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BEME GUIDE

Remote learning developments in postgraduate medical education in response to the COVID-19 pandemic – A BEME systematic review: BEME Guide No. 71

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ABSTRACT

Background: Prior reviews investigated medical education developments in response to COVID-19, identifying the pivot to remote learning as a key area for future investigation. This review synthesized online learning developments aimed at replacing previously face-to-face 'classroom' activities for postgraduate learners.

Methods: Four online databases (CINAHL, Embase, PsychINFO, and PubMed) and MedEdPublish were searched through 21 December 2020. Two authors independently screened titles, abstracts and full texts, performed data extraction, and assessed risk of bias. The PICRAT technology integration framework was applied to examine how teachers integrated and learners engaged with technology. A descriptive synthesis and outcomes were reported. A thematic analysis explored limitations and lessons learned.

Results: Fifty-one publications were included. Fifteen collaborations were featured, including international partnerships and national networks of program directors. Thirty-nine developments described pivots of existing educational offerings online and twelve described new developments. Most interventions included synchronous activities (*n* Fif5). Virtual engagement was promoted through chat, virtual whiteboards, polling, and breakouts. Teacher's use of technology largely replaced traditional practice. Student engagement was largely interactive. Underpinning theories were uncommon. Quality assessments revealed moderate to high risk of bias in study reporting and methodology. Forty-five developments assessed reaction; twenty-five attitudes, knowledge or skills; and two behavior. Outcomes were markedly positive. Eighteen publications reported social media or other outcomes, including reach, engagement, and participation. Limitations included loss of social interactions, lack of hands-on experiences, challenges with technology and issues with study design. Lessons learned highlighted the flexibility of online learning, as well as practical advice to optimize the online environment.

Conclusions: This review offers guidance to educators attempting to optimize learning in a post-pandemic world. Future developments would benefit from leveraging collaborations, considering technology integration frameworks, underpinning developments with theory, exploring additional outcomes, and designing and reporting developments in a manner that supports replication.

KEYWORDS
Best evidence medical education; remote learning; online learning; postgraduate medical education; COVID-19

Background

Since the emergence of COVID-19 and its evolution into a global pandemic (Johns Hopkins Coronavirus Resource Center 2021), the approach to postgraduate medical education (PGME) has dramatically changed. Educational programs and accreditation bodies collectively adapted to new realities (Nasca 2020) and programs pivoted to distance learning for residents, fellows, and practicing physicians. While workplace-based learning in PGME largely continued, conferences and traditional 'classroom' activities (e.g. core content and specialty-specific lectures, grand round presentations, small groups, workshops, journal clubs, pathology and radiology image reviews, and procedural skills practice) had to pivot to online formats.

The rapid shift to online learning during the COVID-19 pandemic has been contextualized through the lens of 'emergency remote teaching' (ERT). This was defined by Hodges et al. (2020) as a temporary shift of instructional delivery to an alternate mode prompted by crisis circumstances. ERT placed immense strain on medical educators, who persistently innovated and adapted, despite personal burnout, and physical and emotional exhaustion. The initial

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Supplemental data for this article can be accessed here.

Practice points

- Design a hybrid future state that optimizes flexibility for postgraduate medical education (PGME) learners, while ensuring opportunities for in-person connections.
- Leverage collaborations to address common educational needs (e.g. common core requirements) and to extend access, regionally, nationally, and internationally.
- Apply technology integration frameworks (e.g. the PICRAT) to amplify or transform teaching, and augment learner interactivity and creativity.
- Underpin work with theories, considering both traditional learning theories (e.g. active learning theory) and emerging online learning theories (e.g. technology enhanced learning, Mayer's multimedia principles, and the ADDIE instructional design model).
- Design and report educational developments in a manner that attends to quality, using tools, such as the MERSQI as a guide.

goal of ERT was to provide continued access to instruction during the acute emergency. The educational innovations that emerged during ERT were not necessarily intended as long-term solutions, yet their success, as well as the prolonged nature of the pandemic, has meant that many online interventions have persisted. Now educators are trying to make informed decisions about what should remain in a post-pandemic world.

Dedeilia et al. (2020) previously conducted a systematic review of educational developments in response to COVID-19 with a search end-date in April 2020 and noted early on a 'scarcity of available sources.' Our review team followed this work with additional reviews to assess the emerging COVID-19 education landscape; a rapid systematic review (Gordon et al. 2020) followed by a scoping review (Daniel et al. 2021) to map the rapidly expanding body of literature. The team identified numerous developments focused on the pivot to online learning (*n* to8), several developments on simulation (*n*), 4), and smaller numbers of developments in other important areas (e.g. interviews, assessment, and well-being). The team noted that some of these areas, including the pivot to online learning, would benefit from future in-depth reviews to further characterize the innovative work being done.

The aim of this systematic review was to synthesize published reports of developments in PGME in response to the COVID-19 pandemic, focusing on the pivot to online learning or de novo developments in remote learning for non-workplace-based (i.e. classroom or conference) activities. This review was conducted as one of three parallel reviews. The other two focused on pivots from 'classroom' learning in Undergraduate Medical Education (UGME) (Stojan et al. 2022) and workplace-based learning across the UGME – PGME continuum (Grafton-Clarke et al. 2021). Classroom activities in PGME have historically been episodic, comprising a smaller proportion of a learners' total time, with distinct educational goals compared to UGME. Thus, we considered these innovations as a distinct subset of the online innovations that emerged during COVID.

This review specifically addressed the following:

- What novel solutions or developments in medical education were deployed for postgraduate learners in response to the COVID-19 pandemic as institutions pivoted to remote/online learning? (i.e. description or 'what was done').
- What was the impact of these changes in response to the COVID-19 pandemic? What educational (i.e. Kirkpatrick's), social media, or other outcomes emerged in response to these medical education developments? (i.e. justification or 'did it work?').
- What lessons to be applied in the future were learned and what conclusions were drawn by the teams who deployed these developments or changes? (i.e. implications or 'what's next?').

Methods

This review was conducted rapidly (~16 weeks), yet with methodological rigor, with an aim of providing educators actionable and timely information to build upon during the ongoing pandemic. Systematicity was employed throughout the process, from search strategy to synthesis, following the approaches outlined by Gordon, Daniel, et al. (2019). The search strategy was developed by a librarian using the Accelerator Polyglot search translation tool (Clark et al. 2020), as previously outlined by Daniel et al. (2021). A study protocol containing the complete search strategy was completed a priori and uploaded into the study repository on the Best Evidence in Medical Education (BEME) website (Khamees et al. 2020). We reported our findings in alignment with BEME guidance (Hammick et al. 2010), as well as the STructured apprOach to the Reporting In healthcare education of Evidence Synthesis (STORIES) statement (Gordon and Gibbs 2014).

Search strategy

The intent of this search was to update and add to the searches previously conducted by Gordon et al. (2020) and Daniel et al. (2021). Consistent with the search strategy in the prior reviews, we searched four electronic databases (CINAHL, Embase, PsychINFO, and PubMed). Additionally, a manual electronic search of MedEdPublish was performed. The searches were run on 21 December 2020. The PubMed date limit was set from 1 August 2020 to present, overlapping the Daniel et al. (2021) review by one month to ensure no publications were missed. All other databases were searched from 1 January 2020 to present, as they do not have an option to delineate by month. Collectively, the search date range for all databases was 1 January 2020–21 December 2020, when the prior reviews were added to this review. Citations were uploaded into a data management system (DistillerSR – Evidence Partners, Ottawa, Ontario, Canada). Initial deduplication was conducted in Endnote using the modified Bramer method (Bramer et al. 2016), and further deduplication was conducted in DistillerSR.

Study selection

The following inclusion criteria were used:

- The study described a development in medical education explicitly deployed in response to COVID-19.
- The study involved a pivot to online learning or a novel remote learning development intended to continue learning previously delivered face-to-face in classrooms or similar 'non-clinical' or 'non-workplace' environments.
- The study was in PGME.
- The study included postgraduate learners (e.g. residents, fellows, or physicians).
- The study described Kirkpatrick's outcomes (Level 1: satisfaction/reaction; Level 2a: changes in attitudes; Level 2b: changes in knowledge or skills; Level 3: behavioral changes; Level 4a: changes in organizational practice; Level 4b: change in clinical outcomes) (Kirkpatrick and Kirkpatrick 2016) OR other outcomes (e.g. social media metrics).
- The study was in any language.
- The study was published as any article type (including abstracts in order to capture early efforts), *as long as the development was deployed and outcomes were described.*

The following exclusion criteria were applied:

- The study was an opinion piece, letter to the editor, perspective, commentary, call for change, needs assessment, abstract or other study *where no actual development was deployed and no outcomes were described*.
- The study only included other healthcare professionals or undergraduate medical students.
- The study described remote or distance learning explicitly deployed to replace workplace-based (clinical) learning or simulations.

Titles and abstracts were reviewed independently by pairs of two authors, with eight total reviewers (DK, WP, JS, CP, AH, HU, CGC, and MD) against the above inclusion and exclusion criteria. Inter-rater reliability was calculated using Cohen's Kappa (McHugh 2012). Full texts were also screened independently by pairs of two authors in multiple stages (DK, WP, JS, CP, AH, HU, CGC, and MD), with reasons for exclusion at each stage documented. In Stage 1, we used the full text screening form previously published by Daniel et al. (2021). This allowed us to identify and categorize all new developments in medical education since our last review. In Stage 2, we screened out all developments from the prior two reviews (Gordon et al. 2020; Daniel et al. 2021) and this updated search which were not explicitly focused on the transition to online learning. In Stage 3, we grouped these developments into three categories: 1) remote learning intended to replace 'classroom' (i.e. non-workplace-based) learning for *undergraduate* learners, 2) online learning intended to replace 'classroom' learning for *postgraduate* learners (this review), and 3) remote learning aimed at continuing workplace-based learning across the continuum. Disagreements at all stages were resolved through discussion, including a third author where necessary, until consensus was reached.

Data extraction

Based on BEME guidance we devised a data extraction form and posted it online in Google Sheets to allow synchronous review and sharing of extracted data. Key items included in the data extraction sheet were:

- Article identifiers (authors, title, journal, type of article, and month of publication).
- Context (type and number of learners, specialty, region of origin, organization responsible, and collaborations).
- Characteristics of the educational development (focus, synchronicity, and techniques used to increase virtual engagement).
- Purpose of development.
- Summary of development (description).
- Intervention classification (category and PICRAT coding – see below).
- Resources (financial cost, time, and material resources needed to implement).
- Explicit theories or frameworks underpinning development.
- Outcome measures (Kirkpatrick's, social media metrics, or other outcomes).
- Summary of results.
- Limitations as reported by the authors.
- Lessons learned as reported by the authors.
- Conclusions as reported by the authors.
- Risk of bias (of study reporting and study methodology – see below).

