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ORIGINAL RESEARCH

A Scoping Review of Ultrasound Teaching in Undergraduate Medical Education

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Abstract

Introduction Increasingly, medical schools are integrating Point of Care Ultrasound (POCUS) into their curricula. This review investigated the available literature on how best to integrate POCUS in the teaching of medical students and the benefits of doing so.

Methods Given the heterogeneous literature that has emerged on POCUS education, a scoping review was conducted. Relevant medical databases, including PubMed, MEDLINE, PsycINFO, EMBASE and CINAHL, were searched between January 1980 and August 2016, using keywords identified by the authors. Inclusion criteria were as follows: prospective or retrospective studies, observational or intervention studies, and studies describing how medical students learn to use ultrasound.

Results The literature search yielded 593 articles, of which 128 met the inclusion criteria. Studies that met the inclusion criteria were sub-categorised under the following headings: those that described or evaluated an ultrasound curriculum, those that employed ultrasound as a means of teaching another topic in the curriculum (i.e., anatomy, physical examination, physiology, invasive procedures), those that investigated the learning curve of ultrasound education and those that employed adjuncts or peer mentoring to teach ultrasound.

Conclusions The reviewed literature indicates that the integration of ultrasound in undergraduate medical education is both feasible and beneficial to medical students. This article is intended to inform medical educators aiming to integrate ultrasound into their medical school curricula.

Keywords Medical education · Curriculum evaluation · Undergraduate teaching · Ultrasound education · Point of care ultrasound (POCUS)

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Introduction

Training programs in ultrasound (particularly point of care ultrasound (POCUS)) are already well-established for postgraduate medical practitioners [1]. More recently, undergraduate medical programs are integrating ultrasound (US) into their curricula. The Ultrasound in Medical Education Portal lists over 200 medical schools on the AIUM (American Institute of Ultrasound Medicine) website as having a curriculum which includes an ultrasound component [2]. In 2014, the American Academy of Emergency Medicine issued a clinical practice statement declaring that 'Ultrasound should be integrated into undergraduate medical education curricula' [3]. The purpose of this study is to provide a guide for medical educators of the available evidence regarding how best to integrate ultrasound (e.g., correlating human anatomy with corresponding ultrasound images or sonoanatomy) and the possible learning opportunities associated with it (e.g., using it as a teaching tool to demonstrate blood flow or focusing on

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its clinical applications). We aimed to inform medical educators of the following:

(i) the different categories of literature available on the topic of undergraduate ultrasound
(ii) findings of importance from researchers in this field
(iii) future directions for ultrasound in undergraduate medical education

Given the heterogeneous literature that has emerged in this field, a scoping review was conducted. Scoping reviews differ from systematic reviews in that they have a broader focus and are often employed as a means of defining the parameters of the literature on a given subject [4].

Methods

Data Sources and Searches A search of electronic databases (Pubmed, EMBASE, CINAHL, Medline, PyscINFO) was conducted for educational studies published between January 1980 and August 2016 that either directly taught medical students the use of ultrasound or that reviewed an ultrasound program for medical students. Search terms were combined as per Table 1. Hand searched articles, including articles we found while examining reference lists from identified primary papers, were also examined for inclusion.

Study Selection The process for article screening is outlined in the PRISMA flow (Fig. 1). Only full-length articles published in English were considered for inclusion. Duplicate articles within or between databases were excluded with the help of the referencing software Endnote (version X7.4). The remaining full-text articles were screened independently for inclusion by two reviewers (CN, JB). Discrepancies between reviewers were resolved through consensus. Inclusion criteria were prospective or retrospective studies, observational or intervention studies and studies describing how medical students learn to use ultrasound. Articles were excluded as per the PRISMA flow (Fig. 1; for citation references, see Appendix A). Studies that met the inclusion criteria were reviewed by two reviewers (CN, JB) for thematic commonalities. Once categories were formulated the major findings from these categories were discerned and discussed.

Results

The literature search yielded 593 articles, of which 128 were considered eligible for inclusion.

