

Medical education challenges and innovations during COVID-19 pandemic

Michail Papapanou,¹ Eleni Routsis ,¹ Konstantinos Tsamakis,^{2,3} Lampros Fotis,⁴ Georgios Marinos,⁵ Irene Lidoriki,¹ Marianna Karamanou,⁶ Theodore G Papaioannou,^{6,7} Dimitrios Tsiptsios,⁸ Nikolaos Smyrnis,² Emmanouil Rizos,² Dimitrios Schizas¹

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For numbered affiliations see end of article.

Correspondence to

Dr Eleni Routsis, First Department of Surgery, Laikon General Hospital, National and Kapodistrian University of Athens, Athens 11527, Greece; routsie@gmail.com

MP and ER are joint first authors.

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ABSTRACT

COVID-19 pandemic has undoubtedly disrupted the well-established, traditional structure of medical education. The new limitations of physical presence have accelerated the development of an online learning environment, comprising both of asynchronous and synchronous distance education, and the introduction of novel ways of student assessment. At the same time, this prolonged crisis had serious implications on the lives of medical students including their psychological well-being and the impact on their academic trajectories. The new reality has, on many occasions, triggered the 'acting up' of medical students as frontline healthcare staff, which has been perceived by many of them as a positive learning and contributing experience, and has led to a variety of responses from the educational institutions. All things considered, the urgency for rapid and novel adaptations to the new circumstances has functioned as a springboard for remarkable innovations in medical education, including the promotion of a more "evidence-based" approach.

INTRODUCTION

As of the beginning of 2021, the COVID-19 pandemic continues to unfold. Several countries have responded to the autumnal/winter second wave of the pandemic by imposing curfews or complete lockdown measures in an effort to limit the viral transmission. However, and despite the spark of hope that the newly introduced vaccines have brought, there have been vast repercussions on the economy and education; one of the fields that the pandemic has substantially affected is the education of future medical professionals.

At the onset of the pandemic, the Association of American Medical Colleges proceeded to the unprecedented decision to suspend clinical rotations, and issued guidance for medical students to avoid activities involving direct patient contact, with many countries adopting similar strategies.¹ From that point on, the dynamic everyday changes brought on by the COVID-19 pandemic and the subsequent social distancing measures have resulted in continuous disruption of the routines of medical students, schools and institutions that have been copiously testing the medical educational systems' adaptability worldwide.

In this review, we explore the impact of the COVID-19 pandemic on the education and

assessment of undergraduate medical students, the repercussions on their mental health and future career plans, while exploring their experience as 'frontline workers', along with the institutional responses to these challenges. We also focus on how this unique period could act as a catalyst for substantial changes and further implementation of the 'evidence-based' approach in medical education.

ONLINE VERSUS FACE-TO-FACE EDUCATION

COVID-19 has already triggered the introduction of new methods of learning in medical education. In an effort not to distract the educational process, the academic institutions worldwide have accelerated the development of online learning environment.² Online distance education (ODE) can be generally delivered to medical students in two main formats: asynchronous distance education, such as recorded videos and podcasts, and synchronous (live) distance education (SDE), such as video conferences and virtual classrooms.³ One of the new models is the 'flipped classroom', which is a blended type of learning mode with an asynchronous component that could allow medical students for more schedule flexibility, and a synchronous component that offers interaction between medical students and faculty members.²

In recent years, SDE has been widely used for educational purposes in health science students. A recent meta-analysis of randomised clinical trials demonstrated a higher overall satisfaction (standardised mean difference 0.60, 95%CI 0.38 to 0.83; $p < 0.001$) for SDE compared with traditional education, showing that SDE was quite acceptable by medical students.³ The adoption of online learning in medical education can have several benefits: one of the most positive aspects of ODE is the flexibility of time and location and the subsequent increased convenience,^{4,5} which means medical students are able to adapt their schedule in an easier way. Besides schedule flexibility, ODE can also be much more cost-effective than classroom-based learning, as it does not require educators to move, while more individuals across different institutions (or even countries) can participate in virtual courses.⁶ In addition, e-learning assists medical students to better adapt to a web-based medical world that increasingly uses digital health services.