To pilot the approach, two publications were extracted by all authors and an extraction team meeting was held to ensure that all authors had a shared understanding of the categories. Pairs of authors were then assigned a group of primary publications. Pairs of authors (DK, WP, MaD, CC, MaG, MS, AA, and CP) independently extracted information and then met to ensure consensus. Discrepancies were resolved through discussion or by involvement of the senior author (MD).

PICRAT technology integration framework

We categorized interventions based on author descriptions (e.g. online didactics and remote simulation). We then examined the extent to which teachers integrated technology and promoted learner engagement during the pandemic by applying a technology integration framework known as the PICRAT (Kimmons et al. 2020). PIC stands for Passive, Interactive or Creative and describes a learner's relationship to technology. RAT stands for Replaces, Amplifies or Transforms and describes a teacher's use of technology. To use the tool, two phrases were filled out: 1) the student's relationship to technology was _____ (passive, interactive, or creative), and 2) a teacher's use of technology _____ (replaced, amplified, or transformed) traditional practice. The resulting combinations of letters (i.e. PR, IR, CR, PA, IA, CA, PT, IT, and CT) were plotted on a matrix that represents a technology integration continuum.

Table 1. Quality assessment/risk of bias of the interventions presented.

Bias source	High quality	Unclear quality	Low quality
Underpinning bias (U)	Clear and relevant description of theoretical models or conceptual frameworks that underpin the development	Some limited discussion of underpinning, with minimal interpretation in the context of the study	No mention of underpinning
Resource bias (R)	Clear description of the cost/time/ resources needed for the development	Some limited description of resources	No mention of resources
Setting bias (S)	Clear details of the educational context and learner characteristics of the study	Some description, but not significant as to support dissemination	No details of learner characteristics or setting
Educational bias (E)	Clear description of relevant educational methods employed to support delivery	Some educational methods mentioned but limited detail as to how applied	No details of educational methods
Content bias (C)	Provision of detailed materials (or details of access)	Some elements of materials presented or summary information	No educational content presented

The patterns revealed aided our understanding of the complex, messy phenomena of technology integration during COVID.

Quality assessments

Two major quality assessment areas were considered: quality of the study methodology and quality of study reporting to support replicability. Quality of study methodology was assessed using the Medical Education Research Quality Instrument (MERSQI) for evaluation of medical education developments (Reed et al. 2007; Cook and Reed 2015). Quality of reporting was assessed using a visual RAG (red/amber/green) ranking system. The tool has been previously used by Gordon, Farnan, et al. (2019) and Gordon et al. (2018) and was originally modified from Reed et al. (2005). The visual RAG ranking system was used to report risk of bias across five areas (underpinning, resource, setting, educational methods, and content). Items were judged to be of low quality and high risk of bias (red), unclear quality and risk (amber), or high quality and low risk of bias (green). This ranking system is shown in Table 1. Judgments for risk of bias were made independently by two authors and disagreements were resolved through discussion or involvement of a third author. Of note, poor reporting did not necessarily imply that the educational development was of poor quality, but it did increase the risk that poor quality existed.

Synthesis of evidence

Description. A narrative description was produced, summarizing the data from the extraction form. A visual infographic was also utilized to present key data, similar to Daniel et al. (2021).

Justification. Kirkpatrick's outcomes, as well as other outcomes (e.g. social media metrics) were summarized. While homogenous outcome data was considered for meta-analysis, the heterogeneous nature of interventions meant comparison was not feasible.

Implications. Direct quotations were extracted from papers concerning limitations and lessons learned. We produced a thematic analysis according to the procedures outlined by Clarke and Braun (2013).

Results

A total of 11,111 publications were found *via* database search, as well as 23 additional publications identified by hand search. After duplicates were removed, 7164 publications underwent title and abstract screening, resulting in the further exclusion of 6742 records. Of note, during deduplication, it was noted that a single educational development generated two abstracts with different author orders (Raber et al. 2020; Shayer et al. 2020), one which analyzed the quantitative data and one which represented qualitative data. We treated these as a single development throughout. Screening phase inter-rater reliability was $\kappa = 0.91$, suggesting excellent agreement. The 422 remaining publications underwent full-text review. Of these, 283 were excluded in Stage 1 for the following reasons: the development was not in medical education or not explicitly deployed in response to COVID-19 (*n* fo9), participants did not include medical students, residents, or physicians (*n*), 7), the article was an opinion piece, perspective or survey that did not describe an actual development (*n* esc21), or no outcomes were reported (*n* 1),6). This left 139 publications, of which an additional 58 were excluded in Stage 2 as they did not focus on remote or online learning. Ultimately, 81 publications pertaining to online learning were identified in this update. These were added to 81 publications on remote learning from the prior reviews by Gordon et al. (2020) and Daniel et al. (2021). These 162 publications were then divided into three categories forming the basis of 3 parallel reviews. Fifty-one publications were categorized as postgraduate, online learning pivots or de novo remote 'classroom' activities and thus were included in our final analysis. This process is represented by Figure 1.

The data extracted from all the publications included in this review appears in Supplementary Appendix 1. This data has been collated and presented in a visual summary in Figure 2. For brevity, in the sections that follow, we decided not to list all publications relevant to each results section if this data could be readily found in Supplementary Appendix 1 or Figure 2.

Geographic origin of publications

The origins of publications by region are shown in Supplementary Appendix 1, column region and Figure 2,

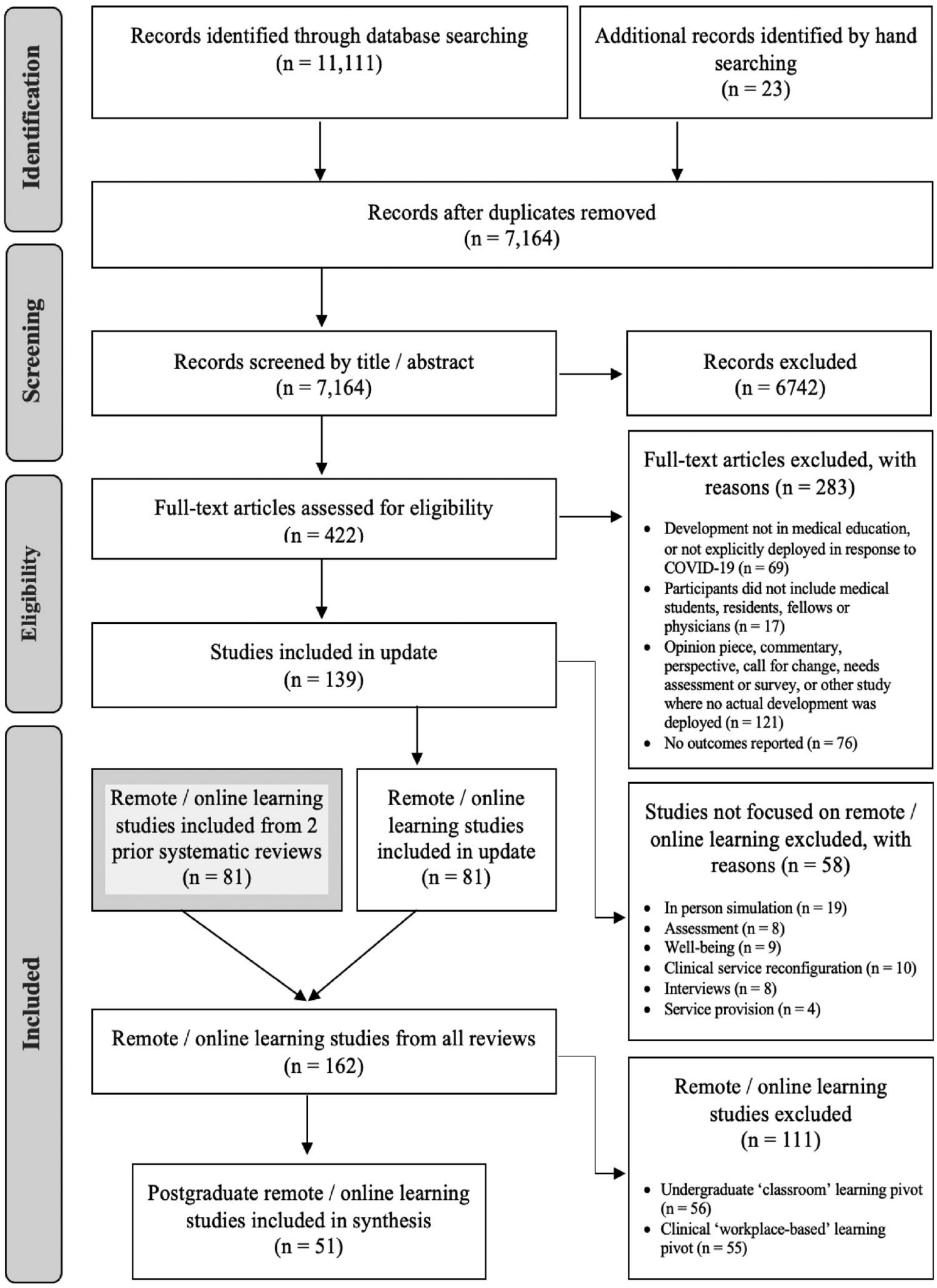

Figure 1. PRISMA flow diagram for included studies.

origin of publication. North America accounted for the majority of publications with 30 (58.8%) from the United States and 4 (7.8%) from Canada. The remainder were distributed across Europe (*n* No, 15.7%), Asia (*n* 15, 9.6%), the Middle East (*n* 9., 3.9%), and Oceania (*n* and, 2%). Only one study (2%) was international.

Month of publication

Our last review ended 9 September 2020 (Daniel et al. 2021). This review found an additional two publications from August 2020 (Aulakh et al. 2022; Hahn 2020). These were likely in press at the time of the previous search. October was the month with the most publications (*n* . T4). The next most productive months (May, July, August, and September) produced 6–8 publications each. Our search only resulted in 1 article for December, but there may have been additional publications following our search date (see Supplementary Appendix 1, column month of publication and Figure 2, month of publication).