The categories that emerged were as follows: papers that described or evaluated an ultrasound curriculum and papers that surveyed those involved in the development and evaluation of these curricula; those that employed ultrasound as a means of teaching another topic in the curriculum (e.g., anatomy, physiology, physical examination, invasive procedures); articles that examined the learning curve for undergraduate ultrasound and articles that described the use of adjunctive methods or technology in the teaching of ultrasound to medical students, including those which used peer mentoring. Where papers featured elements of more than one category, they were classified with respect to the category that best fitted the primary focus of the paper. Tables (1, 2, 3, 4 and 5) are presented for each category.

Curriculum

Papers categorised in the curriculum category either described a fully-formed ultrasound curriculum or described

Table 1 Literature search terms

	AND →		
	Medical students	*Education*	*Ultrasound*
OR ↓	"medical students"	Education	"ultrasound guided"
	"pre residence"	Teaching	Ultrasound
	"pre residency"	"medical school"	

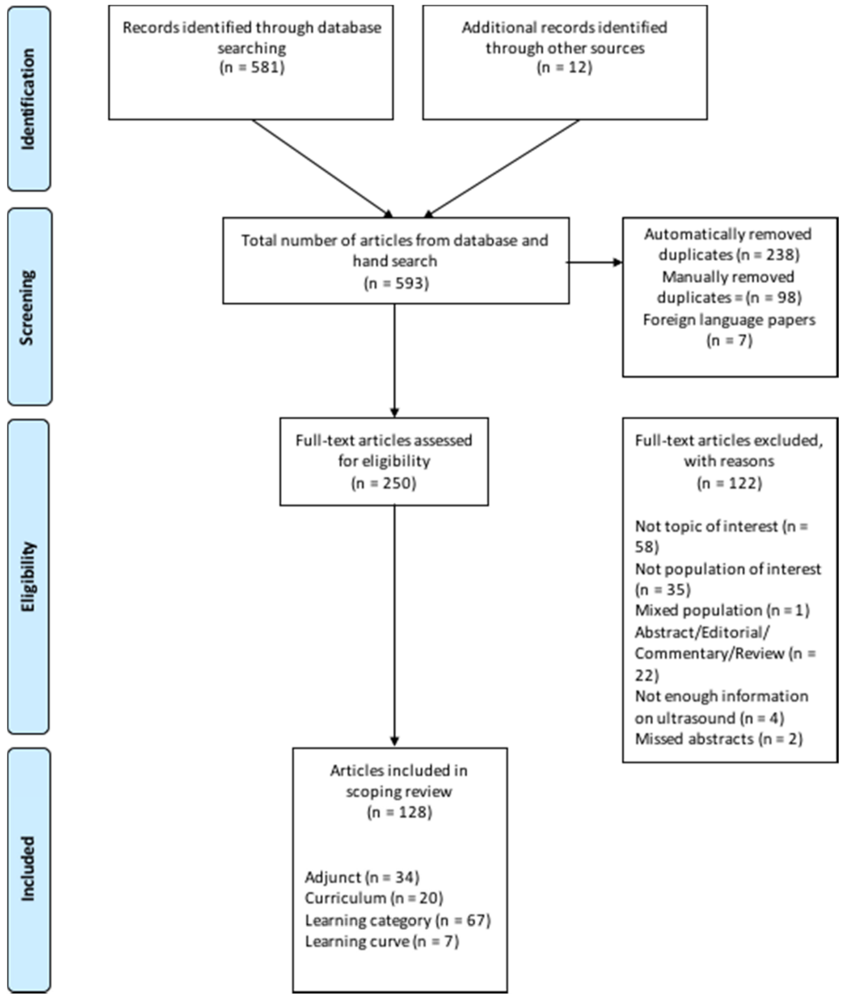

Fig. 1 PRISMA flow of literature search

an ultrasound teaching intervention that spanned more than a single educational theme or goal. We also included in this section papers that surveyed ultrasound educators with respect to ultrasound implementation or assessment in medical schools.

