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REVIEW

TRANSFUSION

E-learning in transfusion medicine: A scoping review

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1 | INTRODUCTION

There is considerable interest in the use of digital education or e-learning in professional development and continuing education, which applies to transfusion medicine (TM) as much as other disciplines. Advantages of e-learning programs may include the ability to engage rapidly with a large target audience, a reduction in costs when compared to traditional training methods, a design that can adapt in a timely manner to new developments, and the ability to use analytics and data on learner engagement to facilitate feedback. E-learning may therefore offer a more flexible, affordable, and accessible alternative to traditional learning as it transcends location and time constraints.[1] Different e-learning or digital formats are well described, including online or offline digital education, open online courses, mobile education, gaming and gamification, virtual reality, and use of virtual patients.[2] Through the range of different modalities, e-learning should enable different and possibly more targeted educational experiences with varying forms and levels of interactivity, immersion, duration, and feedback.[3] These formats of digital or e-learning education should be contrasted with more traditional formats of education, based on face-to-face training and didactic lectures.

There are some specific challenges for education in TM, given the need to support and enable broad target audiences, from donor health to monitoring transfused patients and assessing the appropriate use of blood. This requires an effective approach to target education at a wide range of multidisciplinary healthcare professionals, including clinical, nursing, and laboratory staff in hospitals and blood establishments. It is also recognized that transfusion education should be provided across graduate, postgraduate, and continuing education programs to ensure the acquisition of basic as well as more advanced transfusion knowledge, and to disseminate updated evidence-based practice. During a career, transfusion knowledge uptake is important to prevent process errors, to ensure compliance with evidence-based guidelines, and the rational use of safe blood products. Learner feedback and assessment are crucial to ensure that educational interventions are achieving the targeted objectives and the needs of learners. As might be expected, e-learning programs have been implemented in multiple TM jurisdictions, as reported in a recent survey distributed to the

members of the International Society of Blood Transfusion (ISBT), which demonstrated the widespread use of e-learning courses with a substantial proportion being developed during the Coronavirus disease-19 (COVID-19) pandemic.[4]

Given the increased interest in digital and e-learning which was expanded by many educational departments and institutions during the COVID-19 pandemic, we undertook a scoping review to collate the broad literature relevant to the use of digital and e-learning programs in TM education. The specific aims were to describe the features and characteristics of digital and e-learning programs to date, and to explore how the effectiveness (and cost-effectiveness) of e-learning tools were assessed. We were particularly interested in publications that compared e-learning formats with more traditional forms of education, such as face-to-face teaching.

2 | METHODS

We followed the published guidelines on the design and reporting of scoping reviews.[5] Using a combination of carefully selected index and free-text terms (such as "blood transfusion," "education," "distance," "e-learn*," "on-line," "digital*," "virtual*," "e-module*," "moodle*," and "technology-based"), we conducted a comprehensive search of the following electronic databases to identify peer-reviewed literature: MEDLINE (Ovid), PubMed, Embase (Ovid), CINAHL (EBSCO*Host*), APA PsycInfo (Ovid), Education Collection (ERIC + Education Database) Proquest, Web of Science Conference Proceedings Citation Index – Science (CPCI-S), Book Citation Index – Science (BKCI-S) and Emerging Sources Citation Index (ESCI), and Transfusion Evidence Library (Evidentia). We also searched ClinicalTrials.gov and World Health Organization International Clinical Trials Registry for unpublished clinical trials. The search included literature published from the time of inception of each database to March 28, 2022. We also searched the reference lists of identified studies for additional relevant articles. The full search strategy is detailed in Supplementary material S1.

2.1 | Study selection

We included all studies that described e-learning intervention in any format. The exclusion criteria were unpublished literature, abstracts without full text, conference abstracts or proceedings, review articles, editorials, commentaries, and non-English literature.

