents,” Am. J. Phys., 80 (9), 800–803 (2012).

86. A. A. Soares and T. O. Reis, “Studying Faraday’s law of induction with a smartphone and personal computer,” Phys. Educ., 54 (5), 1–7 (2019).

87. G. A. Sobral, “Development of a metal detector for smartphones and its use in the teaching laboratory,” Phys. Educ., 53 (4), 1–10 (2018).

88. E. Arribas, I. Escobar, C. P. Suarez, A. Najera, and A. Beléndez, “Measurement of the magnetic field of small magnets with a smartphone: a very economical laboratory practice for introductory physics courses,” Eur. J. Phys., 36 (6), 1–11 (2015).

89. Y. Ogawara, S. Bhari, and S. Mahrley, “Observation of the magnetic field using a smartphone,” Phys. Teach., 55, 184–185 (2017).

90. T. Rosi and P. Onorato, “Video analysis-based experiments regarding Malus’ law,” Phys. Educ., 55 (4), 1–5 (2020).

91. M. Monteiro, C. Stari, C. Cabeza, and A. C. Martí, “The Polarization of Light and Malus’ Law Using Smartphones,” Phys. Teach., 55, 264–266 (2017).

92. K. Malisorn et al., “Demonstration of light absorption and light scattering using smartphones,” Phys. Educ., 55 (1), 1–8 (2020).
93 J. Freeland, V. R. Krishnamurthi, and Y. Wang, “Learning the lens equation using water and smartphones/tablets,” Phys. Teach., 58, 360–361 (2020).
94 C-M. Chiang and H-Y. Cheng, “Use smartphones to measure Brewster’s angle,” Phys. Teach., 57, 118–119 (2019).
95 I. Salinas, M. H. Giménez, J. A. Monsoriu, and J. C. Castro-Palacio, “Characterization of linear light sources with the smartphone’s ambient light sensor,” Phys. Teach., 56, 562–563 (2018).
96 P. Onorato and L. M. Gratton, “Measuring the Raman spectrum of water with a smartphone, laser diodes and diffraction grating,” Eur. J. Phys., 41 (2), 1–14 (2020).
97 H. Ghalila et al., “Hands-on experimental and computer laboratory in optics: the Young double slit experiment,” SPIE Optical Engineering + Applications, San Diego, CA (2018).
98 M. Pirbhai, “Smartphones and Tracker in the e/m experiment,” Phys. Educ., 55 (1), 1–5 (2020).
99 J. Durelle, J. Jones, S. Merriman, and A. Balan, “A smartphone-based introductory astronomy experiment: Seasons investigation,” Phys. Teach., 55, 122–123 (2017).
100 J. Vandermarlière, “On the inflation of a rubber balloon,” Phys. Teach., 54, 566–567 (2016).
101 K. Forinash and R. F. Wisman, “Smartphones as portable oscilloscopes for physics labs,” Phys. Teach., 50, 242–243 (2012).
102 O. Schwarz, P. Vogt, and J. Kuhn, “Acoustic measurements of bouncing balls and the determination of gravitational acceleration,” Phys. Teach., 51, 312–313 (2013).
103 P. Vogt and J. Kuhn, “Analyzing free fall with a smartphone acceleration sensor,” Phys. Teach., 50, 182–183 (2012).
104 J. Kim et al., “A Measurement of Gravitational Acceleration Using a Metal Ball, a Ruler, and a Smartphone,” Phys. Teach., 58, 192–194 (2020).
105 J. Kuhn, P. Vogt, and F. Theilmann, “Going nuts: Measuring free-fall acceleration by analyzing the sound of falling metal pieces,” Phys. Teach., 54 182–183 (2016).
106 L. A. Testoni and G. Brockington, “The use of smartphones to teach kinematics: an inexpensive activity,” Phys. Educ., 51 (6), 1–7 (2016).
107 E. Azhikannickal, “Sports, Smartphones, and Simulation as an Engaging Method to Teach Projectile Motion Incorporating Air Resistance,” Phys. Teach., 57, 308–311 (2019).
108 C. Fahsl and P. Vogt, “Determination of the drag resistance coefficients of different vehicles,” Phys. Teach., 56, 324–325 (2018).

109 V. L. B. de Jesus and D. G. G. Sasaki, “Modelling of a collision between two smartphones,” Phys. Educ., 51 (5), 1–7 (2016).

110 V. Pereira, P. Martín-Ramos, P. P. da Silva, and M. R. Silva, “Studying 3D collisions with smartphones,” Phys. Teach., 55, 312–313 (2017).

111 J. Kuhn and P. Vogt, “Analyzing acoustic phenomena with a smartphone microphone,” Phys. Teach., 51, 118–119 (2013).

112 J. Kuhn and P. Vogt, “Analyzing spring pendulum phenomena with a smart-phone acceleration sensor,” Phys. Teach., 50, 504–505 (2012).