On the other hand, ODE can potentially hinder interpersonal contact and interaction between medical students and the faculty members, while



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at the same time it limits the students' opportunities to practise interviewing⁷ and thus cultivate the necessary communication and empathy skills for interacting with patients and their colleagues. Indeed, restricted access to clinical environment is a main obstacle to students' preparation for clinical practice, thus lowering their self-confidence.⁸ Although the lack of hands-on training in the preclinical years may have serious implications on the training of students, which might result in difficulties in the following clinical years, preclinical medical students may experience a lower impact on their education compared with those in the clinical years because preclinical activities are mainly lecture based.^{9–10} During the last year, there have been also serious implications in anatomy education including cadaveric education; medical students are given limited chances to handle basic surgical instruments and thus develop manual dexterity, while having less opportunities to deal with the three-dimensional relationship of anatomical structures.¹¹ Online attempts to substitute hands-on education as much as possible have been made, including demonstrations of practical procedures, remote patient consultation programmes and simulated cases. More such solutions are described in online supplemental table 1.^{12–36}

Furthermore, it is important to consider the technical challenges that online teaching and learning in medical students can pose, which include problems with audio and video, downloading or streaming errors, login problems, poor internet quality, security issues, as well as limited technical skills in both students and instructors.^{37–38} These difficulties can be more evident in developing countries which encounter many more technological challenges compared with technologically advanced countries that can implement ODE much easier.^{13–15}

In summary, the outbreak of COVID-19 has brought on new and unforeseen challenges in the field of medical education, related to the development of online learning. As the shift to online education poses important challenges, medical schools should be prepared to ensure a successful educational environment for medical students through emphasising the tech-based pedagogy, advising, motivating, inviting medical students' feedback, as well as through supporting medical educators to adapt to the new reality.^{39–40} The adoption of online learning is a key strategy for ensuring continuity in medical education during COVID-19 pandemic.

EXAMINATIONS

Another aspect of medical education that has been disrupted by the outbreak of the SARS-CoV-2 is the examinations of medical students.⁴¹ In many countries, clinical and written examinations have been postponed, cancelled or delayed or have been replaced by online examinations or new methods of assessment.⁴² For example, for objective structured clinical examinations (OSCEs), approximately one-third of medical schools in the UK had these clinical examinations cancelled. Four medical schools in the UK adjusted by using actors rather than real patients.⁴³ According to a structured qualitative survey including medical students from 32 UK medical schools, the effect of examination disruptions for both OSCEs and written examinations indicated a significant negative impact on preparedness ($p=0.0005$). On the contrary, the examination disturbances were not significant regarding confidence (written examinations $p=0.369$, OSCEs $p=0.738$).⁴³ With universities and educators having to adapt to the new reality of this pandemic, a debate between open book examinations (OBEs) and closed book examinations (CBEs) has arisen.⁴⁴ Due to the incapacity for organising examinations in person, OBE has been suggested as an alternative tool

of rigorous assessments in medical schools.⁴⁵ For example, at Imperial College London, the online assessment consists of an OBE of 150 questions. Randomising the order of questions for each student was necessary in order to prevent cheating. Medical students were presented with simulated patients and had to answer the requested questions through provided history and findings from clinical examination.⁴⁶ On the one hand, OBE has several advantages, especially in the time of the pandemic. First of all, the use of OBEs discourages medical students to solely memorise information and enhances their critical thinking, their analytical skills, as well as their conceptual understanding of medicine.⁴⁷ OBEs as an assessment for deep learning are more authentic to clinical practice and real-life expectations, reinforcing at the same time evidence-based medicine.⁴⁴ Integration of knowledge from multiple sources and the use of internet, as an invaluable learning tool for medical students, could help medical students to be more self-directed learners, while OBEs may foster deeper processing more effectively and strengthen their long-term memory. This type of assessment also reduces the anxiety surrounding the examination in medical students, who feel less pressured when sitting on a familiar and comfortable location, such as their room in their own home.⁴⁴ On the other hand, traditional CBEs are more familiar to both medical students and professors, and the adaptation to the new reality of OBEs during pandemic could be significantly stressful for them. According to Eurboonyanun *et al*, medical students prefer a traditional CBE over an online OBE.⁴⁸

Grading is also an important factor for medical students during their studies. Comparing fourth-year medical students' scores in the online surgery clerkship assessments with the traditional written examinations shows that mean scores are significantly different which has important implications regarding grading among medical students. Medical students who participated in the online OBE had a significantly higher mean score in both multiple choice questions ($p<0.001$) and essay examinations ($p<0.001$), but a significantly lower mean score in short answer examination ($p<0.001$) compared with the traditional written examinations. On the contrary, the online OBE group had a significantly lower correlation between the essay score ($p=0.005$) and their grade point average (GPA) ($p=0.029$) than the traditional groups.⁴⁸ Such data are essential in order to provide information about the comparison between the two methods of examinations with a view towards the reliable and fair medical students' assessment in the incoming online era.

In summary, OBEs and CBEs can both contribute to a blended assessment programme due to their complementary advantages. Changes enforced by this pandemic offer a vital opportunity to evaluate alternative modes of medical education and assessment.