Learning Category—Incorporation of Ultrasound into Teaching of Another Curriculum Topic

Sixty-seven papers were categorised as incorporating US into teaching a particular part of the curriculum. Some

Table 2 Curriculum papers—20 papers

Sub-category	Citation reference	Description of subcategory
Curriculum description or evaluation	[5–19]	Fifteen papers describe variously integrated ultrasound curricula. Five studies are notable for the numbers of medical students involved in a formal evaluative process (>150) [5–9]. Heinzow et al. [5] reported that students were evaluated as per DEGUM standards (national sonographer examination standards). Hoppmann et al. [10] published a review of their integrated ultrasound curriculum and is notable for the practical advice it offers educators starting their own ultrasound curriculum. Their 2015 follow-up article details recommendations for student assessment and the value of an US image review portal [11]. Most papers are emergency medicine-led. Two papers [9, 16] are radiology-led.
Curriculum surveys	[20–24]	Five papers featured surveys of curriculum administrators regarding incorporation of ultrasound into medical schools in the USA. Bahner [20] provides a useful cross-section of ultrasound teaching in the USA, where 62.2% of schools that responded reported that ultrasound was a part of their medical school curriculum. Two papers surveyed ultrasound experts using a 'Delphi' methodology to establish ultrasound learning milestones [21] and an assessment tool [22].

Table 3 Learning category—67 papers

Sub-category	Citation reference	Description of subcategory
Anatomy	[25–40]	Ultrasound has been highlighted as an effective means of teaching clinically encountered, 'living' anatomy, as distinct from traditional cadaver or textbook based methods [25–30]. US supported teaching addressed cardiac anatomy [33–35] most commonly, and several other organ systems [30, 32, 36]. Moscova et al. [37] found that students' perception of the ultrasound in the anatomy course varied with prior anatomical knowledge.
Physiology	[41–44]	Brunner et al. [41] reported positive subjective feedback by students to the integration of echocardiography into their teaching of cardiac physiology to medical students. Bell, Wilson and Hoppmann [42] found that students taught cardiac physiology with the help of ultrasound significantly improved their scores on an exam on that topic. Paginini and Rubini [43] describe the integration of a lung ultrasound demonstration to a lecture on lung physiology. In 2016, they reported another lecture [44], this time demonstrating vascular physiologic and cardiovascular reflexes. Both lectures received positive subjective evaluations from students.
Physical examination	[45–81]	The potential to incorporate ultrasound into physical examination teaching led Fox [45] to develop the 'UCI 30'. This is a set of ultrasound examinations that parallel the 'Stanford 25', a set of core physical examinations that institutions recommend should be familiar to students. Dinh et al. [46] found that students that had ultrasound incorporated into their physical examination curriculum obtained greater OSCE scores than a cohort of students that took the exams prior to the introduction of ultrasound, in the same medical school. The educational interventions found here range from those that teach students to scan a wide range of anatomy [47, 48] or regional anatomy [49] to more focused exams of the vascular [50–52], abdominal [53–55], head and neck [56], cardiac [57, 58] and respiratory [59] systems. Some institutions taught students ultrasound-specific protocols such as FAST [60–62] or USEFUL [63] scans. Senior medical students, whose learning objectives have graduated to the diagnosing of disease in real-world patients, have demonstrated significant improvement in their ability to diagnose disease following brief, focused ultrasound teaching programs [64–68]. These benefits are particularly impressive when benchmarked against postgraduate medical practitioners using either physical examination [69, 70] or ultrasound [71, 72]. The obstetric ultrasound study of Hamza et al. is notable for its use German Society of Ultrasound in Medicine (DEGUM) guidelines as the source material for student teaching, and for its use of a standardised teaching approach [73]. Amini et al. [74] report the teaching of ultrasound centred around a clinical problem-based theme, that of hypotension. The intervention taught students about the ultrasound diagnosis of common pathologies that cause hypotension, including pulmonary embolism, pneumothorax and abdominal aortic aneurysm.
Procedures	[82–91]	Ultrasound has been used in conjunction with 'phantom' simulators [82–85] or cadavers [86, 87] to teach invasive procedures such as venous and arterial line placement and nerve blocks. McCrary et al. [88] used a fresh cadaver model to teach ultrasound-guided breast biopsy to medical students on surgery clerkship. Two studies [84, 85] used a randomised group methods to assess differences between ultrasound or landmark-based methods of teaching venous catheter placement. Griswold-Theodorson [85] found that students were safer and more successful when using ultrasound guidance, whereas Osborn et al. [84] demonstrated no difference in success rates, although students' subjective ratings of knowledge gain and ease of use were greater in those who had undergone US-based teaching.

