Microbiology Learning and Education Online

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The ubiquity of devices that connect to the Internet has exploded, allowing for easy dissemination of information. Many teachers from kindergarten to universities use the information obtained online or post material they want their students to access. Online media readily places articles, books, videos, and games at our fingertips. The public in general also gathers health information from the Internet. The following review will explore what has been published regarding microbiology education and learning online and the use of electronic media by microbiologists for scientific purposes.

Definitions of distance learning/education, electronic learning (e-learning), and online learning/education are not well established, and many believe the terms can be used interchangeably. The Merriam-Webster dictionary defines learning as the act of gaining knowledge, while education is the process of teaching a particular knowledge or skill in a school, college, or university (1). Distance education has a long history, as it used to be imparted by sending material to remote areas using the postal service; however, nowadays, a variety of educational tools, such as videos, synchronous and asynchronous interactions, and reading material, can be delivered through the Internet. Some believe that the use of electronic/multimedia technology defines e-learning, while online learning refers to the use of the Internet. A survey by Moore et al. (2) demonstrated the lack of consistency in use of the terms, even though more than half of those surveyed had participated in one or more of the learning environments and had used technology tools, such as discussion boards, learning or course management systems, video conferencing, chats, and other types.

In the field of microbiology, are there e-learning materials available? For which age groups? Are there distance microbiology education courses? Have electronic tools been used to engage students in microbiology classes or to reinforce concepts? How do microbiologists use electronic media? Have these online tools been evaluated? In order to answer these questions, a search in PubMed using the terms “online,” “Internet,” “e-learning,” “electronic,” “distance,” “microbiology education,” and “microbiology learning” was performed. This review includes articles that have either described or evaluated available websites or online tools related to microbiology education and learning. It is not intended to be a comprehensive listing of all available microbiology online material. Table 1 presents education and electronic media concepts that the reader will encounter in the review and their definitions, as these concepts may not be familiar to microbiologists.

### MICROBIOLOGY, SEARCH ENGINES, AND THE GENERAL PUBLIC

Nowadays, everyone uses search engines at work, home, or on the road because of the ubiquity of devices connected to the Internet. Examples of popular health-oriented websites found using search engines include NHS Direct Online (http://www.nhs.uk/pages/home.aspx), MedlinePlus (https://www.nlm.nih.gov/medlineplus/), WebMD (http://www.webmd.com/), and Mayo Clinic Diseases and Conditions (http://www.mayoclinic.org/diseases-conditions). Laurent and Vickers (3) set out to determine how Internet search engines ranked different online health information. They were particularly interested in how the search engines ranked the English Wikipedia. They found that Wikipedia surpassed MedlinePlus and NHS Direct Online and had more viewers for certain topics. The authors of articles in any encyclopedia provide their knowledge but also their bias. Wikipedia, being an open online encyclopedia, uses the general public to create and correct the articles, not the authorities in a particular field. The scientific articles are aimed at the general public and suffer from omission of data that would be useful to the specialized study of a particular topic. Wilson and Likens (4) set out to find inaccuracies in Wikipedia by analyzing the edits performed per day of seven scientific articles. Although the articles studied were not related to health, it is interesting to note that those articles surrounding controversial topics, such as evolution or global warming, were much more vulnerable to frequent corrections to the detriment of accurate scientific information.

Publications that have shed some light on the use of Wikipedia for microbiology topics include a general public survey in the Netherlands during a Salmonella outbreak that showed that many of the respondents found information regarding salmonellosis on Wikipedia (5). Hickmann et al. (6) assessed Wikipedia hits to five articles that referred to influenza to forecast the actual number of cases that were reported to the Centers for Disease Control and Prevention (CDC) during the 2013-2014 influenza season. They showed that the number of hits to the website predicted the official number of cases before these were published by CDC (6). An evaluation of the accuracy of Wikipedia articles regarding microbiology has not been published.