Types of publication and journals where developments were published

We identified 30 full length articles, which accounted for a majority of our total publications (58.8%). The remaining publication types included 12 brief reports or innovations (23.6%), four letters to the editor (7.8%), and five abstracts (9.8%). Most developments (76.5%) were published by journals whose main focus was not specifically or exclusively medical education, while only 12 (23.5%) developments were published by journals with a focus on medical education. The majority of these (*n* bst) were brief reports or innovations, which were only 1–2 pages in length. *Medical*

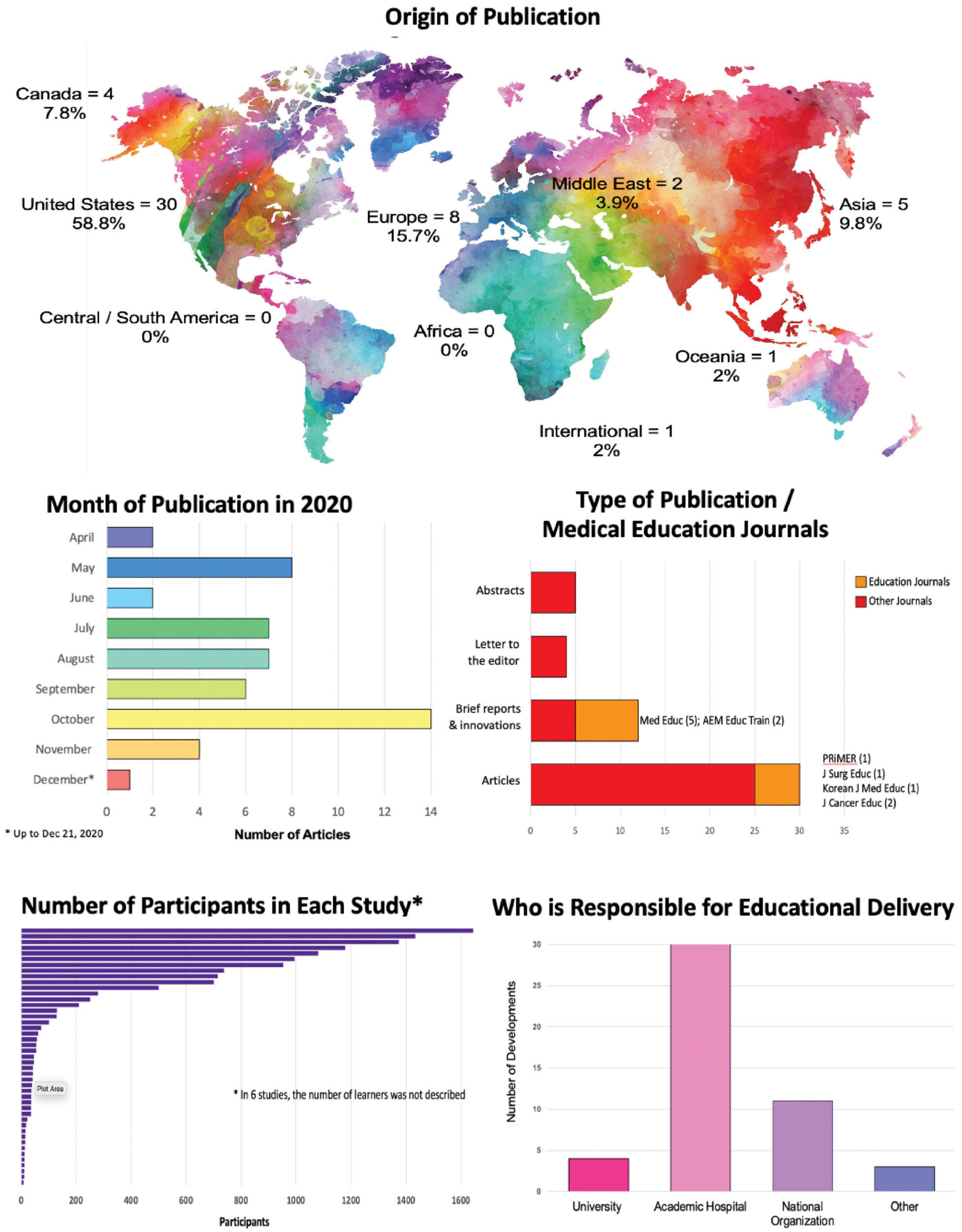

Figure 2. Visual summary of included publications.

Education was the only high impact factor education journal represented in our sample (see Supplementary Appendix 1, column journal and Figure 2, type of publication/medical education journals).

Participants, institutional setting, and medical specialty

The number of participants in each study is shown in Supplementary Appendix 1, column learners and Figure 2, number of participants in each study. The number ranged from 8 (Balakrishnan et al. 2020) to over 1600 (Lai et al. 2020). There were a large number of publications with over 100 participants (43.2%), though most included fewer (56.8%). Ten developments included over 500 participants. These 10 developments featured trends distinct from the rest, with a higher likelihood of being conducted by a national organization (50%) and/or a collaboration (60%), as well as more internationally diverse participants (60%). Six publications did not provide information on the number of learners involved.

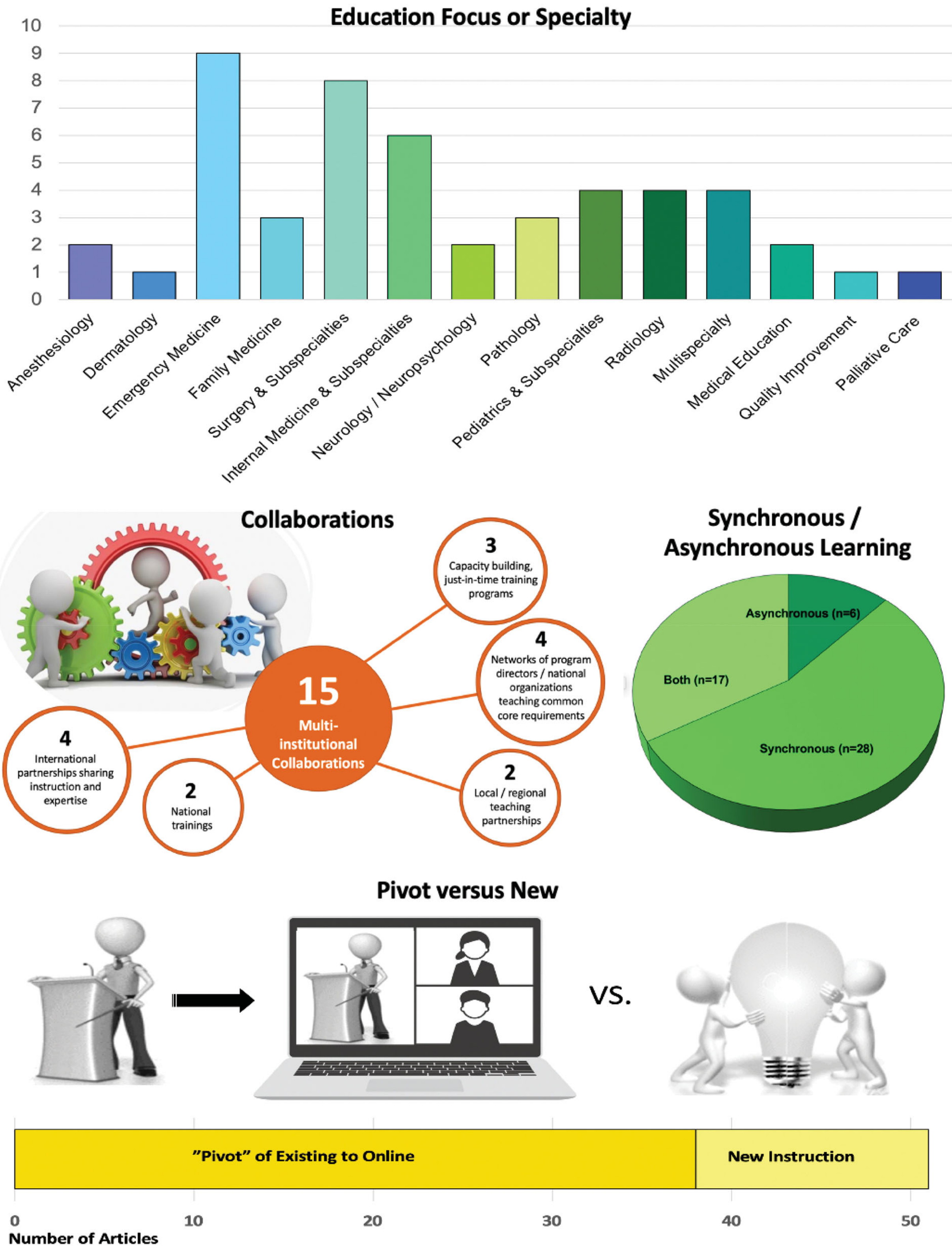

Figure 2. Continued.

Thirty developments (58.8%) were implemented by academic hospitals, 11 by regional or national organizations (21.6%), four by universities (7.8%), and three by other entities (5.8%) (see Supplementary Appendix 1, column organization responsible and Figure 2, who is responsible for educational delivery?).

Distribution of author groups' medical specialties is shown in Supplementary Appendix 1, column specialty and Figure 2, education focus or specialty. Emergency medicine leads with nine developments (17.6% of all included publications). They are followed by surgery and surgical subspecialties (*n* eve, 15.6%), and internal medicine and medical subspecialties (*n* 15, 11.7%).