2.2 | Data abstraction

Data abstraction was performed on an initial set of articles to ensure consistency across the reviewers using a Microsoft excel electronic form. Seven reviewers dually and independently abstracted data using the pre-designed data abstraction form. Disagreements were resolved by consensus or with the help of a third reviewer. Data abstraction included study characteristics (e.g., publication year, country of origin, setting/type of institution, study design, sample/control size), methodology details (e.g., research question) and key findings related to characteristics of e-learning such as time required to complete, source (developed in-house vs. externally acquired), type (solo vs. hybrid/part of blended learning with other means of education), format, mode of delivery (webinar, modules, virtual simulation, others), and accreditation status. We also extracted information on the type of learners, their level of education (undergraduate, graduate/post-graduate, continued education), and content/topics covered. Moreover, we extracted how outcome assessment was performed, if learners' feedback/satisfaction was obtained, if there was a criterion used to define successful completion of the course/module (pass score, pass/fail, or certification), and if comparison with other forms of education was performed. Outcome of learnings was categorized as per the Kirkpatrick model framework for evaluating training programs. The levels of assessment include level 1 (reaction), level 2 (learning/knowledge), level 3 (behavior), and level 4 (outcomes) (Supplementary material S2).[6] Finally, a needs assessment was performed using a preset agreed criteria that included information on resources required for development (e.g., cost and time), any gaps identified in the papers (lack of reporting any of the above variables), and lessons learned/ recommendations that can be made from the perspective of the reviewers.

2.3 | Data analysis and reporting

A descriptive analysis of the extracted data was performed, summarizing the characteristics of the included studies, and key findings related to the topic of interest. Summaries were developed of each article related to the author, year, location of study, study design, study methods, sample size, characteristics of e-learning method used, outcome assessment, gaps identified, and recommendations of the individual selected study.

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines to report the findings of our scoping review.[5] Given the exploratory nature of scoping reviews, we did not conduct a formal quality