MENTAL HEALTH

The challenge of going through medical school and medical education in general may contribute to the development of psychological distress such as anxiety, depression and stress among medical students; medical students are recognised as an at-risk group for developing anxiety disorders, with significantly larger rates than the general population, even under normal circumstance.⁴⁹ Medical students typically encounter stressful situations including high workload, many evaluations and assessments, the pressure of clinical environment, numerous responsibilities, anxiety regarding their grades, long hours of studying as well as concerns about their future career.^{50–51} A large systematic review and meta-analysis of 129 123 medical students in 47 countries estimated that the prevalence of depression or

depressive symptoms was 27.2% (95% CI 24.7% to 29.9%, $I^2=98.9\%$) and the overall pooled crude prevalence of suicidal ideation was 11.1% (95% CI 9.0% to 13.7%, $I^2=95.8\%$).⁵² COVID-19 pandemic has been associated with high levels of anxiety and panic, both in the general population and particularly in those working in healthcare settings.⁵³⁻⁵⁵ Imposition of unfamiliar public health measures including social distancing and lockdown, social fear related to COVID-19, closures of universities, fear of being infected by the SARS-CoV-2, anxiety for their removal from clinical practice, worry about older relatives and the abrupt swift to a new reality have negative impact on the psychological well-being of medical students.⁵⁶ While individual studies from Turkey, India and Iran and European countries like Malta⁵⁷⁻⁶¹ showed that the prevalence of depression and anxiety in medical students was significantly high, a recent systematic review and meta-analysis indicated that the prevalence of anxiety in medical students is similar to that prior to the pandemic.⁴⁹ Interestingly, a cross-sectional study showed that medical students' burnout syndrome, depression, anxiety and somatic symptoms rates decreased during online learning.⁶²

On the contrary, sleep quality of medical students appears to have deteriorated during the pandemic, with insomnia, difficulties falling asleep and frequent awakening during the night being commonly reported. Decreased appetite was also reported.^{60 61} Female gender was frequently associated with higher levels of anxiety and depression,^{57 61 63} while other predisposing factors leading to higher levels of psychological distress comprise of low monthly income of the family, lower GPA and experience of COVID-19 symptoms.^{60 61}

Students' mental well-being is of critical importance. Even though data on medical students' mental health during COVID-19 have been somewhat conflicting, early detection and intervention strategies should be implemented in order to help future physicians go through this challenging period and be better prepared for next large-scale crises.

RESIDENCY SELECTION

COVID-19 has an indirect impact on the selection of residency for many medical students at a global level. Due to the necessity for the containment of the contagious nature of this disease, medical students were temporarily removed from clinical settings. The inability to explore the specialties of interest, the loss of electives and core rotations may put more pressure and uncertainty on medical students about their career choice.⁶⁴ Medical students also encounter reduced clinical exposure to the field and limited access to the real-life residency. Research shows that exposure to the specialty of interest is critical for the professional development and strengthens medical students' confidence concerning their possible career choice.⁶⁵⁻⁶⁷ Furthermore, during this new challenging COVID-19 landscape, the input of mentors is probably needed more than ever.⁶⁸ Clinical exposure to positive role models may help some students to pursue a specialty that they had not previously considered. Due to their absence from clinical settings, medical students have limited personal exposure to positive role models and members of faculty and this may negatively influence career decisions and professional identity formation.⁶⁷

Another major concern about residency selection involves disruption of away rotations. Away rotations are elective activities that take place away from the student's academic environment, where students have the opportunity to gain experience with a different hospital, medical record system, faculty and patient population. Elective cancellations due to COVID-19

may induce difficulties not only in regards to away rotations, but also in obtaining meaningful letters of recommendation, as well as obstacles to improving one's curriculum vitae.^{65-67 69} The lack of letters of recommendation, specific grades and geographical preferences raises concerns about application process.⁷⁰ Medical students possibly feel less competitive, as a result of fewer opportunities and this may have a negative impact on their future. Other changes such as implementation of pass/fail grading system, devaluation of US Medical Licensing Examination (USMLE) Step 1 scores, limited access to USMLE 2 will affect students' application for residency selection.^{71 72} The disruptions caused by the pandemic will probably increase the number of applications and discomfort of medical students, while programme directors may rely on less reliable characteristics such as school reputation.

MEDICAL STUDENTS AS 'FRONTLINE WORKERS'

Conflicting views have been expressed on the role of medical students in the frontline of this pandemic.^{42 73-78} Should they have an active role by assisting the management of infected patients, thus gaining valuable clinical experience in times of health crisis, yet with the increased risk of exposure? Should they be assigned responsibilities for patients other than the ones infected, in order to somewhat alleviate their senior colleagues' burden by simultaneously continuing their bedside education, though still not minimising their chances of infection? Should they be entirely kept far from hospitals due to potential inadequacy of personal protective equipment (PPE), training, experience or emotional resilience and focus instead on reinforcing, for instance, their institutions or local communities? It seems that there is no universal commonly accepted view, especially given the variety of student characteristics (eg, pre-clerkship or clerkship, with or without health morbidities) and institutional settings. However, and despite the lack of consensus, the primary aim remains the establishment of a mutually beneficial situation for both students' and health systems' needs, local and governmental policies.