Multi-institutional collaborations

The pivot from in-person to online learning has broadened the potential for working together, as evidenced by 15 developments (29.4%) that featured exemplary

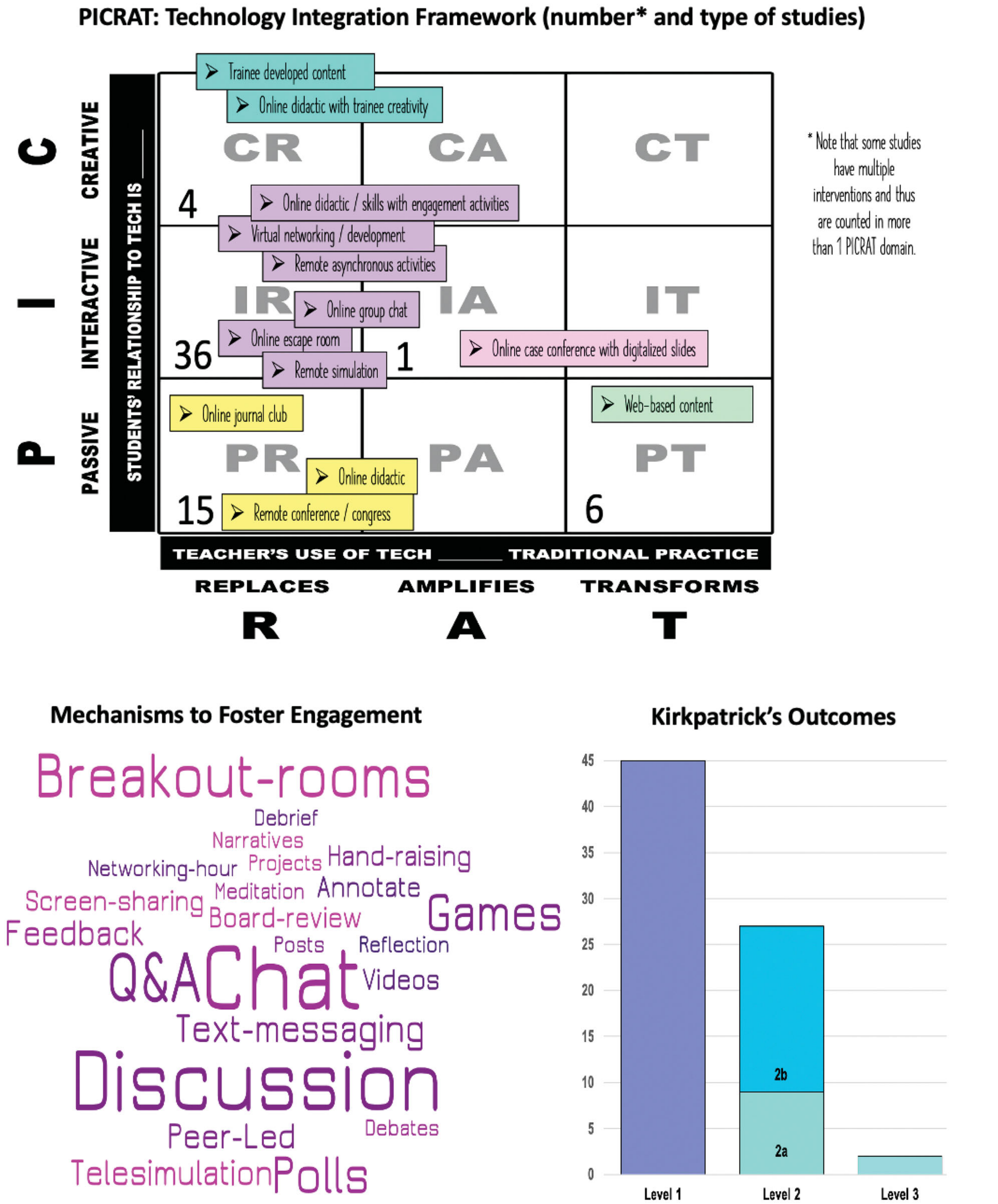

Figure 2. Continued.

collaborations. Four collaborations represented international partnerships sharing instruction and expertise, four represented networks of program directors or national organizations teaching common core requirements, three represented capacity building just-in-time training programs, two were regional teaching partnerships and two were national trainings (see Supplementary Appendix 1, column collaborations and Figure 2, collaborations). Examples included the following:

Pathology departments across the United States, India and Brazil collaborated to develop a 'breast case challenge,' wherein clinical vignettes and accompanying slides were placed online, and learners posted responses to a series of questions (Balakrishnan et al. 2020). Self-isolating anesthesiology trainees at the National Health Service (NHS) Foundation Trust in the UK created an online, globally available curriculum for their international peers (Eusuf et al. 2020). A multi-institutional team of spinal neurosurgeons, neuroradiologists, and orthopedists developed the Virtual Global Spine Conference, an online curriculum of lectures delivered *via* Zoom and YouTube, to address potential disparities in

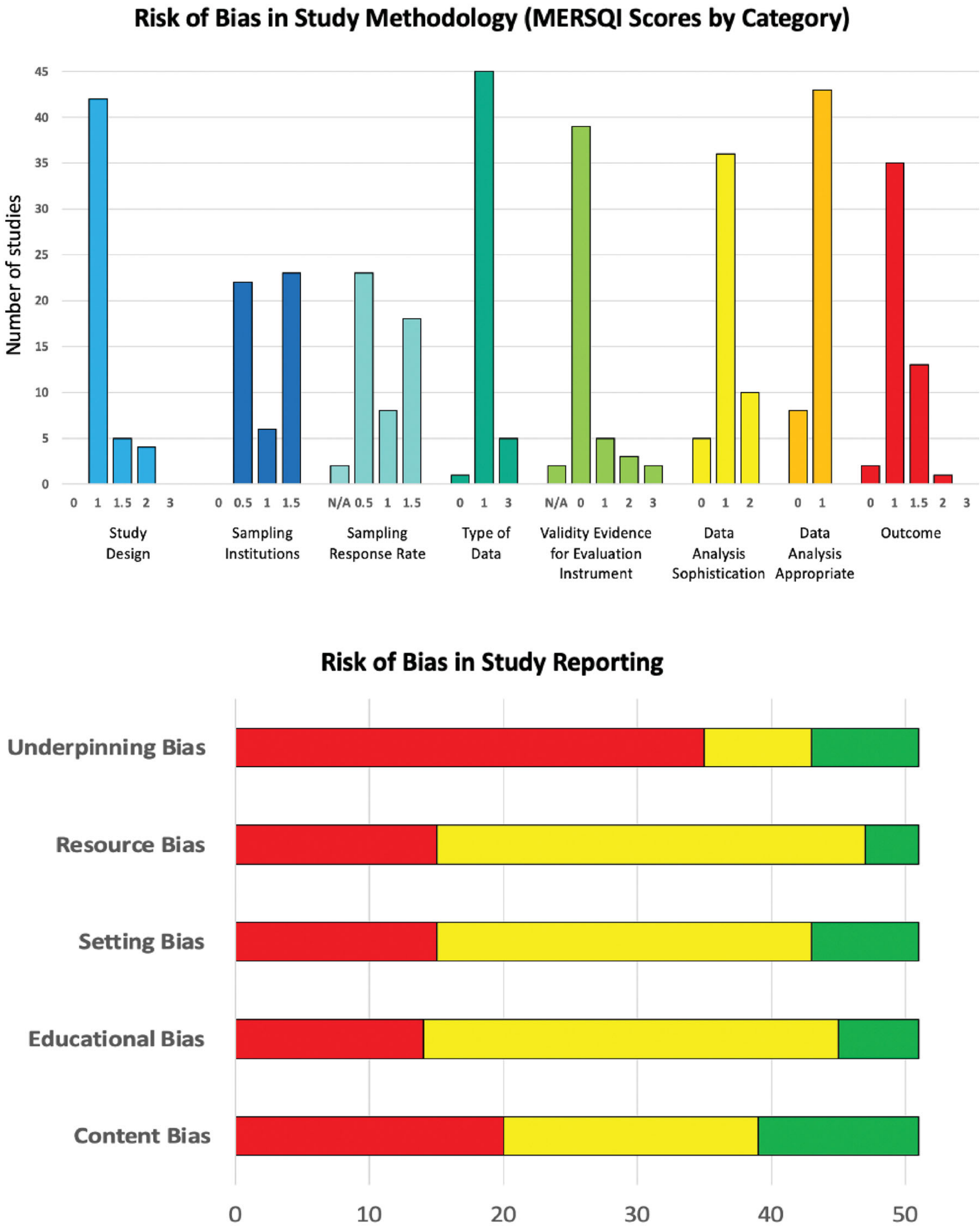

Figure 2. Continued.

access to quality education during COVID-19 (Rasouli et al. 2020).

A collaboration of Program Directors from the American Geriatrics Society and the Association of Directors of Geriatrics Academic Programs utilized Zoom to connect fellows nationwide for a series of lectures, workshops, and breakout discussions (Duggan et al. 2020). Members of the Organization of Neonatal-Perinatal Medicine Training Program Directors, which connects neonatology and pulmonary fellowship programs across the United States, utilized an online flipped classroom model with materials from a preexisting national neonatology curriculum (Beer et al. 2020). The Association of Postdoctoral Programs in Clinical Neuropsychology, comprising 97 American and Canadian postdoctoral programs in clinical neuropsychology, launched a multi-site didactic initiative (Domen et al. 2021).

A hub and spoke capacity-building education program, the Extension for Community Healthcare Outcomes (Project ECHO), linked interprofessional teams of specialists at academic centers ('Hubs') with primary care providers in regionally dispersed healthcare facilities ('Spokes'), to facilitate knowledge dissemination and collaborative learning within communities of practice (Steeves-Reece et al. 2021; Lingum et al. 2021). These Project ECHO interventions were quickly deployed across a wide network by leveraging preexisting relationships.

Pivot of established offerings online versus new educational developments

Most developments described a pivot or transition of existing face-to-face educational activities to the virtual or remote environment (*n* ost9, 76.5%). Many described transitioning didactics or lectures online. For example, Johnson et al. (2020) moved curriculum on the approach to treating *C. difficile* infections to an online setting, Shayer et al. (2020) moved 'X-waiver' training online (i.e. buprenorphine for opiate addiction treatment), and Maeda et al. (2020) moved otolaryngology teaching topics with procedural videos online. Many initiatives stemmed from inability to complete pre-existing educational activities that would have otherwise been done in person, such as journal clubs, pathology cases, and radiology readouts (Astani et al. 2020; Aulakh et al. 2022; Srivastava et al. 2020; Wlodarczyk et al. 2020; Evans et al. 2021). Only 12 developments (23.5%) represented new educational initiatives; McNally et al. (2020) described a de novo educational activity teaching telemedicine *via* remote simulation with standardized patients. Other new initiatives included live virtual instruction on electroencephalogram interpretation for neurology residents (Yadala et al. 2020) and the creation of open access radiology podcasts (Shiang et al. 2021).

Synchronous versus asynchronous

Almost all developments (45 publications, 88.2%) detailed synchronous activities (i.e. those which allow educators and learners to connect in real time, providing increased potential for interaction). While the majority of publications (*n* tho8, 54.9%) were of solely synchronous design, some groups (*n* , 57, 33.3%) utilized both synchronous and asynchronous activities. One such example, the Self-isolating Virtual Education (SAVEd) project, consisted of 80 pre-recorded didactic sessions (available at www.mmacc.uk), complemented by 24 live tutorials on Zoom (Eusuf et al. 2020). Only six developments (11.8%) described educational activities with only an asynchronous design. This is seen in Supplementary Appendix 1, column focus and synchronicity of development and Figure 2, pivot *versus* new.