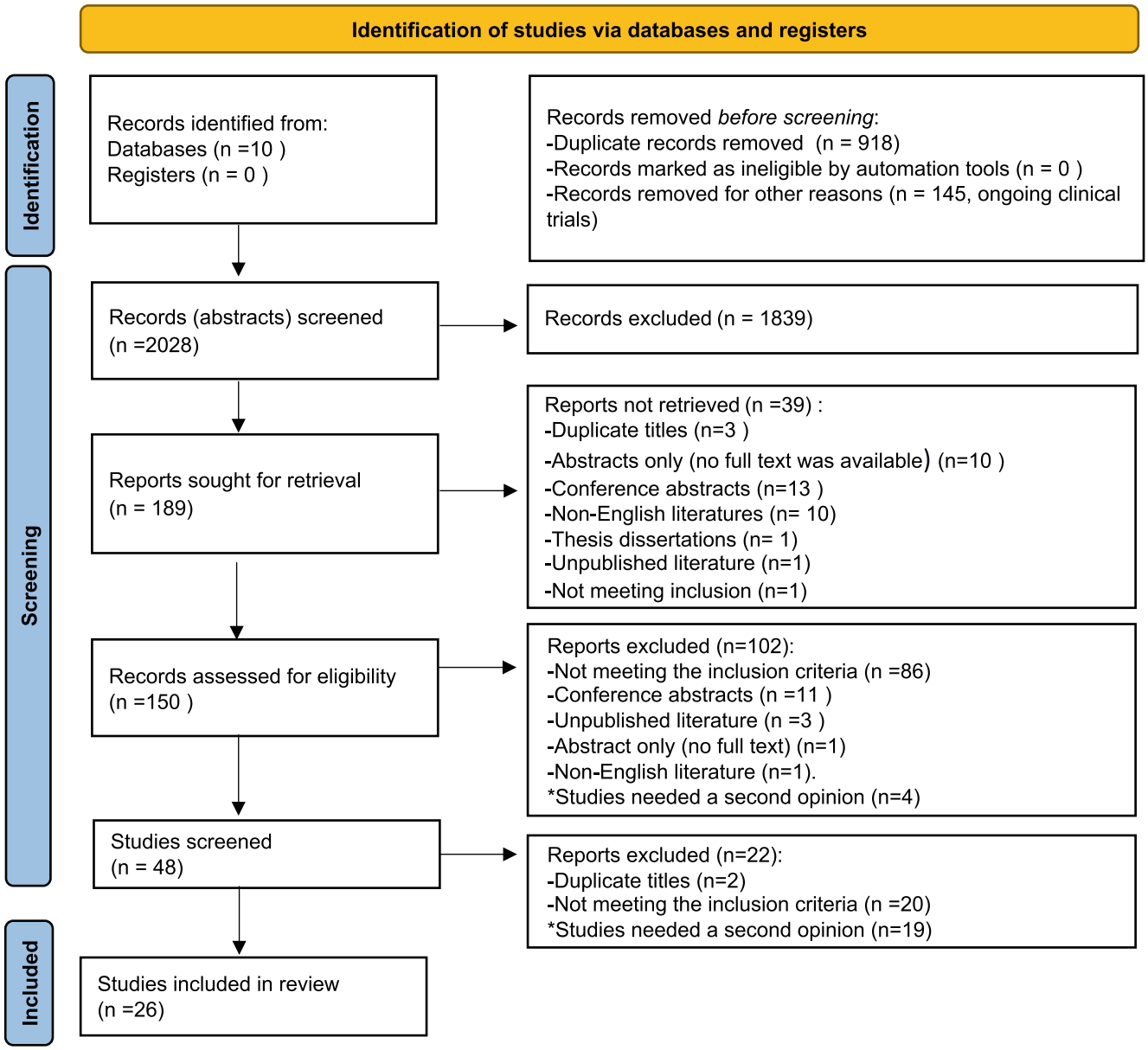

FIGURE 1 A PRISMA diagram of the scoping review. [Color figure can be viewed at wileyonlinelibrary.com]

assessment of the included studies. This protocol was not registered under PROSPERO as it does not accept scoping reviews for registration. The review of the literature and data abstraction was completed over a one–year period (March 2022–March 2023).

3 | RESULTS

3.1 | Study selection

The search retrieved 2946 articles and 266 ongoing trials. After eliminating duplicate literature, the total number was reduced to 2028 references and 145 ongoing trials. Eight reviewers independently screened titles and abstracts of the articles in pairs for potential inclusion. Guided by the inclusion and exclusion criteria, full-text articles were retrieved for studies that met the inclusion criteria or had unclear eligibility. Full text of 150 records were assessed for eligibility based on inclusion and exclusion criteria. After full text screening, 26 studies were included in the scoping review (Figure 1).

3.2 | Included studies

The 26 publications were from 14 countries including seven from the United States,[7–13] six from the United

TABLE 1 Summary of the included studies ($n = 26$).

Characteristic	Number of studies (%)
Study design	
• Observational	20 (77)
• Case Control	2 (8)
• RCT	4 (15)
Median number of participants (range)	40.5 (7–556)
Type of learner (multi-choice)	
• Physicians/medical students	13 (50)
• Nurses/midwives/nursing students	10 (38)
• Laboratory technologists/students	2 (8)
• Healthcare professionals	3 (12)
Educational interventions (multi-choice)	
• Module/Model/Moodle	16 (62)
• Virtual/video simulation	10 (38)
• Educational online material	4 (15)
• Game-based	2 (8)
Kirkpatrick level (multi-choice)	
• Level 1	16 (62)
• Level 2	16 (62)
• Level 3	2 (8)
• Level 4	4 (15)
• No details	2 (8)
Evaluation methods	
• MCQ	8 (31)
• Attitude	7 (27)
• Competency-based exam/practical exam	7 (27)
• Change in organization practice/clinical outcomes	2 (8)
Topics	
• Blood administration	18 (69)
• Transfusion reaction	13 (50)
• Laboratory practice	10 (38)
• Massive hemorrhage and PPH	6 (23)
• Patient Blood Management	5 (20)
• Hemovigilance	5 (19)
Accreditation	2 (8)

Abbreviations: MCQ, multiple-choice exam; PPH, post-partum hemorrhage; RCT, randomized control trials.

Kingdom,[14–19] four from other countries in Europe,[20–23] and five from low- and middle-income countries (Brazil,[24,25] India,[26] Morocco,[27] and Egypt[28]) (Table 1).[29] The vast majority of the institutions in these studies were academic or university affiliated (70%). There were two programs that were accredited, one by the Royal College of Physicians and Surgeons of Canada,[30] and one by Junta de Andalucía's Health Quality Assurance Agency in France.[23] An outline of the studies that were analyzed and their e-learning programs is presented in Table 2 and Supplementary material S3.