113 S. Hellesund, “Measuring the speed of sound in air using a smartphone and a cardboard tube,” Phys. Educ., 54 (3), 1–5 (2019).

114 S. O. Parolin and G. Pezzi, “Measuring the speed of sound in air using a smartphone and a cardboard tube,” Phys. Teach., 51, 508–509 (2013).

115 A. Yavuz, “Measuring the speed of sound in air using smartphone applications,” Phys. Educ., 50 (3), 281–284 (2015).

116 S. Staacks, S. Hutz, H. Heinke, and C. Stampfer, “Simple Time-of-Flight Measurement of the Speed of Sound Using Smartphones,” 57, 112–113 (2019).

117 J. Bonato, L. M. Gratton, P. Onorato, and S. Oss, “Using high speed smartphone cameras and video analysis techniques to teach mechanical wave physics,” Phys. Educ., 52 (4), 1–5 (2017).

118 M. Monteiro, C. Stari, C. Cabeza, A. C. Marti, “A bottle of tea as a universal Helmholtz resonator, Phys. Teach., 56, 644–645 (2018).

119 S. H. Hawley and R. E. McClain, “Visualizing Sound Directivity via Smartphone Sensors,” Phys. Teach., 56, 72–74 (2018).

120 M. Thees, K. Hochberg, J. Kuhn, and M. Aeschlimann, “Adaptation of acoustic model experiments of STM via smartphones and tablets,” 55, 436–437 (2017).

121 A. Müller, M. Hirth, and J. Kuhn, “Tunnel pressure waves – A smartphone inquiry on rail travel,” 54, 118–119 (2016).

122 R. P. Smith and E. H. Matlis, “Gravity-driven fluid oscillations in a drinking straw,” Am. J. Phys., 87 (6), 433–435 (2019).
123 U. Dilek and S. K. Şengören, “A new position sensor to analyze rolling motion using an iPhone,” Phys. Educ., 54 (4), 1–4 (2019).
124 P. Vogt and J. Kuhn, “Analyzing radial acceleration with a smartphone acceleration sensor,” Phys. Teach., 51 182–183 (2013).
125 M. Monteiro, C. Cabeza, and A. C. Martí, “Exploring phase space using smartphone acceleration and rotation sensors simultaneously,” 35 (4), 1–9 (2014).
126 I. Salinas, M. H. Gimenez, J. A. Monsoriu, and J. A. Sans, “Demonstration of the parallel axis theorem through a smartphone,” 57, 340–341 (2019).
127 U. Pili and R. Violanda, “Measuring average angular velocity with a smartphone magnetic field sensor,” Phys. Teach. 56, 114–115 (2018).
128 J. Chevrier, L. Madani, S. Ledennat, and A. Bsiesy, “Teaching classical mechanics using smartphones,” Phys. Teach., 51, 376–377 (2013).
129 S. Mau, F. Insulla, E. E. Pickens, Z. Ding, and S. C. Dudley, “Locating a smartphone’s accelerometer,” Phys. Teach., 54, 246–247 (2016).
130 S. Macchia, “Analyzing Stevin’s law with the smartphone barometer,” Phys. Teach., 54, 373 (2016).
131 M. Monteiro, P. Vogt, C. Stari, V. Cabeza, and A. C. Marti, “Exploring the atmosphere using smartphones,” Phys. Teach., 54, 308–309 (2016).
132 A. Girot, N-A. Goy, A. Viliquin, and U. Delabre, “Studying Ray Optics with a Smartphone,” Phys. Teach., 58, 133–135 (2020).
133 B. Underwood and Y. Zhai, “Moving Phones Tick Slower: Creating an Android App to Demonstrate Time Dilation,” Phys. Teach., 54, 277–279 (2016).
134 J. Kuhn, A. Molz, S. Gröber, and J. Frübis, “iRadioactivity – Possibilities and Limitations for Using Smartphones and Tablet PCs as Radioactive Counters,” 52, 351–356 (2014).
135 M. Meißner and H. Haertig, “Smartphone Astronomy,” Phys. Teach., 52, 440–441 (2014).
136 A. Mazzella and I. Testa, “An investigation into the effectiveness of smartphone experiments on students’ conceptual knowledge about acceleration,” Phys. Educ., 51, 1–10 (2016).
137 J. Lincoln, “Enhancing physics demos using iPhone slow motion,” Phys. Teach., 55, 588–589 (2017).
138 M. Kubusch, J. Nordine, and D. Hadinek, “Using smartphone thermal cameras to engage students’ misconceptions about energy,” Phys. Teach., 55, 504–505 (2017).
K. Alexandros, L. Panagiotis, T. Serafeim, T. Pavlos, and V. Athanasios, “Possible Technical Problems Encountered by The Teacher in The Incorporation of Mobile Phone Sensors in The Physics Lab,” Eur. J. Phys. Educ., 11 (2), 5–23 (2020).