In addition, before medical students undertake roles as 'frontline workers', it is essential to first examine their willingness, motives or competence for undertaking such a role. In the Netherlands, students were eager to priorly arrange all necessary insurance issues and receive basic training in acute care principles, in order to assist their university or even regional health institutions.⁷⁹ In the UK, more than 5500 final-year students have been brought into the workforce, considering this kind of 'volunteerism' as a brand-new opportunity for self-directed clinical and research learning.^{61 80 81} A structured qualitative survey including students from a single institution in the UK found that their basic motivations to voluntarily support the National Health System were to 'contribute', 'learn', 'benefit from remuneration' and 'do something active during national lockdown'.⁸² According to a similar single-institution cross-sectional study conducted in Denmark, 80% of 486 student-participants had decided to join the pandemic workforce, with 'care', 'learning' and 'pride' constituting their top motivations.⁸³ Students also highlighted institutional support, especially in terms of provision of PPE and clarification of study plans, as a matter of top priority.⁸³ In King Saud University of Saudi Arabia, 34.3% and 23.1% of final-year students stated that they were 'willing' or 'somewhat willing', respectively, to contribute to the pandemic workforce.⁸⁴ The same study also demonstrated a positive correlation between willingness and self-perceived student competence in essential clinical skills. Similarly, students of Duke-NUS Medical School

in Singapore who were more willing to return to a clinical environment during the pandemic, exhibited greater internal motivation and sense of professional responsibility, and lower self-perception of harbouring risk to the patients.⁸⁵ Interestingly, one-third of participants in this survey were not in favour of recommencement of clinical rotations.⁸⁵

With regard to students' competence, surveys from Turkey and Iran displayed moderate to high levels of student knowledge on pandemic-related subjects, with the two studies using different testing strategies, yet the same quantitative cut-offs when defining these levels.^{86,87} A recent systematic review also revealed that the implementation of 'pandemic and disaster-themed training programmes' can be an effective intervention in boosting students' knowledge, attitude and skills and enhancing their pandemic preparedness.⁸⁸ Although this would be an ideal scenario, the aforementioned Iranian study interestingly displayed a significant difference in perception of COVID-19-related risks between students being trained in emergency and those trained in non-emergency wards, as well as a significant negative association of risk perception with preventive behaviour.⁸⁷ Haque *et al* further showed that adherence to preventive measures increased with age and educational attainment.⁸⁹ The latter indicate that in spite of knowledge and skills remaining a prerequisite, readiness to respond to pandemic-related duties varies between students and depends on their age, stimuli and experience.

In summary, although the usefulness of medical students acting as frontline workers during COVID-19 has not been universally agreed on, the emerging literature shows that a significant number of students have seen this as an opportunity to learn, volunteer and contribute. Online supplemental table 2 presents several illustrative actions and initiatives of students acting as 'frontliners'^{25 73 79 80 90–95} during the pandemic, which were organised either at a student, institutional or nationwide level.^{25 73 79 80 90–95}

INSTITUTIONAL ADAPTATIONS AND INNOVATIONS

The need for substitution of the daily live and hands-on education during this pandemic has cultivated the incorporation of a variety of innovational ideas into medical education across the world, that have involved the introduction of new technological concepts, and also novel ways for medical educators to interact with their students. All these innovative methods should be carefully examined, as they could constitute a source of future inspiration for medical educators. These encompass social media initiatives, virtual core clerkships and digital clinical placements, new teaching models, sessions of remote patient consultation, even the use of patient simulators.^{12–36} Online supplemental table 1 describes in detail such adaptive ideas, designed and executed by different institutions, groups or organisations during the COVID-19 pandemic.^{12–36}

A 'CRASH TEST' FOR EDUCATION IN THE FUTURE?

It appears that the urgency of the current predicament has forced a rapid transition from the conventional more 'analogue' approach to a more 'digital' model, even in settings in which the utilisation of digital tools was far less extensive.⁹⁶ There are two ways of examining future implications of this unparalleled period, at least as far as medical education is concerned. First and foremost, this pandemic has forced us to realise that medical education can become an extremely vulnerable asset in times of health crises and should not always be taken for granted in its traditional form, especially in the context of future COVID-19 waves and future pandemics.⁹⁷ In Singapore, medical educators

were driven by the past H1N1 pandemic to prepare a contingency plan for similar future crises.³⁴ Creating a hybrid environment of fundamental traditional methods with novel technological tools could solidify the provision of medical education even in times in which its integrity is threatened. As illustrated by the responsiveness of medical educators across the world, used technical means may range from feasible, everyday and easy-to-acquire applications to more complex systems of patient simulators or virtual-reality technologies and holographic representation of three-dimensional objects (online supplemental table 1).^{12–36} Such advanced technologies, however, may not be promptly and broadly incorporated into medical education, especially when considering the negative financial impact of the pandemic on institutions and states.⁹⁸ As Keegan and Bannister highlight, the