### MICROBIOLOGY IN KINDERGARTEN THROUGH GRADE 12 ONLINE EDUCATION

At home, children are exposed to a variety of Internet-connected devices from a very early age as they use their parents’ phones, tablets, or computers to play games. Many games have some degree of educational content. The availability of computers in elementary and secondary schools in the United States was surveyed...
TABLE 1 Education and electronic media concepts with definitions as they appear in the text

<table>
<thead>
<tr>
<th>Education or electronic media concept</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Internet</td>
<td>Networking infrastructure. You access the information on the Internet through the World Wide Web.</td>
</tr>
<tr>
<td>Learning</td>
<td>Act of gaining knowledge</td>
</tr>
<tr>
<td>Education</td>
<td>Process of teaching a particular knowledge or skill in a school, college, or university.</td>
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<tr>
<td>Synchronous format</td>
<td>Online learning and courses that take place in real time, meaning the instructor and students must be online and communicate with each other at the same point in time while in different locations.</td>
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<tr>
<td>Asynchronous format</td>
<td>Online learning in which instructor provides online material that students can access and discuss at their own pace.</td>
</tr>
<tr>
<td>Course (learning) management systems</td>
<td>Software systems used by colleges and universities for the administration, delivery, and tracking e-learning programs, including online courses and as an enhancement to in-person courses. Teachers post documents, track who has accessed them, post tests, have synchronous or asynchronous discussions, etc.</td>
</tr>
<tr>
<td>Search engine</td>
<td>Computer software that is used to search for information. Examples include Google, Bing, Yahoo, and others.</td>
</tr>
<tr>
<td>Webpage/website</td>
<td>Document on the World Wide Web that can consist of different files.</td>
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<tr>
<td>Problem-based learning</td>
<td>Student-centered form of instruction in which students are presented with a problem and master competencies through brainstorming and finding solutions to the problem.</td>
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<tr>
<td>Flipped classroom</td>
<td>Classroom model in which the students prepare before coming to class by researching a topic through videos or reading material and dedicate class time to have discussions, do a project, or solve exercises.</td>
</tr>
<tr>
<td>Interactive modules</td>
<td>Short online modules focused on a specific topic and that require active participation from the student. There is flow of information between the online module and the user. Examples include games, simulations, and drills.</td>
</tr>
<tr>
<td>Title IV institution</td>
<td>Postsecondary institutions that participate in the federal student financial aid program under the Higher Education Act.</td>
</tr>
<tr>
<td>Facebook</td>
<td>Social networking website that allows registered users to create profiles, upload photos and video, send messages, and keep in touch with friends, family, and colleagues.</td>
</tr>
<tr>
<td>Online 2 + 2 college</td>
<td>Partnership that allows community college students to transfer to a 4-year university to earn a bachelor’s degree upon completion of a 2-year associate’s degree.</td>
</tr>
<tr>
<td>Blended curriculum</td>
<td>Course that combines traditional face-to-face instruction with online supplements and supports.</td>
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<tr>
<td>Flash animation</td>
<td>Animated cartoon short film. It can be created by different software, including Adobe Flash.</td>
</tr>
<tr>
<td>Massive open online courses (MOOC)</td>
<td>Open-access online course aimed to have unlimited participants. It usually includes lectures, reading material, problem sets, discussion boards, and other content.</td>
</tr>
<tr>
<td>Signature track</td>
<td>Online courses that offer a certification of completion and mastery of competencies.</td>
</tr>
<tr>
<td>Online polling software/audience</td>
<td>Wireless technology that facilitates interaction between presenter and audience. There is a need for both software and hardware. With this technology, a lecturer can present questions and record the anonymous responses of participants so a discussion can be generated or feedback provided.</td>
</tr>
<tr>
<td>response systems</td>
<td></td>
</tr>
<tr>
<td>Case-based learning/teaching</td>
<td>Instructional design model in which factually based, complex cases are used to stimulate collaborative, student-centered exploration. The student analysis of the questions does not necessarily have one correct answer.</td>
</tr>
<tr>
<td>Social media</td>
<td>Forms of electronic communication in which users create online communities or networks to share information, ideas, personal messages, and other content.</td>
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<tr>
<td>Blog</td>
<td>Website that consists of small entries (posts) that are presented in reverse chronological order and are updated by an individual or small group.</td>
</tr>
<tr>
<td>Microblogs (Twitter)</td>
<td>Web service that allows broadcasters to post short messages to other subscribers. Twitter is an example of a microblog.</td>
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<tr>
<td>Listserv</td>
<td>Trademarked application that distributes messages to a list of subscribers.</td>
</tr>
<tr>
<td>Podcast</td>
<td>Digital audio or video file that is posted on the Internet, typically available as a series to subscribers.</td>
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by the National Center for Education Statistics in 2009 (7). They found that 97% of teachers had computers in their class, with an average ratio of 5.3 students per computer. Ninety-three percent had access to the Internet. The use of computers in school varied, with more frequent use occurring with those teachers having <9 years of experience. Students tend to use computers for word processing or to investigate a subject. The use of computers increases with the age. Following, we describe the work published by two groups that use online educational material for children.