Table 4 Learning Curve—seven papers

Citation reference	Description of subcategory
[92–98]	Training medical students in POCUS for 1 year appears to provide them with a significant advantage in the postgraduate arena [92]. Retention of knowledge can be problematic (one paper reported a 17% decrease in knowledge learned after 1 year). Medical students in this study achieved scores that were 55% greater than those of their US-naïve counterparts in an US OSCE [92]. Small group teaching is associated with better knowledge retention [93]. Low fidelity models are sufficient for improving hand-eye co-ordination prior to procedures on patients [94]. The learning curve to enable novices to detect major cardiac abnormalities with acceptable diagnostic value when compared with experienced echocardiographer findings is short [95]. Ultrasound 'knobology' has been shown to be responsible for a large portion of the cognitive load for novice ultrasound learners [96, 97]. Gradl-Dietsch et al. [98] found no effect of gender on either objective performance during assessment or subjective preference when learning ultrasound.

Table 5 Adjunct category—34 papers

Sub-category	Citation reference	Description of subcategory
Social and event-based adjuncts	[99–103]	The use of ultrasound-themed events and competitions has been employed as an adjunct to stimulate student interest and enthusiasm in ultrasound [99–101]. Two papers in our search detail social groups centred on an interest in ultrasound. One was student-led [102], the other was delivered through social media [103]. Both are discussed in terms of opportunities for stimulating student engagement and interest.
Devices and simulators	[104–116]	The primary objective of these papers was to describe or evaluate ultrasound simulators (or 'phantoms') or devices adjunctive to the ultrasound machine itself. Ultrasound simulators are models of human anatomy designed to provide a means of practicing ultrasound skills where practice on a human is impractical, dangerous or unethical. Our search found studies that tested both commercially available simulators [104–108] and institutions that built their own simulators with varying degrees of complexity [109–111]. Many of the simulators available work by linking movements of a 'dummy' ultrasound probe on a non-human model with a 3D imaging dataset, linking real-time changes in the image visible on-screen with hand movements. Three papers in this category used a randomised method in comparing simulators with live patients in the teaching of ultrasonography to medical students. Both Bentley et al. [105] and Damewood et al. [108] randomly allocated students to be taught the FAST scan using either a human model or a simulator; both groups of students were then evaluated in their ability to perform a FAST scan on a live patient, post-intervention. No significant difference in OSCE scores was found between the two groups in either study. However, Moak et al. [106] found that students trained with a simulator demonstrated poorer scanning technique and image acquisition than those that trained with live models when learning transvaginal sonography. Kusonose et al. [104] randomly allocated students to take part in either a simulator-based training course or textbook-based learning prior to undergoing hands-on ultrasound training. Simulator-trained participants scored better in the quality of image obtained in each of the seven transthoracic echocardiography views. Guidance systems for ultrasound-guided vascular access have been shown to reduce procedure times [112–114], and the learning curve [112] for medical students. These technologies may provide a 'safe space' in which students can learn the fundamentals of ultrasound-guided vascular access before attempting such procedures on patients. Benninger [115] combined an ultrasound finger probe and Google Glass to integrate ultrasound visualisation with physical palpation. Sheehan et al. [116] reported that remote (telemedicine) feedback could be used to improve student performance of ultrasound versus verbal direction.
Online and e-learning technologies	[117, 118]	In a written exam taken prior to a hands-on ultrasound course, Hempel et al. [117] report that students who took part in a case-based e-learning course performed better than those who were taught with a classroom-based presentation; Hughes et al. [118] described benefits for students in collating a portfolio of ultrasound images as a means of tracking their learning and development.
Novel teaching techniques	[119–125]	This category describes papers in which a novel teaching technique was itself the primary focus of the paper. Learning benefits are reported for practicing in pairs instead of alone [120]; physician-patient role play [121]; students learning about ultrasound through their participation as simulated patients [122] and the equivalence of self-directed podcasts as a didactic learning method compared with lectures [123]. Some educators have trialled enhanced ultrasound images through fusing US images with MRI, or the employment of simple line drawings to provide a reference for the 2D sonoanatomy images [124]. These are all measures that educators can consider as a low-cost means of enhancing ultrasound teaching.
Peer-mentoring	[126–132]	In the course of evaluating articles which integrate POCUS in a novel way, peer mentoring emerged as a major theme in ultrasound education. In the peer mentoring studies reviewed, medical students in clinical or clerkship years (typically third or fourth year) teach preclinical medical students (first or second year). The utilisation of peer mentors in ultrasound education programs has been proposed as a means of decreasing the number of senior faculty required to deliver ultrasound education to medical students, thus allowing education to take place in staff or resource-deprived settings [126]. Advantages for the education of medical students also extend to the peer tutors themselves [127, 128]. There may, however, be a limit to the extent to which peer tutoring can replace faculty instruction, with Kühl et al. [129] finding student's knowledge gains to be less when taught by peer mentors compared with faculty. Though this point is contradicted by Knobe et al.'s [128] randomised controlled trial, subjective feedback in this and Dickerson et al.'s study [130] show that not all students find peer teaching as acceptable as that delivered by faculty.