Main messages

- ▶ The rapid spread of COVID-19 has the potential to affect medical students physically, academically, financially and psychologically.
- ▶ Medical students have reacted in a variety of ways as frontline workers, according to their personal, institutional and even national needs.
- ▶ Several medical educators during the pandemic have used a 'develop, test and apply' model for educational innovations, reinforcing the concept of 'evidence-based medical education'.

Research questions

- ▶ What was the impact of COVID-19 pandemic on medical education, assessment, career plans, as well as, mental health of medical students?
- ▶ How did medical students react to the COVID-19 pandemic as frontline workers and how did medical educators adapt to these unforeseen circumstances?
- ▶ How can medical education benefit from this predicament in the future?

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Self assessment questions

1. Medical students during the COVID-19 pandemic:
 - a. Have been assigned the same responsibilities across different countries.
 - b. Have totally avoided frontline roles.
 - c. Have reacted in a variety of ways, depending on their personal, institutional and even national needs.
 - d. Have only undertaken roles inside their institutional environment.
2. During the COVID-19 pandemic:
 - a. Student–faculty partnership has been severely and universally undermined.
 - b. Student-centred social media initiatives have been organised.
 - c. Several medical educators have implemented a develop, test and apply model to promote innovative educational programmes.
 - d. An opportunity to reinforce the concept of evidence-based medical education has emerged.
3. The adoption of online learning in medical education can have several benefits:
 - a. One benefit is the flexibility of time and location.
 - b. Online learning can also be much more cost-effective than classroom-based learning.
 - c. Online learning can potentially enhance interpersonal contact and interaction between medical students and the faculty members.
 - d. Restricted access to clinical environment is a main benefit of online learning.
4. During COVID-19 pandemic:
 - a. The disruption of clinical exposure had an indirect negative impact on the selection of residency for many medical students.
 - b. Clinical exposure to positive role models may not help some students to pursue a specialty that they had not previously considered.
 - c. A major concern about residency selection involves disruption of away rotations.
 - d. Implementation of pass/fail grading system, devaluation of US Medical Licensing Examination (USMLE) Step 1 scores and limited access to USMLE 2 will affect students' application for residency selection.
5. During COVID-19 pandemic:
 - a. In many medical schools, clinical and written examinations have been postponed, cancelled or delayed.
 - b. Sleep quality of medical students appears not to have deteriorated.
 - c. Open book examination has been suggested as an alternative tool of rigorous assessments in medical schools.
 - d. E-learning assists medical students to better adapt to a web-based medical world that increasingly uses digital health services.

majority of institutions should first explore low fidelity solutions, such as feasible smartphone applications and the social media, focusing more on policy or mentality modifications and later seek more technologically advanced means.⁹⁸

From another point of view, the educational expeditious amendments that this pandemic has brought might soil the ground for further implementation of 'evidence-based education' in medicine. Many authors have used a 'develop, test and apply' model during

the pandemic, meaning that they developed their own innovational method of teaching or interacting with students, subsequently tested the method by acquiring the students' feedback or by comparing it with a more traditional approach, and then applied it with the ultimate purpose of continuous educational evolution.^{12–30 32–36 99 100} This model can be further implemented in the future. Data on application of a new method, along with its perceived strengths and limitations and results from the students' feedback, may then be published in order to inform or aspire educators from other settings across the world. These methods can prove to be even more efficient from both the educator's and the student's perspective, in case special teams composed for this purpose and consisting of both faculty members and student representatives participate in their development. The 'student–educator interaction' is essential, so that both the concepts of 'evidence-based teaching' and 'evidence-based learning' are combined harmoniously. Mehta *et al* have underlined this partnership as a determining facilitator of smooth curricular adaptation to the status quo of the pandemic.²⁷

CONCLUSIONS

In conclusion, the outbreak of COVID-19 pandemic has forced a rapid transition to online teaching of medicine and introduction of alternative student assessment methods, while it has created challenges in residency selection and future career plans of students, as well as having a significant psychological impact on them. Medical students have undertaken a variety of 'frontline' roles, with their actions being adapted to institutional and national healthcare needs, as well as their own knowledge, experiences and preparedness, which has been viewed by many students as an important learning experience. The urgency of the pandemic has rapidly brought on the development of many innovative educational strategies across the world, the majority of which encompass the use of a variety of digital tools. Such initiatives must act as a stepping stone for evidence-based medical education to thrive even more in the future. More large-scale studies from all over the globe are required to accurately depict how this unparalleled period has affected all aspects of medical education. Along with all the difficulties it brought, this pandemic reminded us that human collaboration through science is one of the greatest tools of humanity to deal with threats. Applying the same collaborative science in education, and specifically in medical education, could raise our optimism for the future of medicine. Education is our future, or in the words of Christine Gregoire: 'Education is the foundation upon which we build our future'.