A group from the United Kingdom has used a webpage (http://www.e-bug.eu) with short videos, animations, and games to teach microbiology concepts to children from elementary to high school (8). The concepts they introduce at an early age include washing their hands, how to clean your kitchen, and what happens when someone sneezes, to present the idea of “good and bad” microorganisms. For children around 12 years old, they have games in which a miniaturized human cartoon fights fungi, bacteria, and viruses in different settings. For older elementary/junior high students, the short videos and animations are more complex and introduce concepts, such as antibiotics, immunity, and vaccines. For high school students, the game uses the concept of problem-based learning. These students are asked to solve a mystery: was the person sick because of natural transmission of the microorganism, or was it a deliberate attack? The authors of the webpage have translated it to multiple languages and have published information on how the microbiology concepts are accessed by the different age groups (9). The average monthly online activity of the e-Bug website is calculated to be >20,000 views per month, from a range of countries.

Short videos that provide minimal foundational instruction have been advocated as a manner of flipping the classroom. The Khan Academy has created many of these short videos for a variety of subjects, including health care. Many teachers incorporate these videos in their classes; however, the popularity of these vid-
management university (being all online has been done for nonbiology majors in a hospitality mathematics. underrepresented minorities in science, technology, engineering, and program is a way to increase the number of students, particularly done their first 2 years on campus. Their experience suggests that this on-campus students, and that their degree of preparation for the later distance education students' experiences were similar to those of the which some theoretical portions of the course were entirely online,ing its first years. Their final product was a blended curriculum in
rarity, and marketing and recruitment of students interested in long-
courses, definitions of ways to maintain academic quality and integ-
the different community colleges, faculty development, design of the
lists their study guides (12) to those that describe the process that took
place to establish online courses and perform evaluations of how using
these have impacted training. Following, we will present some of the
latter.

The Microbiology and Cell Science Department at the College of
Agricultural and Life Sciences at the University of Florida, Gainesville,
FL, has developed an online curriculum to engage underrepresented
minorities in science, technology, engineering, and mathematics (STEM) (13). They realized that in order to increase the number of
minorities in these careers, they needed to increase the number of students from 2 + 2 community college programs that fed into the
university. Using the framework described by Rovai and Downey (14), they had a 3-year planning period that included engagement of
the different community colleges, faculty development, design of the
courses, definitions of ways to maintain academic quality and integ-
rity, and marketing and recruitment of students interested in long-
distance learning. They obtained a grant to finance the program dur-
ing its first years. Their final product was a blended curriculum in
which some theoretical portions of the course were entirely online,
while laboratories and exams were face-to-face. Last, they assessed
outcomes of the program from 2009 to 2014 and showed that dis-
tance education students' experiences were similar to those of the
on-campus students, and that their degree of preparation for the later
2 years in the larger university was equal to that of students who had
done their first 2 years on campus. Their experience suggests that this
program is a way to increase the number of students, particularly underrepresented minorities in science, technology, engineering, and
mathematics.

Conversion of an entire face-to-face microbiology course to one being all online has been done for nonbiology majors in a hospitality
management university (15). To construct the course, faculty had to
adapt the lectures into a written format and add appropriate visual
aids, such as short videos and Flash animation. Faculty needed to
decide on the scheduling of the release of the material so that students
could access it. Evaluations during the course included homework
assignments and chats/discussions (synchronous [live chats] or asyn-
chronous [discussion boards]). However, two components of the
course remained live face-to-face: the laboratory and proctored ex-
aminations. An evaluation of 3 years comparing face-to-face and on-
line courses showed no statistical difference in demographics and
scores, suggesting that the two manners of teaching theoretical con-
cepts are equally satisfactory. The authors comment that posting an
online course requires tremendous amounts of planning and effort,
as just posting a faculty lecture or notes is not enough to engage
trainees. Another group of educators at Texas A&M University, Col-
lege Station, TX, has done a similar conversion of a poultry food
safety microbiology master’s level course and found that many of the
students used the online material to supplement what they had
learned in class rather than using it as a substitute (16). This online
master’s level course consisted primarily of videotaping classroom
presentations and making PowerPoint presentations available to stu-
dents.

