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Narrative review

E-learning in clinical microbiology and infectious diseases

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ABSTRACT

Background: Becoming and staying competent is a challenge in clinical microbiology and infectious diseases because of dramatic increases in medical knowledge, discovery of new pathogens, emerging infections, new resistance mechanisms and laboratory techniques. E-learning is an effective way of meeting educational needs by providing more efficient and flexible training. E-learning resources have become more important to acquire new knowledge and skills, especially at a time of physical distancing.
Objectives: This review aims to summarize the implementation of e-learning in clinical microbiology and infectious diseases with references to existing examples and resources.
Sources: Literature and online resources for e-learning, online teaching/education in medical education, clinical microbiology and infectious diseases.
Content: The principles and common methods of e-learning and frequently used digital tools are described. For all aspects of e-learning/distance learning, available resources and examples of applications in clinical microbiology and infectious diseases are presented.
Implications: The techniques, tools and resources described in this article should be considered for the development and implementation of e-learning programmes in clinical microbiology and infectious disease training. **A. Arzu Sayıner, Clin Microbiol Infect 2021;▪:1**
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"The only thing that is constant is change" – Heraclitus of Ephesus (*c.* 535 to *c.* 475 BCE)

Introduction

Clinical microbiologists and infectious disease specialists need to be life-long learners due to the discovery of new pathogens, emerging infectious diseases, new therapies, increasing antimicrobial resistance and rapid technological developments. E-learning is an effective way to make learning faster, more efficient and more flexible and to access the latest content when needed in a self-directed manner. Teachers and students increasingly appreciate the role of e-resources in complementing or even replacing other learning materials. A survey among European trainees in clinical microbiology (CM) and infectious diseases (ID) showed that e-learning was useful but only a minority had a chance to experience it, and almost half wanted to have more access to this learning modality [1]. This survey thus identified the limited use of e-learning in CM and ID training programmes in Europe, which is in contrast to other medical fields, such as radiology [2].

COVID-19 pandemic has had a major impact on medical education [3]. Educators are faced with the need to adapt to a changing teaching/learning environment, i.e. virtual classrooms and to use e-learning methods in order to deliver effective education safely. Fellows in training have experienced disruptions in their education due to the cancellation of rotations, the decrease in the variety of patients and the need to focus on meeting the increased workload associated with the pandemic. E-learning techniques have thus become more important in order to fill gaps in education and to acquire new knowledge and skills, especially at a time of physical distancing.

This review aims to summarize the implementation of e-learning in CM and ID training in the light of existing examples. The principles of e-learning and common methods are discussed in the first part, while the second part comprises examples of e-learning applications and existing resources in CM and ID.

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E-learning

E-learning is an approach to teaching/learning that is based on the use of electronic media and devices as tools for improving access to training, communication and interaction and that facilitates the adoption of new knowledge, skills and/or behaviour/attitude [4,5]. It is a flexible and engaging method that includes synchronous and/or asynchronous structured activities, encourages interaction and collaboration. E-learning can be integrated into different teaching approaches. Blended learning and flipped classroom bring online teaching and traditional face-to-face teaching together. In such programmes, the student learns the basic concepts at home, and then the time spent with the expert is used more efficiently for practical teaching and problem solving. Many of these concepts can be used for residency training and continuing medical education [6].

Goals and principles of e-learning

E-learning in medical education should be based on general education principles and a learner-centred educational approach [7,8]. It is essential to support student motivation, to use multimedia principles in creating content, to be selective in learning goals, to use tools that provide multidirectional interaction and to evaluate with measurement tools that focus not only on the result but also on the process [7,8]. E-learning-specific roles of student, teacher and institution require different competencies than face-to-face learning [9]. The role of the teacher evolves from the traditional informer to the facilitator [10].

Advantages and limitations of e-learning

E-learning is an effective way of meeting educational needs by providing time- and place-independent interaction [10]. Developments in education technologies and affordable internet helped e-learning to become a preferred method over the years [11–13]. A systematic review provided evidence that students using the flipped classroom technique had higher educational participation and motivation than traditional methods [14]. In addition, e-learning methods and techniques have emerged as almost the only option to ensure continuity of medical education at all levels during the COVID-19 pandemic [3,15,16]. The intensive e-learning experience, training of trainers and infrastructure investments in this period and the possibility of similar epidemics in the future, strengthen the role of e-learning in medical education [17–22]. Still, acceptance and success of e-learning methods depend on correct application and accessibility [3,23].