Author affiliations

¹First Department of Surgery, Laikon General Hospital, National and Kapodistrian University of Athens, Athens, Greece

²Second Department of Psychiatry, 'Attikon' University Hospital, National and Kapodistrian University of Athens, Athens, Greece

³Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, UK

⁴Third Department of Paediatrics, 'Attikon' University Hospital, National and Kapodistrian University of Athens, Athens, Greece

⁵Department of Hygiene, Epidemiology and Medical Statistics, National and Kapodistrian University of Athens, Athens, Greece

⁶Department of History of Medicine and Medical Ethics, National and Kapodistrian University of Athens, Athens, Greece

⁷First Department of Cardiology, Hippokraton Hospital, National and Kapodistrian University of Athens, Athens, Greece

⁸Department of Clinical Neurophysiology, South Tyneside and Sunderland NHS Foundation Trust, Sunderland, UK

Twitter Konstantinos Tsamakias @Ktsamakias

Contributors KT and DS conceptualised and planned the review. MP, ERoutsis and KT searched the literature. MP, ERoutsis, KT and DS wrote the first draft of the manuscript. MP and ERoutsis designed the tables. KT, LF, GM, IL, MK, TGP, DT, NS,

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ORCID iD

Eleni Routsis <http://orcid.org/0000-0002-0480-8520>

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Answers

1. (a) false; (b) false; (c) true; (d) false
2. (a) false; (b) true; (c) true; (d) true
3. (a) true; (b) true; (c) false; (d) false
4. (a) true; (b) false; (c) true; (d) true
5. (a) true; (b) false; (c) true; (d) true

Author	Institution	Country	Innovation / program	Short description	Technical means/ applications
Alkhowailed et al. ¹²	Qassim University & Cairo University	Saudi Arabia	Organized digitalization plan during COVID-19 lockdown	Composition of digitalization committee that designed new sessions for problem-based and team-based learning & survey on students' feedback	Blackboard learning management system, Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA), WhatsApp application
Bhaskar et al. ¹³	Faculty of Medicine, Macau University of Science and Technology	China	Online spirometry practical demonstration	Online spirometry practical demonstration with students' involvement in analysis of graphs by remote control	Vernier Go Direct wireless spirometer, laboratory technician, Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA)
Chandra et al. ¹⁴	Sidney Kimmel Medical College, Thomas Jefferson University	USA	Virtual emergency medicine clerkship	Review of electronic health records & subsequent video calls to patients previously evaluated in the ED	Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA)
Darnton et al. ¹⁵	School of Clinical Medicine, University of Cambridge	UK	Remote patient consultation	Remotely supervised medical students who undertook remote patient consultations & assessment of this educational intervention	Microsoft Teams, AccuRx (a clinical video consultation tool) or telephone
De Ponti et al. ¹⁶	School of Medicine, University of Insubria	Italy	Medical training including virtual reality	Online training sessions using an online virtual reality platform with simulated clinical scenarios of patient-based cases	Body Interact™ Clinical Education, TakeTheWind, Coimbra, Portugal
Durfee et al. ¹⁷	Brigham & Women's hospital, Harvard Medical School	USA	Virtual Radiology Core Clerkship	Large didactic lectures, online flipped modules, small-group homework activities, standardized online exams & survey on students' feedback	Aquifer, Inc modules, Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA), moderator for control of the chat room
Finn et al. ¹⁸	Hull York Medical School, University of York	UK	The #pandemicpedagogy social media initiative for knowledge exchange	Live Twitter chats to engage the wider academic community in an exchange of ideas around adaptation of teaching methods during the COVID-19 pandemic by using the hashtag #pandemicpedagogy	Twitter (Twitter Inc., San Francisco, CA, USA)