PICRAT technology integration framework

We analyzed all 51 developments using the PICRAT model (Kimmons et al. 2020), which allowed for the analysis of teachers' integration of technology and learner engagement for a given educational intervention. Teachers' use of technology almost exclusively replaced traditional practice (PR = 15, IR = 36, and CR = 4). Students' relationship to technology spanned passive, interactive, and creative engagement, with interactive being the most common (see Supplementary Appendix 1, column PICRAT code and Figure 2, PICRAT: technology integration framework).

Thirty-six developments described interventions classified as interactive-replacement (IR), including the categories of online session with engagement activities (Johnson et al. 2020; Astani et al. 2020; Eusuf et al. 2020; Maeda et al. 2020; Beer et al. 2020; Durrani 2020; Eltayar et al. 2020; Rose et al. 2020; Duggan et al. 2020; Lin 2021; Rotoli et al. 2020; Carroll et al. 2021; Elledge et al. 2020; Elsayes et al. 2021; Hahn 2020; Laloo et al. 2020; Lee, King, et al. 2020; Lee, Park, et al. 2020; Lingum et al. 2021; McMahon et al. 2021; O'Connell et al. 2020; Seow et al. 2020; Srivastava et al. 2020; Steeves-Reece et al. 2021; Teele et al. 2021; Turner et al. 2020; Wlodarczyk et al. 2020; Yadala et al. 2020), online escape room (Cates et al. 2020), remote conference/congress (Martin-Gorgojo et al. 2020; Rasouli et al. 2020), remote simulation (McNally et al. 2020; Huang et al. 2020; Patel et al. 2020), virtual networking/development (Buckley 2020), online group chat (Lee, King, et al. 2020; Lee, Park, et al. 2020; Henderson et al. 2020), and remote asynchronous activities (Rotoli et al. 2020). The teachers' technology use in these developments was only to replace the no- or low-tech option, usually in-person formats.

Fifteen developments described interventions classified as passive-replacement (PR), including the categories of online journal club (Wlodarczyk et al. 2020; Srivastava et al. 2020; Aulakh et al. 2022; Astani et al. 2020) and online session without engagement activities (Singhi et al. 2020; Herman et al. 2020; Henderson et al. 2020; Bhashyam and Dyer 2020; Moyle et al. 2020; Merali et al. 2020; Shayer et al. 2020; McNally et al. 2020; Johnson et al. 2020; Brader 2020; Domen et al. 2021; Tang et al. 2021). The learners' relationship with technology use in these developments was passive; they were not obligated to interact with the technology to receive the teaching. The teachers' technology use was to replace the no- or low-tech option of in-person activities.

Six developments described interventions classified as passive transformation (PT); all of these belong to the category of web-based content (Lang et al. 2020; Moyle et al. 2020; Lai et al. 2020; Wlodarczyk et al. 2020; Shiang et al. 2021; Teele et al. 2021). These were considered transformative because the no- or low-tech option of passively providing the content, such as paper copies or emails, were not 'reasonable' alternatives with respect to anonymous and/or international learners/users of the content (Kimmons et al. 2020). The integration of technology (website-hosted content) allowed some learners to reach learning outcomes they otherwise may not have achieved.

Four developments described interventions classified as creative replacement (CR); these were represented by the categories trainee-developed content (Eusuf et al. 2020; Eltayar et al. 2020; Wlodarczyk et al. 2020) and online session with trainee creativity (Balakrishnan et al. 2020). These were considered creative since the learning outcomes were presumably met through the learners' development or creation of some product, such as a lecture or other assignment. The teachers' use of technology was, again, to replace the traditional in-person formats.

One group of authors described the development and use of an online case conference with digitized slides as an intervention for pathology trainees (Evans et al. 2021). This was the only article and category classified as interactive amplification (IA). Its interactivity is similar to others as previously described. These were considered amplifying because the use of tech allowed learners to better achieve learning outcomes compared to no- or low-tech options, which allows it to have greater impact than simply 'replacing' the lower-tech options, but the use of tech is not strictly necessary to achieving these learning outcomes, in which case it might be considered 'transformative.'

Strategies for virtual engagement

Several publications commented on the challenges of maintaining learner engagement in the virtual environment, and discussed specific approaches used to combat this challenge. Thirty-five publications (68.6%) described the use of technology for the purpose of increased interactivity and engagement. There were a variety of strategies, including virtual hand raising (Beer et al. 2020; Maeda et al. 2020), screen sharing (Lin 2021; Rotoli et al. 2020), and a virtual whiteboard or other real-time annotation tools (Elledge et al. 2020; Yadala et al. 2020; Elsayes et al. 2021). The most common of such strategies was the chat function, described in 14 developments. Educators discussed use of chat functions built into virtual meeting software, such as Zoom and Microsoft Teams (Maeda et al. 2020; Beer et al. 2020; Elledge et al. 2020; Henderson et al. 2020), as well as use of separate, chat-only platforms, such as WhatsApp and Telegram (Srivastava et al. 2020; Martin-Gorgojo et al. 2020). Several developments reflected on the challenge of simultaneously teaching and managing a group chat, recommending an assistant or moderator to assist with this task.

Other techniques include web-based polling and breakout sessions, almost equally cited by author groups (seven and eight developments, respectively). Breakout groups split larger groups into smaller subgroups for discussion or a specific activity (Cates et al. 2020; Johnson et al. 2020; Rotoli et al. 2020; Eltayar et al. 2020; Rose et al. 2020; Beer et al. 2020; Turner et al. 2020; Lin 2021). Real-time polling and quizzing were mentioned by several developments (Beer et al. 2020; Seow et al. 2020; Eusuf et al. 2020; Durrani 2020; Elledge et al. 2020; Teele et al. 2021) as a method used for both audience engagement and knowledge testing.

One study incorporated principles of gamification by using many of these tools simultaneously, including breakout rooms, chat function, and multiple rounds of quizzing (O'Connell et al. 2020). Several groups incorporated online games into their educational interventions (Elledge et al. 2020; Rotoli et al. 2020; Hahn 2020). These results are shown in Supplementary Appendix 1, column techniques used to increase virtual engagement and Figure 2, mechanisms to foster engagement.

Explicit use of theory by study authors

For this review, we adopted a broad stance concerning theory – from grand theories (e.g. constructivism, cognitivism, and behaviorism), to mid-range theories, to pedagogical approaches (e.g. blended learning and flipped classroom) – in order to encompass the wide range of perspectives demonstrated in health professions' education (Laksov et al. 2017). One-third (*n* hir7, 33.3%) of developments made some mention of theory. In nine of these the link to theory was loose or implicit (Bhashyam and Dyer 2020; Cates et al. 2020; Durrani 2020; Johnson et al. 2020; Carroll et al. 2021; Shiang et al. 2021; Steeves-Reece et al. 2021; Tang et al. 2021; Teele et al. 2021). Eight developments clearly wove theory into their study designs (Buckley 2020; Eltayar 2020; O'Connell et al. 2020; Rotoli et al. 2020; Seow et al. 2020; Wlodarczyk et al. 2020; Lingum et al. 2021; McMahon et al. 2021). Many authors cited andragogy (i.e. adult learning theories), active learning and blended learning. Collaborative learning theory and communities of practice were described by Lingum et al. (2021) and Steeves-Reece et al. (2021). Cognitive apprenticeship was robustly described as a guiding framework for a faculty development workshop by Eltayar et al. (2020) and briefly mentioned by Bhashyam and Dyer (2020). Social network theory was utilized by Buckley (2020) for faculty development. Spaced repetition and the testing effect were mentioned by Durrani (2020) and Wlodarczyk et al. (2020), with the latter leveraging a commercially available question bank. Game theory was deployed to develop a virtual 'Escape room' wherein teams competed to solve toxicology puzzles (Cates et al. 2020), and to develop a team competition with elimination rounds modeled off the TV show 'So you think you can dance?' (O'Connell et al. 2020). Flipped classroom approaches were described by two authors (Johnson et al. 2020; Wlodarczyk et al.2020) and problem-based learning was mentioned by Bhashyam and Dyer (2020). Several authors cited more than one theory or approach as informing the development of their educational intervention: Seow et al. (2020) were exemplary for its application of both blended learning principles (i.e. teaching, social and cognitive presence) and the ADDIE instructional design model in a quality improvement intervention; and Rotoli et al. (2020) described their use of '"Knowles" continuum of pedagogy and andragogy, Mayer's 12 principles of multimedia learning, [and] Brookfield's overview of experiential and self-directed learning.'

Kirkpatrick outcomes

Forty-five developments (88%) documented Kirkpatrick level 1 outcomes (satisfaction or reaction). Most of these adapted a previously existing, in-person activity to an online format and surveyed participants' feelings regarding the new format. Twenty-five developments (49%) described Kirkpatrick level two outcomes, of which seven described Kirkpatrick level 2a (changes in attitudes), sixteen described level 2b (changes in knowledge or skills), and two described both. Only two developments included Kirkpatrick level three outcomes (change in behavior). McNally et al. (2020) utilized a virtual standardized patient encounter to teach telemedicine skills. They used a pre-posttest design and reported on improved telemedicine competencies (behaviors) in the simulated setting. No developments described Kirkpatrick level four outcomes (see Supplementary Appendix 1, column Kirkpatrick outcome and Figure 2, Kirkpatrick's outcomes).

A content analysis of the reported results (Supplementary Appendix 2) revealed that learners were largely satisfied with online learning and they reported mostly positive reactions. Many cited ease of access and flexibility as primary drivers of their satisfaction. Others cited free or lower costs. Remarkably, respondents almost uniformly preferred online learning to face-to-face alternatives in developments that assessed both. Developments further reported almost uniformly positive improvements in comfort and confidence, as well as knowledge and skills.

Social media and other outcomes

Eighteen developments (33.3%) described social media or other outcomes. Most (*n* igh7) described these outcomes in addition to Kirkpatrick's outcomes, although one study (Lai et al. 2020) exclusively described social media metrics. The most commonly described social media metrics were *reach* and *engagement*. Reach reflects the number of unique users (i.e. viewers or subscribers) interacting with your content. Engagement reflects how involved the audience is with online content and consists of likes, comments, mentions, shares, retweets, clicks, and replies. Other outcomes reported included *in-app engagement* (e.g. number of comments in the Zoom chat) and *participation*, with the latter largely reflecting attendance.