E-learning has its advantages and limitations (Table 1). The main limitation is the somewhat compromised communication between the student and the trainer. The trainer should therefore strengthen interaction using all kinds of visual, written and audio sources. An important strength of e-learning is that it allows the use of online open resources to access information. At this point, the educator acts as the organizer and facilitator of learning [9].

Techniques and tools

Online learning offers numerous tools and digital techniques for content creation, interaction and assessment. These include web-based multimedia, virtual patients, simulations, Twitter, podcasts, webinars, massive open online courses (MOOCs), etc. 'Twelve tips' guides are regularly published by the Association for Medical Education in Europe (AMEE) for using of these techniques and tools [24]. The use of simulation in education provides chance for integrating basic and clinical sciences [25]. Online simulations can be virtual patients, laboratory simulations or mathematical simulations where different epidemic scenarios can be created for epidemiology-related goals [9,26,27]. There are many studies indicating that the use of simulation in training has a positive effect on patient care. Simulation-based central venous catheter training given to internal medicine and emergency medicine residents significantly reduced catheter-related bloodstream infections [28]. The virtual patient collection created with an international collaboration during the COVID-19 pandemic has been successfully used in clinical reasoning training [29]. Similarly, MOOCs developed by the Brussels, Montreal and Geneva Medical Schools and used online on Coursera and EduLIB platforms have provided successful results in clinical reasoning training for educators [30].

Designing e-learning

Many instructional design models can be used in e-learning [31]. A good guide for educators new to e-learning is the ADDIE (Analysis, Design, Development, Implementation and Evaluation) model which requires working in five areas. First, an analysis is made to determine learners' needs, trainers' readiness, the state of the technological infrastructure and resources. The design is based on the results of this analysis. The goals should be group specific and meet the current needs [11]. Digital tools should be reliable, user-friendly and suitable for the existing infrastructure, preferably appropriate for use on mobile devices. Then the content is developed (presentation, video, etc.) and the system is set up. The programme should be regularly evaluated, and necessary modifications should be made [32].

Evaluation requires assessment of students and the programme. In evaluating the student, formative and summative (decision-making) assessment methods can be used [33]. For formative assessment, observation of student skills, mini-clinical evaluations and case-based discussions can be performed using digital tools and assignments can be given. Summative evaluation is usually done by final exams and thesis/project presentations. Evaluation of an e-learning programme is crucial and a blueprint including the aims, objectives and anticipated outcomes should be prepared prior to its implementation. However, due to the diversity of e-

Table 1
Advantages and limitations of e-learning

Advantages	Limitations
Choice among various resources in different formats	Intense planning for a successful program/module
Available anywhere at any time	Need for self-motivation and time management skills
Personalized learning and pacing	Lack of face-to-face interaction
Interactive and independent	Lack of emotional impact of learning experience
Networking opportunities	Structured program may lack flexibility
Allowing quality time with the expert in blended learning or flipped classroom teaching	Difficulty in determining the authenticity of the student's work
Opportunity to reach inspiring instructors	Security problems of online programmes
Cost-effective	

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learning methods, assessing the effect of the programme is difficult and there appears to be a lack of validated tools and no consensus regarding the indicators that can be used [5].

Organizations such as The European Accreditation Council for Continuing Medical Education (EACCME) and the American Association of Continuing Medical Education (AACME) provide accreditation for e-learning activities in continuing professional development/continuing medical education (CPD/CME). EACCME introduced accreditation criteria for e-learning materials in 2009. Accredited events can be searched through its web site (https://eaccme.uems.eu/).

Web-based digital tools

The use of digital tools provides motivation, evidence of learning and strengthens communication with the instructor (Table 2). Authoring tools offer the possibility to create individualized e-learning activities with different functionalities. Padlet, which is a kind of digital board, can be used to explain what to learn and to ensure and control the readiness of the learners. Other digital tools widely used in education include Quizizz and Socrative for instant questions and answers, Spiral to obtain written answers to verbal questions, Wooclap for instant content analysis of written responses, Edpuzzle to insert questions between videos and Nearpod to make live lessons more interactive and obtain real-time answers. Padlet, Mural, Mindmeister and Cmap can be used for creating concept maps and group work. Flipgrid, a widely used video platform, is be recommended for performance-oriented studies where students can shoot a live video of a given task and give feedback to each other. Spiral's Teamup feature allows group presentations. Peergrade is another digital tool that can be used to obtain peer feedback for a project or an article. In these tools, feedback can be standardized by using predetermined rubrics, and the person receiving the notification can interpret the received feedback and send it to the trainer.