Flotte et al. ¹⁹	University of Massachusetts Medical School, University of Massachusetts Memorial Medical Center	USA	Accelerated graduation and system of early deployment of new physicians	Composition of a review board that determined whether 4 th year medical students fulfilled criteria for 2-month earlier graduation – new physicians were deployed as limited-licensed physicians, called “surge contractors”	NR
Hall et al. ²⁰	Faculty of Medicine, University of Southampton	UK	Online Neuroanatomy education	Implementation of the already developed SotonBrainHub website with online educational content & recorded lectures on neuroanatomy, head & neck anatomy & cranial nerve examination	SotonBrainHub website, Youtube channel & Instagram account
Huddart et al. ²¹	The “Becoming A Doctor” UK-based national organization supporting medical students, representatives from General Medical Council, Health Education England, National Health Service England & the World Health Organization	UK	The #MedStudentCovid social media initiative	A 1-hour Twitter discussion addressing medical students’ uncertainty over pandemic-related disjointed information & promoting student initiatives dealing with COVID-19 – responses by the invited representatives from various organizations contained the hashtag #MedStudentCovid so that they are easily accessible by all participants	Twitter (Twitter Inc., San Francisco, CA, USA)
Iqbal et al. ²²	College of Medicine, Imam Abdulrahman Bin Faisal University	Saudi Arabia	Use of the Telegram application for supplementary medical education	Access to educational resources – addition of unlimited members & uploading of multiple files in all formats and size to facilitate online learning – qualitative survey on students’ feedback	Telegram application
Jeong et al. ²³	University of Washington School of Medicine	USA	Virtual peer teaching	Online clinician teacher elective & virtual peer teaching	NR

Joseph et al. ²⁴	Brighton, Sussex & Bristol Medical Schools, Medical Schools Council, Health Education England	UK	Collaborative effort for sharing of online content	Sharing of online resources between different medical schools by developing the online platforms “Capsule” (developed by Brighton and Sussex Medical School) and “Speaking Clinically” (Bristol Medical School); sharing also available by “Health Education England” (e-Learning for Healthcare Hub) & supported by the national academic mailing list service, “JiscMail”	Online platforms, “Capsule”, “Speaking Clinically” & national academic mailing list, “JiscMail”
Kochis et al. ²⁵	Harvard Medical School	USA	Student-led development of a COVID-19 curriculum (educational for the students who designed it & all its users)	Faculty reviewed, available online & constantly updated learning resource that summarizes the most valuable educational material about the pandemic, all designed by medical students	NR
Lieberman et al. ²⁶	University of Washington	USA	Development of MedSci 585C, an online-only clinical pathology clerkship program	Remote clinical pathology clerkship program with mixed-formatted lectures, student presentations & participation in clinical conferences, rounds & discussions (also on pandemic-related subjects)	Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA), Zoom “breakout room” feature for small groups, cloud-based Canvas Learning Management System (Canvas GFX) for distribution of course material and submission of assignments
Mehta et al. ²⁷	Faculty of Medicine, University of Toronto	Canada	Student-faculty partnership as an enabler of curricular adaptation to the standards of the pandemic; establishment of the weekly “MD EducationMatters” educational newsletter	Contribution of students in decision making with regard to curricular modifications (minimization of students’ anxiety in front of changes); establishment of a weekly educational newsletter covering topics requested by students & perspectives of faculty members from the frontline	NR

Parker et al. ²⁸	University of Washington	USA	Remote anatomic pathology program	Lectures, discussions, virtual slides, case-based activities (“Detective Case”, “Good Will Hunting Case” – program comprising of 10 big topics with both morning and afternoon sessions	Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA), Microsoft PowerPoint, the PathPresenter online digital platform, Canvas Learning Management System (Canvas GFX), Microsoft Teams (Microsoft)
Roberts et al. ²⁹	University of Bristol	UK	Peer-led teaching sessions	Re-adjustment of peer-led teaching sessions by a university medical students’ society: re-training of tutors on how to deliver & designing of 2 teaching branches; 4 th year teaching 3 rd year students symptom-based medicine & surgery topics, and 3 rd year teaching 2 nd year students systems-based pathology	Online meeting platform, PowerPoint
Roskvist et al. ³⁰	University of Auckland	New Zealand	Online programs for replacing clinical general practice attachments	E-learning program composing of 3 domains: asynchronous discussion; a symposium for social interactions and contact with faculty; and a portfolio for personal goal aspects	Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA), Goodfellow Unit continuing professional development website, BMJ Learning modules
Sam et al. ³¹	Imperial College London	UK	Digital clinical placement	Weekly set of interactive cases for students (including history, physical examination findings, investigation and management plan) on an online platform – discussion of cases in webinars – supplementary video cases	Online platform for patient data, cloud-based tool for interaction during webinars