Other educators have created an electronic multimedia guide to
laboratory equipment and common microbiology techniques so that
students come to laboratory practices with an idea of what needs to be
done (17). The online material includes video clips, graphics, text,
interactive features, and quizzes on different topics. A comparison of
the test scores of students participating in the laboratory practices that
had not had the online guide versus those who used the online guide
showed that those who used the guide scored statistically significant
higher. This was attributed to the fact that instructors had more time
to dedicate to the laboratory practice itself rather than spend time
teaching basic laboratory skills.

One of the problems with not having a live face-to-face experience
and relying entirely on electronic material is the lack of emotional
impact. This was explored by a group of pathologists and educators
from University of Nebraska, Lincoln, NE, when they compared
medical student training on autopsies (18). Although the emotional
impact of attending an autopsy is likely larger than that in going to the
microbiology laboratory, the fact is that pure online education for
microbiology translates to a lack of engagement with laboratory tech-
nologists if only online education is available. In addition, historically,
an important component of recognizing bacteria includes their odor,
which will not be appreciated online, although many laboratories will
not allow the use of smell for biosafety reasons.

Coursera and EdX are the two largest providers of massive open
online courses (MOOC). Both have partnered with top universities
to create courses that are usually four to 10 weeks long and contain
videos of lectures, quizzes, weekly exercises, peer-graded assign-
ments, and sometimes a final project or exam. Students that take the
courses in the “signature track” receive verified certificates that can be
used for college credit, while those that take it on demand do not.
There are a large number of courses available, including physics, hu-
nanities, biology, mathematics, computer sciences, marketing, and
many others. A group of Danish educators reviewed the course de-
scriptions and found that 165 courses had content that was relevant to
health care providers (19). Courses related to microbiology include
“Bacteria and chronic infections” by the University of Copenhagen
(Copenhagen, Denmark), “Virology: how viruses work” by Co-
lumbia University (New York, NY), and “Antimicrobial stew-
dardship: optimization of antimicrobial practices” by Stanford
University (Stanford, CA).

ELECTRONIC TECHNIQUES IN ADULT MICROBIOLOGY
EDUCATION

Several electronic techniques have been used to increase the engage-
ment of adults in microbiology education. Like what was described in

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child education, the use of short videos in class has become commonplace in adult education. The founders of the Khan Academy are working with university faculty to create videos for higher-level education, including a “reimagined medical training.” These aids can help drive a point and break the monotony of a class, although they do not necessarily engage the audience. Audience response systems (ARS) allow questions to which the audience responds to be added to presentations (Fig. 1). The questions can help the presenter define how much the audience knows about the topic so they can focus on those areas in which knowledge is lacking or review if the concept they just presented was understood. There are several ARS programs available that not only allow an anonymous connection with the presenter but also tally the answers given. Some of the programs use mobile devices, such as smartphones. Chaudhry (20) evaluated a microbiology course using ARS and demonstrated more engagement and increase in scores the year when the ARS was used than those from a year when it was not used.

Complementation of what was presented in class using online material is something that trainees seek (21). Many teachers post a video of their lecture or the material that was presented online; however, these are repetitions and do not engage the trainee. The use of programs that allow engagement by asking questions that have immediate feedback of structured topics has been used to teach microbiology online using a webpage on which case-based microbiology vignettes are housed (http://www.path.emory.edu/Vignettes/username and password MicroV for both) (21). Each vignette contains 8 to 18 questions that need to be answered by the trainees so they can proceed to the end. An evaluation of the online vignettes was done to add microbiology education during an infectious disease rotation that internal medicine residents were taking. A comparison of microbiology knowledge before and after having accessed the online modules during the rotation showed increase knowledge. A blended-learning approach in which some of the case material is online but the students need to present written answers to questions has also been used to teach microscopy in a microbiology course (22).

Nowadays, many of us read textbooks and articles we have downloaded onto our laptop computers, tablets, and other devices. These textbooks and articles have links to the original manuscripts, and readers can access the cited material as they read along. Frank and Dreyer (23) have taken the concept further as it applies to a radiology electronic textbook model. In this concept textbook, there are animations, audio, and interactive modules that engage the reader. They suggest the use of stories, cases, or problems at the beginning of each topic or chapter so that readers better understand the different concepts. Liu (24) has written a piece for which links to virology concepts, many with animations, can be found online, encouraging the integration of electronic media into an article.