E-learning resources for clinical microbiology and infectious diseases

To identify the e-learning resources for CM and ID, searches were carried out in PubMed and Google in January 2021, using the terms “e-learning”, “online”, “distance”, “clinical microbiology”, “infectious diseases”, “teaching”, “education” and “learning”. In addition, websites of major institutions and organizations (WHO, ECDC, ESCMID, etc.) were examined for e-learning material. Searches concentrated on finding resources in English which can be used for training and CME and did not intend to provide a comprehensive list of all available online material.

Professional scientific societies offer various platforms for online learning (Table 3). The fact that the content provided by these sites is reliable and up to date is an important advantage [34]. The European Society of Clinical Microbiology and Infectious Diseases (ESCMID) provides an e-library where all the material from conferences, summer schools and courses are available to the members. In addition, presentations of COVID-19 web symposia are free and open to on-demand viewing on the ESCMID YouTube channel. The American Society of Microbiology (ASM) has a resource library that provides links to four previously developed collections containing vetted and reviewed educational resources [35]. These include an image gallery, standard laboratory protocols, a curriculum archive and visual media briefs, which were previously available at MicrobeLibrary.org [36]. The ASM also provides videos including talks, presentations, interviews and training material. The ASM's weekly podcasts related to microbiology, virology and parasitology can be easily searched by topic, audience or publication year. Members of the society can join professional networks through more than 20 Listservs specific to topics ranging from education to clinical laboratory issues. The Infectious Disease Society of America (IDSA) also provides wide range of online learning resources including modules, practice exams, courses for infection control and antimicrobial stewardship.

The primary target audience of the Centers for Disease Control and Prevention (CDC) and the European Centre for Disease Prevention and Control (ECDC) is public health professionals. ECDC has an online learning platform (ECDC Virtual Academy) where free e-learning courses, simulation exercises and training material for trainers are available. E-learning activities are mainly related to communicable disease prevention, preparedness, detection, assessment and control of public health threads. CDC provides wide range of e-learning material including e-courses, podcasts and videos. They have initiated a virtual reality (VR) training project, which already produced a 60-minute VR course on the use of BSL-2 cabinet. Some of the on-demand courses are available for syndication in other learning management systems (LMS). CDC's “E-learning Essentials Guide” helps course developers and training decision makers in the creation of quality e-learning by identifying key instructional components.

Incorporation of non-traditional approaches beyond lecturing enhances the teaching of CM and ID. Videos in particular, offer a flexible, asynchronous information source for learning/teaching practical skills and for reaching large student groups. Professionally produced 3–6 minute teaching videos demonstrating core techniques in microbiology were produced and used for a blended learning approach in NUI Galway, Ireland [37]. Students who used the videos reported increased understanding of the principles, ability to carry out techniques and improved confidence in communicating science. The great international attention the videos received after being widely available through a free YouTube channel (https://www.youtube.com/channel/UCsP4xz5aq7sWfR9eXSCd_QQ) demonstrated the need for such teaching resources. Another use of the videos in e-learning is recording the student's technical performance and review for self-assessment, peer feedback or programme evaluation [38].

Case-based learning materials and virtual patients have unique potential to narrowing the theory–practice gap, developing/

Table 2
Examples of teaching digital tools[a]

Objective	Feature	Programmes
Providing information	Visualization	Canvas, Thinglink, Prezi, Power point, Genially, Microsoft Whiteboard,
	Presenting a concept map	Mindmeister, Mindmodo, Cmap
	Creating a training video	Zoom, Prezi video, Camtasia, Screencastify, Screen Recorder
	Interactive video	EDpuzzle, Nearpod
Creating interaction and evaluation	Team work	Padlet, Zoom, Flipgrid, Spiral
	Interactive and printable activities	Wordwall
	Instant question-answer	Wooclap, Formative, Socrative, Kahoot, Quizlet, Quizizz

[a] https://techagainstcoronavirus.com/edu.