Eight developments described *reach*: Carroll et al. (2021) conducted a serious illness communication skills training that received 1300 visitors to the program's website and 3232 page views; Eusuf et al. (2020) produced a peer-led curriculum for anesthesia trainees that had 1528 unique profile visits, generating 54,000 impressions; Henderson et al. (2020) described a remote curriculum for redeployed physicians to learn to care for patients with COVID-19 that had 814 views; Lai et al. (2020) utilized a web-based application to deliver palliative care resources, which reached 2042 users, 81% of whom were first time users; Laloo et al. (2020) developed a surgical training curriculum to enhance preparation for the Royal College of Surgeons examinations, that had 62 subscribers on Google classroom and 46 subscribers on YouTube, generating 1100 views, and 108 h of total viewing time; Lang et al. (2020) created an online inventory of high-yield topics in the form of succinct, one-page, living documents which was viewed 54,841 times, with 95% of the traffic from the United States; Merali et al. (2020) created Medicine Basecamp, an online internal medicine curriculum for redeployed trainees, which had 19,900 unique page views from six different continents within 34 d of release; and Shiang et al. (2021) deployed a podcast series for radiologists that had 685 listeners from 21 countries. One article described *engagement*: Eusuf et al. (2020) reported 245 retweets, 382 likes, and a 6.6% engagement rate on Twitter.

In-app engagement was described in three developments, with two analyzing the Zoom chat outputs and one examining question answering. Henderson et al. (2020) reported 400 questions and responses in the chat (~8.5 per session). Shayer et al. (2020) analyzed 450 chat postings and found that 53% were questions on course content, course credit, or administrative issues, 25% were comments, and the remainder were seeking discussion, answering a question, or furthering discussion. Wlodarczyk et al. (2020) described the number of questions answered in TrueLearn, a question bank app that tracked question completion rate.

Participation was described as an outcome in nine developments (Astani et al. 2020; Duggan et al. 2020; Herman et al. 2020; Lee, King, et al. 2020; Lee, Park, et al. 2020; Shayer et al. 2020; Domen et al. 2021; Elsayes et al. 2021; McMahon et al. 2021), with most noting higher participation in the online environment. Authors commented on the increased convenience for trainees of online attendance, particularly for those who were post-call or at dispersed hospital sites (Astani et al. 2020). Shayer et al. (2020) were perhaps most illustrative of why enhanced participation can be a critical outcome. Prior to the pandemic, providers reported that the 'time' and 'hassle' of attending an all-day, in-person buprenorphine prescribing class was prohibitive. The online format allowed 799 new providers to become X-Waiver certified, helping address the opioid crisis in the United States.

Quality assessment

Risk of bias in study methodology

The MERSQI was utilized to appraise the methodological rigor of each study (Supplementary Appendix 1, columns, risk of bias in study methodology). While the majority of studies were low to average quality for research methodology, there were high-quality exceptions (e.g. Seow et al. 2020) commendable in the context of ERT. No clear differences existed in methodologic quality across journal type (i.e. educational or clinical journals) or publication length (i.e. conference abstracts, brief reports, or original articles). Table 2 displays the frequencies of scores across eight MERSQI domains. Low subscores predominated across most domains and lack of descriptions was common. The majority of developments (*n* com2, 82.4%) were single group cross-sectional study designs, five (9.8%) were single group pre-post designs, and 4 (7.8%) were two group non-randomized comparisons. Over half (*n*, 89, 56.9%) sampled 2 or more institutions, indicative of a number of collaborations in post-graduate education. More than half (*n*, 56, 51%) had acceptable response rates (i.e. ≥50%). Most developments (*n* 0%)5, 88.2%) described assessments by study participants, with a handful of publications offering more objective data (e.g. observer ratings). Validity evidence for the instruments used to evaluate study outcomes was not described in 39 developments (76.5%), though who developments (Srivastava et al. 2020; Domen et al. 2021) robustly described multiple forms of validity evidence. In regards to data analysis sophistication, 10 developments (19.6%) used tests of statistical inference, 36 developments (70.6%) provided descriptive analyses, and five (9.8%) did not provide any results. The outcomes reported were predominately satisfaction/attitude/perception, though a few developments described knowledge, skill, or behavioral change. The frequency of MERSQI scores is shown in Figure 2, risk of bias in study methodology.

Risk of bias in study reporting

The results of the visual ranking system for risk of bias in study reporting appear in Supplementary Appendix 1, column in study reporting. Risk of bias in reporting seems to correlate with both type of article and the length of the published report with conference abstracts exhibiting the highest risk of bias in reporting, followed by letters to the editor, brief reports, innovations, and articles. Considering the context of ERT, it was notable that eleven developments reported in all five domains, with varying amounts of detail, and O'Connell et al. (2020) exhibited high-quality reporting in 4/5 areas. Six developments had low-quality reporting in 4/5 domains and five developments had low quality reporting in all five domains. *Underpinning* was the domain at highest risk of bias, with 37 (72.5%)

Table 2. MERSQI Categories, response options, scoring, and number of developments.

Category/response options	MERSQI score	Number of developments (%)
Study design (SD)		
Not described	0	0 (0)
Single group cross-sectional or single group posttest only	1	42 (82.4)
Single group pretest and posttest	1.5	5 (9.8)
Nonrandomized, 2 group	2	4 (7.8)
Randomized control trial	3	0 (0)
Sampling institutions (SI)		
Not described	0	0 (0)
1 institution	0.5	22 (43.1)
2 institutions	1	6 (11.8)
3 or more institutions	1.5	23 (45.1)
Sampling response rate (SRR)		
Not applicable	N/A	2 (3.9)
<50% or not described	0.5	23 (45.1)
50 – 74%	1	8 (15.7)
75%	1.5	18 (35.3)
Type of data (D)		
Not described	0	1 (2)
Assessment by study participant	1	45 (88.2)
Objective	3	5 (9.8)
Validity evidence for evaluation instrument (VE)		
Not applicable	N/A	2 (3.9)
Not described	0	39 (76.5)
Content (1)	1	5 (9.8)
Internal structure (1)	2	3 (5.9)
Relationship to other variables (1)	3	2 (3.9)
Data analysis sophistication (DAS)		
Not described	0	5 (9.8)
Descriptive analysis only	1	36 (70.6)
Beyond descriptive analysis	2	10 (19.6)
Data analysis appropriate (DAA)		
Not described or not appropriate for the study	0	8 (15.7)
Data analysis appropriate for the study	1	43 (84.3)
Outcome (O)		
Not described	0	2 (3.9)
Satisfaction, attitudes, and perceptions	1	35 (68.6)
Knowledge and skills	1.5	13 (25.5)
Behaviors	2	1 (2)
Patient/health care outcome	3	0 (0)

This table is adapted from Reed et al. (2007).

developments with low-quality reporting, representing the domain of greatest opportunity for improvement. *Resource, setting, educational methods*, and *content* were at more moderate risk of bias (see Figure 2, risk of bias in study reporting).

Limitations as stated by the primary study authors

Our thematic analysis of the limitations described by study authors (Supplementary Appendix 1, column limitations) revealed both limitations of the developments themselves, as well as limitations in the study designs. The limitations of the online pivots included the loss of social interactions and engagement, lack of physical contact or 'hands-on' experience, and lack of familiarity or challenges with technology (i.e. hardware or software). The limitations of the study designs included low response rates on the evaluation instruments and potential for response bias, lack of higher-level Kirkpatrick outcomes, lack of control groups, and poor transferability.

Loss of social interactions and engagement

The loss of social interactions, amongst trainees and between attendees and facilitators was noted as a limitation of online learning. Elledge et al. (2020) mentioned the loss of collegiality and networking, describing interactions with trainers as 'artificial' encounters where communication was strained. Teele et al. (2021) noted that the 'physical separation and limited face-to-face contact can lead to feelings of disconnection and isolation by either the learner or the educator or both.' Eusuf et al (2020) called attention to the disadvantages incurred by the loss of social contact during the break times of face-to-face tutorials. Buckley (2020) noted that it was harder to have informal or 'sidebar' conversations, which can also be influential for faculty learning. Srivastava et al. (2020) remarked on the increased burden on teachers to foster engagement, particularly when confronted with issues of limited attention spans, multitasking, and distractions in the digital environment. Rose et al. (2020) suggested that residents who were unfamiliar with new technologies (e.g. Slack) may have felt reserved about navigating the digital platform during discussions. This resulted in difficulties establishing the psychological safety that some residents need to empower them to comment and pose questions.

Lack of physical contact or 'hands-on' experience

The lack of physical contact or hands-on experience was described as a limitation, particularly in developments involving skill development. Brader (2020) described a bi-level positive airway pressure (BiPAP) training that was to involve hands-on training with machines, for which there was no real substitute in the online environment. Astani et al. (2020) noted that virtual training cannot replace a modicum of in-person, hands-on training, particularly when it relates to developing adequate skill to perform procedures. Martin-Gorgojo et al. (2020) stated that education involves knowledge, attitudes, and skills, but they cannot influence the latter just by haranguing people through a video link.

Lack of familiarity and challenges with technology

Multiple developments reported difficulties concerning hardware and software. Teele et al. (2021) noted technology literacy challenges, describing the generation gap between learners and faculty as a significant hurdle. Rotoli et al. (2020) described non-familiarity with Zoom for teaching and Beer et al. (2020) described a more global lack of expertise/comfort with online platforms. Tang et al. (2021) and Evans et al. (2021) described multiple technical issues, including poor image resolution, poor sound quality, lags in audiovisuals, and inadequate computing power of hardware. Maeda et al. (2020), Tang et al. (2021), and Srivastava et al. (2020) all noted challenges with the speed of the internet or poor network connectivity, leading to disruptions, which was often exacerbated when learners were obligated to access classes on mobile devices or smartphones. Evans et al. (2021) and Maeda et al. (2020) described system limits on file sizes, which created limitations for sharing pathology slide images and surgical videos, respectively.

Low response rates on the evaluation instruments and potential for response bias

References were made to 'response bias' as a result of either small sample sizes or low response rates in multiple developments (Duggan et al. 2020; Elledge et al. 2020; Herman et al. 2020; Laloo et al. 2020; Lingum et al. 2021; Turner et al. 2020; Yadala et al. 2020; Domen et al. 2021; McMahon et al. 2021; Shiang et al. 2021). Elledge et al. (2020) worried that trainees may have felt 'pressured' into responding positively because they were easily identifiable. The survey evaluation method *per se* was seen as a limitation by a few authors who noted that the design might have favored trainees comfortable with technology (Turner et al. 2020) or that repetition of questions may have introduced an element of fatigue and indifference (Herman et al. 2020). Lai et al. (2020) noted that the way Google Analytics collects and presents social media data can introduce possible sources of bias, since the metrics were designed for business and not health education.