Last, many trainees like to test their knowledge using published questions. A free website (http://pathquestions.com/cgi-bin/q.f.pl) that allows users to test their knowledge in medical microbiology was edited by C. A. Burnham, C. Doern, and M. Roger. This website delivers frequent questions to subscribers. Immediately after the question is answered, the authors provide content-rich feedback. Dissemination of the website is by word-of-mouth, as no publications regarding its development or evaluation are available.

SOCIAL MEDIA AND MICROBIOLOGY COMMUNITIES

The use of social media in research is increasing, as it allows networking with collaborators in other cities and countries. Social media is defined as use of electronic communication to create online communities that share personal messages, ideas, and information (1). It includes websites, blogs, and microblogs (e.g., Twitter). The American Society of Microbiology (ASM) has several examples of social media microbiology communities (http://www.asm.org/index.php/subscriptions-listservs). ClinMicroNet is a listserv with which laboratory directors share experiences and collaborate to establish best practices. Other discussion listserv communities sponsored by ASM depend on the particular interest of the individual; for example, DivFNet is for those interested in mycology, while DvKNet is for those interested in microbial physiology. However, there is a gap between awareness and actual use of the social media tools, as shown by a survey of higher-education students in the United Kingdom (25). In this survey, the authors found that only 23% of 13,500 students follow blogs, and 9% blog themselves. Barriers to use include concerns about the quality of what is posted, the time that is required to maintain a social media presence, and the fact that supervisors can actively discourage their use, as their content is not peer-reviewed.

Blogs are online narratives with illustrations that are arranged in a reverse chronological order. People reading the blog can participate by writing their own comments. Conversations ensue as others answer or post questions. Racaniello (26) has created a virology blog, and he has had up to 500,000 readers from 214 countries. People that tap into the virology blog do so through search engines. Racaniello has also used his virology blog to talk about his research. In some instances, he has expressed problems he has encountered in his re-
search and has received advice from readers. This is a cost-free communication system, which is available to the public and allows the participation of those reading the blog.

Podcasts are conversations that are taped and posted on the Internet. V. R. Racaniello and D. Despmomier have created a podcast on virology (This Week in Virology [TwVi]) and one on parasitology (This Week in Parasitology [TwPi]) (26). They accompany the podcasts with a blog. To engage viewers, they post questions and answer them in subsequent episodes. Their podcasts are downloaded by high school, college, and graduate students, a variety of health care professionals, and the public in general.

Scientists working on environmental microbiology have engaged in online networking (27). They seek to have an open (unrestricted) network with which they can create, curate, and share resources (such as educational presentations and early publications), have announcements regarding meetings, and even communicate with the public for participation in projects. They use blogs, Twitter, Facebook, and other media to communicate.

CONCLUSIONS

There is no doubt that the ways we teach, learn, and communicate today have dramatically changed because of all the tools that are available online. It is evident that these tools are being used in the field of microbiology. An enormous revolution is occurring in our field due to the changes in technology: shortly, there will be no more culture plates but bacterial signatures based on mass spectrometry and minimal manual work because of automation. There will be great need to use the electronic tools to communicate new findings, to teach what the new technology does, and how to transition from the classical to the “new” microbiology. We need to keep our minds, eyes, and ears open, as only the future will tell what we will need to learn and teach new generations and what electronic tools we will use.

REFERENCES

Jeannette Guarner was brought up in Mexico City, Mexico, where she obtained her medical degree from LaSalle University. She did her anatomic and clinical pathology residency training at Emory University in Atlanta, GA. After, she returned to Mexico City, where she was the director of the clinical laboratory at the National Cancer Institute. In 1997, she came back to Atlanta and worked at the Centers for Disease Control and Prevention (CDC) in the Infectious Disease Pathology Branch. In 2007, she joined the faculty at Emory University, where she found many opportunities to teach medical students, residents, and fellows. She is professor of pathology and laboratory medicine and the medical director of the Clinical Laboratory at Emory University Hospital in Midtown. She has developed a webpage with interactive case-based modules to teach laboratory medicine, including microbiology.