authors have described POCUS as the 'new stethoscope' [119] and the majority of the papers which focus on a curriculum topic have taught ultrasound in the context of physical examination (31 papers). Fifteen papers focus on the teaching of sonoanatomy while smaller numbers focus on the topics of physiology and invasive procedures.

The Learning Curve for Undergraduate Ultrasound Education

The learning curve category includes papers that either inform educators regarding factors that enhance or limit student learning ultrasound, or formally examine the learning curve for the acquisition of ultrasound skills.

Adjunctive Technologies and Teaching Methods in Undergraduate Ultrasound Education

The adjunct category comprises papers that describe or evaluate adjunctive technologies and teaching methodologies in the teaching of ultrasound to undergraduates.

Discussion

Our review of the current literature on the integration of US into medical school curricula found that the published research is focused on the following four areas:

(1) Descriptions of various fully and partially integrated ultrasound curricula where ultrasound has been integrated into two or more years of the medical school curriculum. A small number of these programs include objective evaluation. In addition, surveys of program administrators are available, giving insights into the process of successfully integrating ultrasound into an undergraduate medical curriculum.
(2) Descriptions of the incorporation of ultrasound into one topic in the curriculum (i.e., anatomy, physiology, physical examination, invasive procedures). Some authors included an evaluation of these educational interventions.
(3) Descriptions of the learning curve of ultrasound education
(4) Descriptions and evaluations of using adjuncts or peer mentoring to teach US.

Six take home messages from this scoping review:

1. Integrate Ultrasound into the Undergraduate Medical Curriculum—'Just Do It'

The major difference in the papers categorised to category 1 or 2 is one of scale. Incorporation of ultrasound into an entire curriculum is a much larger undertaking than standalone additions to parts of a curriculum. The latter can be achieved in lower-resourced settings but the former, while resource intensive, leads to a more robust program. Twenty-one percent of the papers in this review (27 of 128 publications) have involved three authors from three different institutions that have integrated ultrasound teaching within each year of their medical school curriculum (DP Bahner, JC Fox and RA Hoppmann). Full integration has allowed for the development of such programs over time, with incorporation of feedback and continued improvement [10, 11].

The investment of these medical schools in ultrasound is being rewarded by increased student interest, with some evidence emerging that medical students are choosing programs based on their investment in ultrasound [11] leading to our first take home message which is 'Integrate ultrasound into your undergraduate medical curriculum'. If possible, invest in a fully integrated program. Such programs do require a significant initial investment in terms of faculty, equipment and administration; however, if your medical school does not have the resources for this initial investment, the evidence is there to support integrating ultrasound into one topic in the curriculum such as anatomy and building out from this as resources allow. A recurring theme in the papers that employed ultrasound to teach anatomy was the use of ultrasound to teach 'living anatomy' [25–27].

The majority of papers in this scoping review (67/128) described the use of ultrasound as a tool to enhance the teaching of another topic or a clinical skill.

2. Evaluate your program objectively and incorporate an image management system.

Objective measures of ultrasound performance have been developed but have yet to be validated in the undergraduate population. The majority of papers that we reviewed were satisfied to rely on students' subjective ratings of their own learning experiences. The limitations of such data are clear: students may rate a course as favourable even where their knowledge gains were modest and no reliable comparison is possible between the effectiveness of the various educational interventions described. Students tend to overestimate their performance, but a significant amount of knowledge can be retained at 8 months in a well-structured program [8].

One way of assessing students is to use the national sonographer standard [5]; however, this standard will vary between countries. Although medical students can reach national sonographer standards with a structured integrated approach [5], the majority of student scores tended to be akin to 'a borderline level of competency'. This underscores the need for a structured approach to undergraduate ultrasound education which incorporates a robust image review and management system [15]. Many programs up to this point have been evaluated using various pre- and post-test questionnaires, MCQ exams and checklists; however, validated tools are emerging [21, 22].