Lack of higher-level Kirkpatrick outcomes

Several developments noted as a limitation only assessing satisfaction/reaction rather than knowledge (Bhashyam and Dyer 2020; Henderson et al. 2020; O'Connell et al. 2020; Carroll et al. 2021) or skills (Rotoli et al. 2020). Authors explained that there was no assessment of 'educational efficacy' (O'Connell et al. 2020) and no assessment of the durability of knowledge (Henderson et al. 2020 and Aulakh et al. 2022). Lee, King, et al. 2020; Lee, Park, et al. (2020) noted that satisfaction was assessed early in the pandemic and questioned if such high satisfaction would be maintained as teachers and learners tired of the remote formats and highlighted the need for longer-term outcomes at all levels. Carroll et al. (2021) and Elledge et al. (2020) specifically noted that the knowledge gains reported in their developments were derived from self-assessments, which were potentially flawed and lacking in objectivity.

Lack of control groups

While lack of a control group is not uncommon in medical education, several authors noted this as a limitation. Elsayes et al. (2021) and Henderson et al. (2020) noted that to draw strong conclusions about online learning it would be ideal to directly compare the novel developments to face-to-face or traditional instruction. Aulakh et al. (2022) remarked that the significant improvements shown 'may have had more to do with increased flexibility … brought about by the pandemic than inherent differences between face-to-face and online settings.'

Poor transferability

Limited transferability of findings was reported in numerous publications due to single-institution developments, single department or single program developments, restricted geographic areas or regions, an exclusive focus on physicians as opposed to other healthcare professionals, small sample sizes, and low response rates (Bhashyam and Dyer 2020; Domen et al. 2021; Duggan et al. 2020; Elledge et al. 2020; Hahn 2020; Henderson et al. 2020; Herman et al. 2020; Lai et al. 2020; Laloo et al. 2020; Lingum et al. 2021; O'Connell et al. 2020; Patel et al. 2020; Singhi et al. 2020; Srivastava et al. 2020; Turner et al. 2020; Yadala et al. 2020; McMahon et al. 2021; Shiang et al. 2021). Turner et al. (2020) specifically called attention to the dimensions of the sample (e.g. relative tech-savviness), noting how this could affect transferability, even when reasonable response rates for a voluntary survey were obtained.

Lessons learned as stated by the primary study authors

Our thematic analysis of lessons learned as reported by the primary study authors (Supplementary Appendix 1, column lessons learned) revealed several additional themes. A number of authors commented on how remote learning provided flexibility, removing the barriers of time and the hassle of travel associated with in-person participation (Bhashyam and Dyer 2020; Eusuf et al. 2020; Lee, King, et al. 2020; Lee, Park, et al. 2020; Martin-Gorgojo et al. 2020; Shayer et al. 2020; Wlodarczyk et al. 2020; Yadala et al. 2020; Tang et al. 2021). Others noted drawbacks of online learning, noting that not all aspects of education could be effectively delivered online (Lin 2021; Rotoli et al. 2020; Carroll et al. 2021). Most authors offered some form of practical advice to optimize online learning, which clustered into several thematic areas: increasing participation, optimizing engagement, creating the best experience, augmenting collaborative efforts, choosing tools wisely, ensuring connectivity/accessibility, and addressing privacy concerns. This has been summarized in Table 3.

Conclusions as stated by the primary study authors

One notable theme across papers was that it appears unlikely that online learning will ever fully replace in-person conference attendance in the future (McMahon et al.

Table 3. Practical suggestions derived from a thematic analysis of lessons learned by primary study authors.

Increasing participation
- Make group size small enough to ensure engagement by all participants (Buckley 2020; Huang et al. 2020; Patel et al. 2020).
- Leverage social media advertising to reach a diverse group of participants (Merali et al. 2020).
- Ensure familiarity with tools to ensure learners participate fully (Lee, King, et al. 2020; Lee, Park, et al. 2020; Rose et al. 2020).
- Verify attendance limits of software in advance to ensure all attendees can log in (Elsayes et al. 2021).
- Make access free-of-charge or low cost for faculty (Martin-Gorgojo et al. 2020).

Optimizing engagement
- Vary the formats to maximize engagement (Rotoli et al. 2020).
- Leverage tools (e.g. online polling, chat, hand-raising, and discussions) (Maeda et al. 2020; Singhi et al. 2020).
- Develop strategies (e.g. ask questions, invite comments) to minimize isolation and foster dialogue (Aulakh et al. 2020).
- Recognize that it is an iterative process to achieve the ideal state with new technology (Evans et al. 2021).
- Provide adequate structure, appropriate breaks, and opportunities for interaction (Herman et al. 2020).
- Focus on the user interface/user experience and consider user-specific designs (Lai et al. 2020).
- Keep sessions short and interactive as adult attention spans wane (Laloo et al. 2020; McMahon et al. 2021).
- Encourage videos on when feasible (Maeda et al. 2020; Patel et al. 2020; Turner et al. 2020).
- Use peer-led sessions to increase engagement and protect against burnout (Wlodarczyk et al. 2020).

Creating the best experience
- Provide technology education for faculty members to enhance teaching (Lee, King, et al. 2020; Lee, Park, et al. 2020), create a step-by-step instructional guide (Seow et al. 2020), assess technology literacy of faculty, and provide remote technical support (Teele et al. 2021).
- Plan carefully and test the technology set-up before 'going live' (Evans et al. 2021).
- Arrange for a co-facilitator to monitor questions in the chat (Buckley 2020) or have an evaluating observer help (Bhashyam and Dyer 2020).
- Demonstrate in-the-moment flexibility/adaptability to unanticipated obstacles (Rose et al. 2020).
- Ensure proper design of activities, with opportunities to apply knowledge during and after the session (Eltayar et al. 2020).
- Focus on maximizing interactivity (Turner et al. 2020). Develop interactive case-discussions in a flipped classroom format in lieu of lectures (Laloo et al. 2020).
- Apply multimedia learning principles. Leverage audiovisuals to promote retention (Laloo et al. 2020).
- Employ learning theories in development designs (Teele et al. 2021).
- Record sessions for later viewing and place in an online repository (Wlodarczyk et al. 2020) or otherwise disseminate in a timely manner (Singhi et al. 2020).
- Distribute summary materials post-session to continue learning (Durrani 2020).
- Leverage online repositories to create 'evergreen' (continuously updated) materials (Lang et al. 2020).
- Acknowledge the psychosocial impact of virtual learning (Rotoli et al. 2020) and explore how to build social relationships online (Singhi et al. 2020).
- Integrate online learning into the existing curricula to improve utilization and redistribute dedicated time to use these resources (Shiang et al. 2021).

Augmenting collaborative efforts
- Coordinate among national programs (Beer et al. 2020).
- Facilitate engagement within and across training programs (Rose et al. 2020).
- Decrease the burden on local educators. Enhance networking opportunities and foster professional development (which is especially beneficial for small programs) (Duggan et al. 2020).

Choosing tools wisely
- Use Zoom features to promote interactivity. Familiarize faculty with/promote mastery of the tool (Duggan et al. 2020; Maeda et al. 2020).
- Leverage Twitter to foster widespread collaboration *via* crowdsourcing (Duggan et al. 2020).
- Utilize Microsoft Teams for video conferencing (Aulakh et al. 2020).
- Use Google classroom (rather than Facebook) to avoid crossing personal/professional boundaries (Balakrishnan et al. 2020).
- Invest in a dedicated image repository (e.g. PathPresenter) to facilitate access to slides/radiographs (Hahn 2020; Evans et al. 2021; Tang et al. 2021).
- Use Bluetooth videoconferencing speakers to enhance audio quality and reduce background noise (Hahn 2020).

Ensuring connectivity/accessibility
- Download videos in advance to overcome connection issues (Maeda et al. 2020).
- Provide mobile phone/app-based alternatives to increase accessibility (Lang et al. 2020).
- Ensure learners have access to high-quality computers with set specifications that allow for seamless connectivity and viewing high-resolution images (Evans et al. 2021).
- Invest (at the school level) in reliable networks / adequate broadband (Lee, King, et al. 2020; Lee, Park, et al. 2020; Turner et al. 2020; McMahon et al. 2021).

Addressing privacy concerns
- Use virtual backgrounds for learners with different home environments (Maeda et al. 2020).
- Utilize secure video-conferencing software, password protect webinars, and 'lock' the presentation after beginning to prevent cybersecurity threats and 'Zoom-bombing' (Rasouli et al. 2020; Elsayes et al. 2021).
- Ensure there is no 'leak' of confidential patient details (Tang et al. 2021).
- Restrict screen-sharing to the host (Rasouli et al. 2020).

2021). However, the adoption of a hybrid model as a 'sustainable academic' approach would appear to be a pragmatic solution to the current pandemic crisis and a likely model for the future.

Discussion

Summary of main results and comparison with other reviews

Our PGME review showed a similar geographic distribution to the prior reviews by Gordon et al. (2020) and Daniel et al. (2021), and the concurrent review by Grafton-Clarke et al. (2021), with the majority of developments coming from North America. The UGME review (Stojan et al. 2022) showed a more balanced geographic spread, however, South America and Africa had almost no representation across all five reviews and we would encourage more representation from these areas. Across the three concurrent reviews, we saw the highest numbers of publications 6–10 months into the pandemic, and now we seem to be observing a tapering off. Yet, now is precisely when we might hope to see papers with follow-up data from early innovations, or more longitudinal evaluations of interventions.

One remarkable finding across the three concurrent reviews (i.e. this review, Stojan et al. 2022; Grafton-Clarke et al. 2021) was the paucity of publications in the highest impact factor medical education journals. *Medical Education* was the exception, though these were almost exclusively brief reports. This may be due in part to the level of rigor required by these journals for publication (e.g. emphasis on theory and study design quality), the duration of peer review, or publishing preferences of authors (which during a pandemic may have been directed toward journals with higher acceptance rates). The leading education journals clearly contributed to rich dialogue around COVID-19 by publishing perspectives, reviews, and other article types which would not have been included in these reviews.

The number of publications from Emergency Medicine increased markedly compared to Daniel et al. (2021), and continued high numbers were observed from Surgery and Internal Medicine. Some of this spike in productivity might be explained by a return to academic productivity after the initial surge and management of COVID-19 cases by Emergency Medicine faculty. Educational delivery in PGME was dominated by academic hospitals, which was in contrast to the UGME review (Stojan et al. 2022) which was markedly skewed toward universities.