C. McLoughlin and M. J. W. Lee, “Personalised and self regulated learning in the Web 2.0 era: International exemplars of innovative pedagogy using social software,” Australas. J. Educ. Tec., 26 (1), 28–43 (2010).

U. Matzat and E. M. Vrieling, “Self-regulated learning and social media – a ‘natural alliance’? Evidence on students’ self-regulation of learning, social media use, and student-teacher relationship,” Learn. Media Technol., 41 (1), 73–99 (2015).

S. Manca and M. Ranieri, “Facebook and the others. Potentials and obstacles of Social Media for teaching in higher education,” Comput. Educ., 95, 216–230 (2016).

M. Moran, J. Seaman, and H. Tinti-Kane, “Blogs, wikis, podcasts and Facebook: How today’s higher education faculty use social media,” Boston, MA: Pearson Learning Solutions and Babson Survey Research Group (2012).

E. Hargittai and G. Walejko, “The participation divide: Content creation and sharing in the digital age,” Inform. Commun. Soc., 11 (2), 239–256 (2008).

W. Bao, “COVID-19 and online teaching in higher education: A case study of Peking University,” Hum. Beh. Emerging Technol., 2 (2), 113–115 (2020).

A. Klieger and L. Goldsmith. “Expanding physics learning beyond classroom boundaries—a case study,” Phys. Educ., 55 (2), 1–6 (2020).

D. Bouhnik and M. Deshen, “WhatsApp Goes to School: Mobile Instant Messaging between Teachers and Students,” J. Inf. Technol. Educ. Res., 13, 217–231 (2014).

M. A. Ha¸silo˘glu, H. S. Çalhan, and M. E. Ustaoğlu, “Determining the Views of the Secondary School Science Teachers about the Use of Social Media in Education,” J. Sci. Educ. Technol., 29, 346–354 (2020).

C. Hart, “Factors Associated With Student Persistence in an Online Program of Study: A Review of the Literature,” J. Interact. Online Learn., 11 (1), 19–42 (2012).

Y-C. Hsu and Y-H. Ching, “Microblogging for Strengthening a Virtual Learning Community in an Online Course,” Knowl. Man. E-Learn., 3 (4), 585–598 (2011).

K. Page, “Using social media in a high school physics class,” Phys. Teach., 53, 184–185 (2015).
T. Burden, “K-12 Teachers Uncertain about How to Connect with Students and Parents via Social Media, Reveals University of Phoenix Survey,” (2014). https://www.businesswire.com/news/home/20140114005604/en/K-12-Teachers-Uncertain-Connect-Students-Parents-Social

S. E. Schoper and A. R. Hill, “Using Facebook to Promote a Virtual Learning Community: A Case Study,” J. Learn. Space., 6 (1), 34–39 (2017).

T. Buchanan, P. Sainter, and G. Saunders, “Factors affecting faculty use of learning technologies: implications for models of technology adoption,” J. Comput. High. Educ., 25, 1–11 (2013).

Y. Cao, H. Ajjan, and P. Hong, “Using social media applications for educational outcomes in college teaching: A structural equation analysis,” Brit. J. Educ. Technol., 44 (4), 581–593 (2013).

E. Gibney, “‘Open-hardware’ pioneers push for low-cost lab kit: conference aims to raise awareness of shared resources for building lab equipment,” Nature, 531, 147–148 (2016).

J. DeBoer, C. Haney, S. Zahra Atiq, C. Smith, and D. Cox, “Hands-on engagement online: using a randomised control trial to estimate the impact of an at-home lab kit on student attitudes and achievement in a MOOC,” Eur. J. Eng. Educ., 44 1–2, 234–252 (2019).

D. K. Kennepohl, “Providing Effective Teaching Laboratories at an Open Laboratory,” Int. J. Innov. Online Educ., 1 (4), (2017).

Š. Kubínová and J. Šlégr, “Physics demonstrations with the Arduino board,” Phys. Educ., 50 (4), 472–474 (2015).

J. M. Long, B. P. Horan, and R. Hall, “Undergraduate electronics students’ use of home experiment kits for distance education,” Proc. 119th American Society for Engineering Education Annual Conference & Exposition, San Antonio, TX (2012).

R. W. Hendricks and K. Meehan, Lab in a Box: Introductory Experiments in Electric Circuits (Wiley, New York 2009).

R. Heradio et al. “Virtual and remote labs in education: A bibliometric analysis,” Comput. Educ., 98, 14–38 (2016).

L. Gomes and S. Bogosyan, “Current Trends in Remote Laboratories,” IEEE T. Ind. Electron., 56 (12), 4744–4756 (2009).
D. Hoxley et al., “FARLabs: Enhancing student engagement via remote laboratories,” Proc. Australian Conference on Science and Mathematics Education (2014).