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Table 3
Resources for e-learning in clinical microbiology and infectious diseases

Resource	Website	Description
World Health Organization (WHO)	https://openwho.org/courses	Online courses which can be searched by proficiency level, language, keywords and content
	https://www.who.int/emergencies/diseases/novel-coronavirus-2019/training/online-training	Free COVID-19 online courses
	https://www.who.int/emergencies/diseases/novel-coronavirus-2019/training/simulation-exercise	Simulation exercises to support preparedness for the COVID-19 outbreak
	https://www.euro.who.int/en/health-topics/disease-prevention/antimicrobial-resistance/news/news/2014/05/massive-online-open-course-mooc-on-antimicrobial-stewardship	Online course for antimicrobial stewardship
European Society of Clinical Microbiology and Infectious Diseases. (ESCMID)	https://www.escmid.org/escmid_publications/escmid_elibrary/	Presentations of conferences and courses
American Society for Microbiology (ASM)	https://www.asm.org	YouTube videos Case studies Podcasts (weekly TWiV, TWiM, TWiP) Listservs (for members)
Infectious Diseases Society of America (IDSA)	https://www.idsociety.org	Practice guidelines, courses through IDSA Academy, resources for continuous learning for infectious diseases, antimicrobial stewardship and infection control
	https://www.idsociety.org/professional-development/fellows-in-training-career–education-center/id-fellowship-training-program-director-resources/	Resources to assist program directors in the development and management of infectious diseases fellowship grogram
Pan American Society for Clinical Virology	https://www.pascv.org	COVID-19 resources (free) Case-based virology education content and webinars (members)
Society for Healthcare Epidemiology of America (SHEA)	https://learningce.shea-online.org/course-catalog-list	Courses on antimicrobial stewardship, infection prevention and control, outbreak response
Association of Public Health Laboratories (APHL)	https://www.aphl.org/training/Pages/default.aspx	On-demand training for lab techniques, diagnostic assays, biosafety, tuberculosis, lab informatics
Center for Disease Control and Prevention (CDC)	https://www.cdc.gov/training/development/design/online/index.html	Tools and resources including a guide for creating quality e-learning.
	https://www.cdc.gov/labtraining/syndication.html	Syndication of CDC's laboratory e-learning courses to LMS[a]
	https://www.cdc.gov/labtraining/vr.html	Virtual reality lab training
	https://www.cdc.gov/labtraining?Sort=format%3A%3Aasc	E-learning courses
	https://www.cdc.gov/training/learning/	Searching for training opportunities provided by various resources
	https://www.cdc.gov/labtraining/onelab.html	A network between clinical laboratory training professionals and CDC
European Centre for Disease Prevention and Control (ECDC)	https://eva.ecdc.europa.eu	E-learning courses and training material
Johns Hopkins Center for Clinical Global Health Education	https://main.ccghe.net/education-section	COVID-19 Grand Rounds, clinical case discussions, online courses,
	https://main.ccghe.net/content/johns-hopkins-infectious-diseases-covid-19-grand-rounds	ID Clinical minute (reviewing developments in ID)
	https://main.ccghe.net/content/clinical-case-discussions-and-video-conference-archive	Courses
	https://moodle.ccghe.net	
Emory Pathology e-learning Portal	http://www.path.emory.edu/EPeP/microbiology.cfm	Case-based quiz modules for microbiology (bacteria, mycobacteria, fungi, parasites, viruses)
University of Adelaide Mycology Online	https://mycology.adelaide.edu.au	Descriptions, antifungal susceptibility, lab methods, infections, antifungal therapy, virtual self-assessment
The AMR Studio (Uppsala Antibiotic Center)	https://www.uac.uu.se/the-amr-studio/	podcast dedicated to research on antimicrobial resistance around the world
Hepatitis C online (by University of Washington)	https://www.hepatitisc.uw.edu	Course modules for diagnosis, management, therapy of HepC.
Clinical Virology Network	http://www.clinicalvirology.org/	Links to labs in UK and Ireland, guidelines, virology news, teaching/training resources
ID Images (eMicrobes Digital Library)	https://www.idimages.org	Cases, images, atlas of microorganisms, special collections, self-tests (Joint project of the Massachusetts General Hospital Infectious Diseases Division and Microbiology Lab)
SketchyMicro	https://www.sketchy.com	Visual learning for medical students using videos
NPS Medicinewise learning	https://learn.nps.org.au	Free Courses, podcasts
Coranovirus e-learning programme	https://www.eintegrity.org/e-learning-healthcare-course/coronavirus.html	E-learning healthcare courses Quality assured content. Free (developed by Health Education England)
Case studies in Microscopy	https://courses.cit.cornell.edu/biomi290/microscopycases/	Real life scenarios. Interpretation of the data, analysing results, making a recommendation
Introduction to Diagnostic Medical Parasitology	http://www.parasite-diagnosis.ch/	A training course for important helminth and protozoan diseases of humans with a virtual microscope. Includes basic training to more complicated diagnostic exercises