In 2013, Tolsgaard et al. achieved international consensus across multiple specialties on a generic ultrasound rating scale using a Delphi technique [133]. In 2014, Tolsgaard et al.

published their assessment of 30 ultrasound users. They used their OSAUS scale (Objective Structured Assessment of Ultrasound Skills) to successfully differentiate novice, intermediate and experienced obstetric and gynaecology physician ultrasound users [134]. In 2015, Todsen et al. replicated this work for point of care ultrasound in a group of 24 physician participants [135]. The OSAUS has yet to be validated in the undergraduate population. Our research group believes this is the next step to advance the field of undergraduate ultrasound education.

3. Involve the right people—include emergency physicians, radiologists, sonographers and clinicians who use ultrasound on a daily basis. Consider the value of peer-teaching.

Currently, the majority of programs are led by emergency medicine faculty but there is a growing engagement of radiologists in undergraduate ultrasound teaching [23]. Given the already high demands on faculty for teaching time, institutions should consider enlisting the help of ultrasound professionals such as sonographers, or peer teachers. Near peer teaching offers an opportunity for advanced students to push their learning horizons further, while also relieving an oft-cited limitation in ultrasound program construction—the availability of qualified faculty that can meet a large teaching commitment [126].

4. Ultrasound simulators and phantoms are versatile adjuncts that allow for ultrasound teaching in the absence of patients or cadavers

Some of the most common teaching adjuncts employed in the ultrasound literature were ultrasound simulators and phantoms. The evidence supports the use of simulators as well as several novel low-cost teaching tools for the less well-resourced educator. Ultrasound can also complement cadaver-based teaching, allowing invasive interventional skills (central line placement [85, 86], pericardiocentesis [87], surgical biopsy [88]) to be taught on realistic anatomy without compromising patient safety. Where cadavers are not available, ultrasound simulators and phantoms can fulfil a similar role.

5. Use small group teaching and spend some time on knobology and physics—this accounts for a significant cognitive load for novices

Ultrasound is operator-dependent; however, students can learn quickly [8], particularly with small-group teaching [93]. Jamnickzky et al. [97] highlighted the cognitive load imposed by ultrasound 'knobology' on novice learners, a finding which serves as a warning to educators that teaching the basics of the technology cannot be sacrificed, even in a time-limited setting.

6. Harness student enthusiasm

One constant among the heterogeneous literature reviewed here was in students' responses to ultrasound teaching. In every paper in which students' subjective assessment of ultrasound incorporation into the curriculum was sought, it was very positive. The benefits of active student engagement and leadership have also been demonstrated in student-led ultrasound interest groups [102], where students interested in ultrasound have the opportunity to organise educational events and demonstrate autonomy in their learning. Medical students respond positively to US and, after receiving undergraduate ultrasound instruction, are more likely to use US in their post-graduate practice [24].

Conclusions and Future Directions

Integration of ultrasound into the medical school curriculum is feasible and beneficial to medical students. Those programs with greater integration deliver a more robust ultrasound education. The quality of an ultrasound curriculum is dependent on involving a wide range of ultrasound practitioners, from radiology faculty to peer teaching. Ingenuity in teaching technologies and strategies, including the use of low-cost simulators and near peer teaching, has provided an example of how ultrasound can be taught, even in less well-resourced medical schools.

The following gaps exist: (1) Long-term follow-up studies demonstrating that learners improve with existing teaching methods and (2) the use of validated tools (such as OSAUS) to assess learners and programs.

Ultrasound education researchers should look to the established medical education literature to design follow-up studies which can demonstrate that structured training programs improve the ultrasound skills of students. The authors agree with Hoppmann et al.'s [11] call for 'an international consensus conference on US education to help define the essential elements of US education globally to ensure US is taught and ultimately practiced to its full potential'.

Limitations of This Paper

Limitations of space precluded a comprehensive analysis of each paper uncovered in our search. For this same reason, papers were generally only reported in the category that best fitted their primary focus. For example, a teaching intervention for physical examination that had, as a component, an e-learning module or a simulator was categorised under the physical examination heading and not in terms of the adjunctive technologies employed.

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