The PGME landscape was noteworthy for multiple examples of national and international collaborations, compared to the UGME review (Stojan et al. 2022) which reported none. This may be related to unique differences in medical school curricula which make collaborations more challenging. In PGME, residency and fellowship programs often share common core requirements making collaborations more feasible. Many collaborations were accelerated and strengthened out of necessity during COVID-19 and we must now consider their potential to improve education as necessity wanes. Faculty time is a precious resource. The traditional model wherein each and every postgraduate program creates unique content for a relatively small number of learners is duplicative of efforts and creates many similar programs of variable quality. Collaborations offer the potential to leverage the creativity and expertise of larger faculty networks, to create more innovative and educationally sound products. They also offer the potential for broader faculty exposure, building reputations, and amassing higher numbers of teaching evaluations that can have value in promotions and tenure processes.

Collaborations may be especially beneficial for small, remote, or developing programs. The benefits include: increased access to high-quality speakers and content experts; mitigation of associated costs for travel, hosting, speaker fees, and lost work time; exposure to different perspectives and less groupthink, especially in areas of clinical controversy (Balakrishnan et al. 2020); and enhanced success during peer review due to the perceived strength of multi-institutional endeavors. Collaborations may also increase the number of participants and enhance social connection and belonging (Duggan et al. 2020; Domen et al. 2021). Social media may be a particularly facilitative tool to both advertise and disseminate educational content created through collaborations (Eusuf et al. 2020; Rasouli et al. 2020; Steeves-Reece et al. 2021), which is perhaps why these additional outcomes had a strong presence in this review.

The majority of developments represented a pivot of existing curricula to an online setting as compared to de novo innovations, and most learning opportunities were synchronous. This was in contrast to the UGME review (Stojan et al. 2022), wherein nearly half of the activities were a combination of synchronous/asynchronous or exclusively asynchronous. Many developments reported trainee preferences for online over face-to-face learning, citing the ease of access, flexibility, and low cost as justifications for these preferences. In PGME, the flexibility to avoid travel and tune in from dispersed clinical sites or from home when 'post-call' or attending to familial obligations appears highly valued for well-being. Of course, this must be balanced with the needs for human connection amongst peers and faculty, which can be critical in residencies and fellowships to create a sense of belonging. Many authors stated they 'unexpectedly' were able to achieve what was previously accomplished in face-to-face settings (Astani et al. 2020; Aulakh et al. 2022; Eltayar et al. 2020). Attitudes and knowledge gains were noted in most publications where these outcomes were reported (see Supplementary Appendix 2), though results for skills that required hands-on experience were more mixed (e.g. Lin 2021), suggesting that future in-person time may need to be prioritized for skill development and procedures. The level of positive reactions to online learning was really quite remarkable, with only rare dissenting perspectives (e.g. Huang et al. 2020 clearly stated a preference for in-person learning). Lee, King, et al. (2020) and Lee, Park, et al. (2020) cautioned that this robust enthusiasm might be tempered after additional time using the new formats. These are critical points to consider, as they highlight the need for additional research when the pandemic wanes to determine the optimal hybrid future state.

This study and the UGME review by Stojan et al. (2022) were the first reviews to apply the PICRAT technology integration framework to explore implementation of online learning. The results were quite striking and highlight opportunities for future work. Students' relationship with technology was predominately *interactive* or even *creative*, which was wonderful to see. While we lack direct comparisons in most of these developments to face-to-face learning, it appears interaction may be easier to achieve in the online environment due to various features embedded in video-conferencing software. Teachers' use of technology in PGME was almost exclusively as a tool to *replace* classroom-based activities, unlike in UGME where teachers were more apt to use technology to *amplify* learning. This finding was not surprising during a pandemic where clinical faculty time was limited. Yet, it means there is still untapped potential for technology to both *amplify* and even *transform* teaching practices in PGME. According to Kimmons et al. (2020), technology should serve as 'a means to an end, not an end in itself.' We would thus encourage educators to consider technology integration models during design with a goal of improving pedagogy and learning.

We would also encourage educators to underpin their work with theories, which requires the thoughtful integration of *both* educational *and* online learning theories. During ERT, educators likely made pragmatic tradeoffs. While here was tremendous value in the innovative work educators put forth in this setting, explicitly articulating online theories and constructing interventions on this basis remains an untapped opportunity. The practical affordances offered by technology were what were prominent during ERT. Rotoli et al. (2020) and Seow et al. (2020) were notable exceptions. Several theories have the potential to inform online learning, including technology-enhanced learning (Millwood 2013), Mayer's multimedia principles (Mayer 2014), and the ADDIE instructional design model

(Branch 2009). Lau (2014) also described principles for computer-based module design, highlighting the relevance of 'classic' theories (e.g. cognitive, constructivist, and behaviorist) and 'modern' theories (e.g. technical scaffolding, self-direction, and connectivism). To move the field forward post-pandemic, more explicit operationalization of relevant theory and pedagogical approaches is critical to provide a robust basis for future developments, research, and ultimately evidence-based improvements.

Quality of the evidence base

The overall quality of the evidence in terms of both study methodology and reporting has modestly improved since the first COVID-19 review by Gordon et al. (2020) and our review has highlighted some exemplary developments that can serve as models for authors wishing to enhance the quality of study design (e.g. Seow et al. 2020) and study reporting (e.g. O'Connell et al. 2020).

This review represents one of the first uses of the MERSQI within BEME. The MERSQI is tailor-made for reviewing methodologic quality in medical education and thus, we support its continued use. Of note, we did not present total scores or descriptive statistics for the MERSQI. According to Cook and Reed (2015), total MERSQI scores have no validity as normative data, as they assert a weighting of importance across domains and a hierarchy of methodological features within a domain that have not been established. We concur that the MERSQI should be presented in a manner that reflects the complex and diverse tapestry of educational research. Thus, we further support more nuanced reporting of the MERSQI in the future, using the tool for 'relative rather than absolute judgments', as exemplified by Table 2.

To our knowledge, this and the companion review by Stojan et al. (2022), are the first reviews to utilize both the MERSQI and risk of bias in reporting tools in the same review. Our collective findings support the prior assertion by Gordon et al. (2020) that study design and study reporting are truly two distinct quality constructs, and that both must be considered when conducting systematic reviews in medical education. This is evident in the differences in scoring across these elements, which highlight very different strengths and weaknesses in the primary literature.

A high risk of bias in study methodology compromises generalizability of study results and can undermine the education community's trust in study findings, making the path forward uncertain. Similarly, a high risk of bias in study reporting compromises transferability of educational developments and makes it challenging for educators to adopt and put them into practice. In many publications, it is unclear if high bias in reporting is due to methodological weaknesses (e.g. lack of theoretical underpinning) *versus* reporting issues. This issue transcends the current context of ERT during COVID, has been observed repeatedly by those conducting systematic reviews, and needs to be urgently addressed. Authors of the primary literature and journal editors should share responsibility for improvements moving forward. Practical solutions might include: 1) adding risk of bias in reporting domains to instructions for authors to prompt consideration during the writing process; 2) establishing quality criteria and providing added guidance for peer-reviewers; 3) augmenting publication of supplemental online materials when page or word limits are necessary; and 4) encouraging authors to provide links to websites that house content. The ultimate goal is not to stifle innovation or be too prescriptive or reductionist, but rather help raise awareness of quality in reporting challenges and create the needed space to overcome them.

Strengths and limitations

This review was conducted by an experienced international team, which allowed rapid progress without compromising systematicity (Gordon, Daniel, et al. 2019). Our approach was strengthened by following an a priori protocol and the reporting of findings in accordance with the STORIES statement (Gordon and Gibbs 2014) and BEME guidance (Hammick et al. 2010). Other strengths include the unique application of the PICRAT technology integration framework and assessment of risk of bias of both study reporting and methodology using the MERSQI. In addition, the narrow focus on PGME 'classroom' learning pivots facilitated a more robust content analysis of outcomes, limitations, and lessons learned which led to numerous practical suggestions for educators (Table 3). This review has several limitations. We only searched four databases and manually searched MedEdPublish. Future reviews may wish to consider expanding these searches. To facilitate timeliness of the review, we employed multiple author pairs for study selection, data extraction, and other processes. While these were performed in duplicate for increased rigor, this may increase the risk of pair-to-pair inconsistencies. We found that making judgments concerning risk of bias and PICRAT categorizations was particularly challenging, and we acknowledge the subjective interpretation in this process. Finally, we acknowledge that this review was conducted in the middle of the pandemic and was thus comprised interim studies whose implementation and publication were expedited. Studies with stronger theoretical underpinnings, higher quality methodology and reporting, and longitudinal outcomes may be forthcoming.

Implications for education and research

When the pandemic finally wanes, educators and researchers must consider the implications of this review on future practice. Much of the work done during the pandemic was conducted in the vein of emergency remote learning (Hodges et al. 2020), and we must now enter a period of more thoughtful educational design and delivery that optimizes learning outcomes. The strong preferences of postgraduate learners for online learning identified in this review, coupled with the recognition of the limitations of online learning illuminate a path for a hybrid model in the future. In determining which experiences to convert back to face-to-face learning, educators might consider what delivery modality is most 'fit for purpose.' Where there is an expressed need for flexibility to overcome barriers to participation, online formats should be considered. When hands-on participation would better facilitate learning objectives and human connections, in-person experiences should be prioritized.

When designing, implementing, and reporting on future developments, the following questions should be considered:

- What balance of synchronous/asynchronous online activities, combined with in-person offerings, optimize flexibility while ensuring time for connections and engagement?
- How can collaborations be leveraged (particularly by smaller programs) to develop cost-effective interventions and broaden learner horizons by maximizing exposure to different perspectives and national/international experts?
- How can technology integration be optimized in a manner that amplifies or transforms learning?
- How might educational *and* online learning theories be used to inform design, implementation, and evaluation of the interventions?
- What additional Kirkpatrick's outcomes can be measured (e.g. changes in behavior or practice)? What longitudinal outcomes (i.e. those more reflective of long-term reaction/satisfaction, as well as knowledge and skill gains) can be assessed?
- How might social media metrics be captured and analyzed, as important additional educational outcomes?
- How can developments be designed and reported in a manner that enhances generalizability or transferability by applying the MERSQI and RAG systems as guides?

Conclusions

In response to COVID-19, educators rapidly pivoted from traditionally face-to-face classroom activities to the online environment, transitioning existing material as well as providing new offerings. This review summarized developments, describing what was done, what worked, and what's next for postgraduate medical education. Online learning was embraced beyond many educators' expectations and despite the noted limitations. This portends a bright future, as with added time and attention, technology's potential to transform learning might be more fully realized. Future works should leverage the power of collaborations, thoughtfully underpin developments with theory, and explore additional outcomes. Finally, authors and editors alike should attend to minimizing bias in the primary literature by ensuring high-quality study designs and reporting, to ensure a vibrant evidence base upon which future work can build.

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