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Table 3 (*continued*)

Resource	Website	Description
Massive open online courses (MOOCLIST)	https://www.mooc-list.com/	Directory of free online courses from Coursera, edX, FutureLearn, Udacity and other top providers and universities in a wide range of categories and subjects/skills.
NextGenU	https://nextgenu.org/?redirect=0#frontpage-category-combo	Free courses, certificates
BMJ Learning	https://new-learning.bmj.com	Accredited, peer-reviewed, case-based learning modules in text, video and audio formats.
Aquifer	https://aquifer.org	Virtual case-based courses, tools for clinical reasoning skills, Educator guide providing integration ideas and active learning strategies
Access Medicine	https://accessmedicine.mhmedical.com	Medical microbiology cases
Oxford Medicine Online	https://oxfordmedicine.com	Videos, images, diagrams, charts, online books
Clinical Key	https://www.clinicalkey.com/	Books, journals, videos
Roitt's Essential Immunology	https://www.roitt.com/	Interactive questions, animations, videos, podcasts, PowerPoints related to the book

[a] LMS, Learning management system.

improving clinical reasoning and problem-solving skills. They also offer unique opportunity for teaching of rare diseases [39]. Case-based infectious disease modules complemented with before and after tests showed significant improvement in the applied knowledge and problem-solving skills of the participants [40]. Sites such as BMJ Learning, ASM, Aquifer, Access Medicine and Johns Hopkins Center for Clinical Global Health Education provide case studies, some using videos with full differential diagnosis and literature review (Table 3) [41].

Interactive tele-medicine can be a suitable method when structured training needs to be given to a group at a distance or in a large area. In Brazil, a specialization course for clinical microbiology was implemented using 70% distance learning to reach remote laboratory workers in order to improve their professional skills [42]. Monthly evaluations and a final visit to their workplace showed a significant improvement in laboratory practices.

Several universities and institutes provide online programmes for CM and ID education. The University of Edinburgh offers 1–6 years of online learning programmes for CM and ID, providing different degrees depending on the chosen content. The University of Nottingham has a distance-learning CM programme based on a series of modules with particular emphasis on patient management and infection control. The London School of Hygiene and Tropical Medicine has a distance learning programme for ID using a modular approach. The Institut Pasteur provides online diploma of infectious diseases based on MOOCs.

Several other universities, including the Open University, UK, Stanford University and Harvard University, provide free online courses from the beginner to advanced level on a wide range of subjects including microbiology and infectious diseases. Distance learning digital platforms (Coursera, FutureLearn, edX, Udemy, etc.) that have partnered with some leading universities and institutions are useful for searching courses with different contents and proficiency levels.

Another way to reach (and spread) scientific information and expert opinion in a timely manner is to use social media. Twitter is the most popular network used by scientists and clinicians to engage with each other, exchange ideas and information, share images/videos, discuss articles, follow journals or organizations and even to follow conferences as virtual delegates [43]. The tweets can be indexed and searched by the hashtags and linked to other information on the web. Twitter played a fundamental role in global, real-time scientific communication during the COVID-19 pandemic. The first genomic analyses of SARS-CoV-2 and epidemiologic data were circulated through Twitter [44]. Although the user needs to check whether the data are trustworthy, Twitter has and continues to serve as a valuable medium for providing information on epidemiology, diagnosis, prevention and treatment of infectious diseases, when used appropriately [45].

Conclusion

Rapid growth in medical knowledge and technology are immensely changing all aspects of medicine, including education. Residents of the near future will consist of a generation who actively use technology and social media in all areas of their lives and who can access information instantly. The training in CM and ID therefore needs to be changed accordingly. E-learning tools compatible with European core curriculum and free-access will have an important role in achieving a higher level of proficiency by providing more effective, standardized training and adapting to the needs of the learner. E-learning gives educators new roles, for designing and facilitating better learning experiences with the help of digital technologies.

Transparency declaration

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Author contributions

A.A.S. and E.E. drafted the first and subsequent versions of the manuscript.

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