C. A. Matarrita and S. B. Concari, “Remote laboratories used in physics teaching: A state of the art,” 2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV), Madrid, Spain (2016).

K. Jona and M. Vondracek, “A Remote Radioactivity Experiment,” Phys. Teach., 51, 25–26 (2013).

M. Tawfik et al., “Virtual Instrument Systems in Reality (VISIR) for Remote Wiring and Measurement of Electronic Circuits on Breadboard,” IEEE T. Learn. Technol., 6 (1), 60–72 (2013).

J. G. Zubia and G. R. Alves, Using remote labs in education: two little ducks in remote experimentation (University of Deusto Press, Bilbao, Spain, 2012).

A. Jimoyiannis and V. Komis, “Computer simulations in physics teaching and learning: a case study on students’ understanding of trajectory motion,” Comput. Educ., 36 (2), 183–204 (2001).

C. E. Wieman, W. K. Adams, and K. K. Perkins, “PhET: Simulations that enhance learning,” Science, 322, 682–683 (2008).

C. E. Wieman, W. K. Adams, P. Loeblein, and K. K. Perkins, “Teaching Physics Using PhET Simulations,” Phys. Teach., 48, 225–227 (2010).

G. Hatsidimitris and J. Wolfe, “PHYSCLIPS: Multimedia Resources for Learning and Teaching Physics,” 2nd International STEM in Education Conference, Beijing, China (2012).

D. MacIsaac, “ComPADRE Digital Collections,” Phys. Teach., 44, 398 (2006).

C. Thompson, “How Khan Academy Is Changing the Rules of Education,” Wired Magazine 126, 1–5 (2011).

C. Lindstrøm, “Using Khan Academy to support students’ mathematical skill development in a physics course,” 122nd ASEE Annual Conference & Exposition, Seattle, WA (2015).

M. Kettle, “Flipped Physics,” Phys. Educ., 48 (5), 593–596 (2013).

C. M. Toquero, “Challenges and Opportunities for Higher Education amid the COVID-19 Pandemic: The Philippine Context,” Pedagog. Res., 5 (4), 1–5 (2020).

J. Peppard and J. Ward, “Beyond strategic information systems: towards an IS capability,” J. Strategic. Inf. Syst., 13 (2), 167–194 (2004).
P. Sahu, “Closure of Universities Due to Coronavirus Disease 2019 (COVID-19): Impact on Education and Mental Health of Students and Academic Staff,” Cureus, 12 (4), 1–6 (2020).

P. Odriozola-González, Á. Planchuelo-Gómez, M. J. Irutia, and R. de Luis-García, “Psychological effects of the COVID-19 outbreak and lockdown among students and workers of a Spanish university,” Psychiat. Res., 290, 113108 (2020).

N. Brown, K. te Riele, B. Shelley, and J. Woodroffe, Learning at home during COVID-19: Effects on vulnerable young Australians Independent Rapid Response Report. Hobart: University of Tasmania, Peter Underwood Centre for Educational Attainment. (2020)

O. Calderon, A. P. Ginsberg, and L. Ciabocchi, “Multidimensional Assessment of Pilot Blended Learning Programs: Maximizing Program Effectiveness Based on Student and Faculty Feedback,” J. Asynchronous. Learn. Netw., 16 (3), 23–37 (2012).

S. Guri-Rosenblit, “Eight paradoxes in the implementation process of e-learning in higher education,” Distances et saviors, 2 (4), 155–179 (2006).

K. Mac Keogh, “National Strategies for the Promotion of On-Line Learning in Higher Education,” Eur. J. Educ., 36 (2), 223–236 (2001).

G. Mihhailova, “E-learning as internationalization strategy in higher education: Lecturer’s and student’s perspective,” Balt. J. Manag., 1 (3), 270–284 (2006).

T. Hatziapostolou and I. Paraskakis, “Enhancing the Impact of Formative Feedback on Student Learning through an Online Feedback System,” Electron. J. E-Learn., 8 (2), 111-122 (2010).

M. Jara and H. Mellar, “Quality enhancement for e-learning courses: The role of student feedback,” Comput. Educ., 54 (3), 709–714 (2010).

S. Watson, “Closing the Feedback Loop: Ensuring Effective Action from Student Feedback,” Tertiary Educ. Manag., 9 (2), 145–157 (2003).

M. T. Afzal, A. Safdar, and M. Ambreen, “Teachers Perceptions and Needs towards the Use of E-Learning in Teaching of Physics at Secondary Level.” Am. J. Educ. Res., 3 (8), 1045–1051 (2015).