Singh et al. ³²	All India Institute of Medical Sciences	India	Online classroom	Implementation of an online classroom environment by adopting “G Suite for Education”	“G Suite for Education” – “Google Classroom” for the online classroom environment & “Google Meet” for video-conferencing
Tabari et al. ³³	Clinical Education Research Center, Shiraz University of Medical Sciences	Iran	Online peer- and faculty-led educational and psychological support for medical students	Recruitment of faculty members, academic coaches & senior medical students to support junior peers with psychological & educational issues through virtual peer mentoring & online conversations	NR
Tan et al. ³⁴	National University of Singapore	Singapore	Simulated patient-based exams	Assessment of history-taking skills and ability for detection of abnormal signs using models of body parts and Harvey mannequins	Body part models, Harvey mannequins
Torres et al. ³⁵	Medical University of Lublin	Poland	Simulation-based teaching	Electronic simulated patient data system – students’ remote ordering of laboratory and imaging tests – instructor receives orders and returns the results to update the patient scenario	SimMan 3G (Laerdal, Stavanger, Norway); a technician (substituting for 'students' hands'); patient's monitor; instructor; Zoom™ (Zoom Video Communications Inc., San Jose, CA, USA)
Wickemeyer et al. ³⁶	University of Illinois at Chicago	USA	Adoption of the “R4 teaching model” for remote medical student education in Otolaryngology	Adoption of the R4 model which consists of “Read” (background information), “Respond” (to questions developed by faculty), “Review” (online with faculty) & “Realize” (application of knowledge & decision-making) – model includes real patient cases, journal clubs, interactive quizzes, flipped classroom, and attending-lead discussions on social justice & bioethics	NR

Supplementary table 1. Educational innovations and adaptations during the COVID-19 pandemic. Abbreviations: USA, United States of America; UK, United Kingdom; COVID-19, Coronavirus Disease 19; BMJ, British Medical Journal; NR, Not Reported.

Author	Institution	Country	Initiative/ action	Short description
Kochis et al. ²⁵	Harvard Medical School	USA	Student-led development of a COVID-19 curriculum (educational for the students who designed it & all its users)	Faculty reviewed, available online & constantly updated learning resource that summarizes the most valuable educational material about the pandemic, all designed by medical students
Wang et al. ⁷³	Medical deans Australia & New Zealand	Australia & New Zealand	Release of a statement outlining specific roles for final-year medical students	Final-year medical students involved in a variety of clinical settings, undertaking roles with which they are already familiar
Bosveld et al. ⁷⁹	Maastricht University Medical Centre & Maastricht University	Netherlands	Students assigned supportive tasks in the ICU	Senior undergraduates involved as supportive staff for nurses (tasks such as washing/ shaving patients, collecting blood samples, making ECGs, completing charts, turning patients to supine/ prone position, transporting samples or other necessary material & participating in ALS teams)
Ding et al. ⁸⁰	All UK Medical Schools	UK	Formal participation of over 5,500 medical students in the NHS workforce	Provisional registration for final-year medical students to initiate their Foundation Interim Year 1- students without provisional registration undertook responsibilities of porters/ phlebotomists or healthcare assistants
Aron et al. ⁹⁰	Columbia-Bassett Track at Bassett Healthcare & Columbia University Vagelos College of Physicians and Surgeons	USA	The student-led Pandemic follow-up clinic	Telephonic follow-up of vulnerable patients by medical students – prioritization of patients according to social/ geographical status

Boodman et al. ⁹¹	University of Manitoba, Winnipeg	Canada	Student research teams – release of updated weekly newsletter	Clinical medical students integrated into inter-professional research teams to produce a weekly newsletter as a direct response to COVID-19-related questions by doctors – separate section also for pediatric concerns
Lapolla et al. ⁹²	All Medical Schools of Italy	Italy	Fast-tracking of almost 10,000 Italian final-year medical students into the healthcare system after graduation	Permanent change in graduation policy of final-year medical students – rules of Italian board examinations were changed according to the “Cura Italia” Decree passed by the Council of Ministers
Long et al. ⁹³	Penn State College of Medicine	USA	Student-led “COVID-19 Response Team”	A voluntary “response team” formed by student leaders & staff with the aim of identifying and prioritizing students’ duties not only according to the health system needs but also outside the health care workforce (e.g., medical school, local community)
Rupley et al. ⁹⁴	Columbia University Irving Medical Center	USA	Student-led “COVID-19 Student Service Corps”	A voluntary COVID-19 pandemic response initiative organized by both students and faculty with four categories of service-learning projects for students: Patient-facing; Faculty, Staff and Student-facing; Community-facing; and System-facing.
Soled et al. ⁹⁵	Harvard Medical School	USA	“COVID-19 Medical Student Response Team”	A voluntary student-led response team serving as a mobilizer of peers & a linkage to the institutional administration & hospital leaders – 4 virtual committees assigned the following tasks: Education for the Medical Community, Education for the Broader Community, Activism for Clinical Support, and Community Activism

Supplementary table 2. Examples of initiatives/ actions involving medical students as “frontline workers” during the COVID-19 pandemic. Abbreviations: Abbreviations: USA, United States of America; UK, United Kingdom; COVID-19, Coronavirus Disease 19; ED, Emergency department; PCR, Polymerase chain reaction; ICU, Intensive care unit; ECG, Electrocardiogram; ALS, Advanced life support; NHS, National Health System; NR, Not Reported.