All articles identified were original articles except for one short communication. The majority of the studies were observational, four were randomized trials, and three were qualitative research. The number of subjects ranged between 7 and 556 (median 40.5 subjects per study).[8,22,27,31]

3.3 | Target audiences and topics covered in transfusion medicine e-learning

The educational programs targeted undergraduate (12 studies), continuing education (12 studies), and graduate/post-graduate education (four studies) level audiences. Physicians including interns/residents/foundational-year trainees (six studies), medical students (six studies), and nurses/midwives (six studies) were the common targeted learners, followed by nursing/midwifery students and staff in the first year of training (four studies) and laboratory technologists/scientists students (one study). Three publications described targeting multiple healthcare professional learners.[18,23,24]

The common topics covered were blood administration ($n = 18$), transfusion reactions ($n = 13$), laboratory practices ($n = 10$), hemovigilance ($n = 5$), and patient blood management (PBM) ($n = 5$). Other topics appeared less frequently, such as blood component production, massive hemorrhage, and reversal of anticoagulation, which were only covered once or twice each (Table 2).

3.4 | Types and formats of TM e-learning

The studies comprised of different formats of education including modules and models ($n = 13$), simulation ($n = 10$); virtual, video, computer-based patients and simulated laboratory, online presentations/lectures, interactive videos, or reading material ($n = 4$) and game-based learning ($n = 2$) (Table 2). More than half of the institutions developed the transfusion e-learning tools in-house ($n = 16$, 62%), while 35% obtained it from external sources and one was developed with support by a third party.[32] The majority of the learning was done as part of blended learning ($n = 19$, 73%), while five studies used e-learning as the sole method of learning. Two studies did not give details on how the learning was incorporated in the education. The literature described various methods of delivery for educational activities, with the most common being web-based platforms ($n = 16$) (Table 3). Integration into laboratory information system

TABLE 2 Characteristics of the included studies.

Author, year, country	Study design	Level of education	Type of learners	Subjects/ controls[a]	Educational intervention	Kirkpatrick level	Evaluation methods	Topics
Aloweni, F, 2021, Singapore	Observational, qualitative	Continued education	Nurses/midwifes	11/NA	Game-based	Level 2 Level 3	Quizzes, skill application	Blood administration Transfusion reaction
Bhaskar, A, 2014, India	Observational	Under-graduate	Medical students	95/NA	Game-based	Level 1	Evaluation of the course	Blood administration Laboratory practice
Brunetta, DM, 2021, Brazil	Observational	Under-graduate Continued education	Medical students and other healthcare professionals	365/NA	Educational cards & videos	Level 1 Level 4	Questionnaire Change in organization practice/clinical outcomes	Blood administration PBM Transfusion reaction Laboratory practice Immunohematology Massive hemorrhage & PPH
Cottrell, S, 2013, UK	Observational, qualitative	Continued education	Registered nurses	7/NA	Modules	Level 1	Attitudes (Thematic analysis from the semi-structured interviews)	Blood administration Transfusion reaction Hemovigilance
Gouifrane, R, 2020, Morocco	Randomized trial	Under-graduate	Nursing students	16/16	Model	Level 2	MCQ, written exam	Blood administration Transfusion reaction Laboratory practice Immunohematology
Huang, H, 2021, Taiwan	Case–control	Continued education	Nurses	38/36	Virtual simulation (VVR)	Level 1 Level 2	Attitude (class room engagement questionnaire), MCQ, Likert scale questionnaire	Blood administration
Joyce, KM, 2015, Ireland	Case-control	Graduate/post-graduate	Physicians (interns)	27/30	Module Simulated computer-based patients	Level 2 Level 3	Competency-based exam/practical exam, direct observation for any change in behavior/ practice	Blood administration Hemovigilance Transfusion reaction Sample labeling
Kato, C, 2017, Japan	Randomized trial	Continued education	Midwifes	40/41	Module simulation	Level 1 Level 2	Self-evaluation, MCQs, competency-based exam/practical exam	PPH
Kelly, SL, 2013, UK	Observational	Continued education	Physicians	41/NA	Module	Level 4	Change in organization practice/clinical outcomes	Blood administration PBM Blood component traceability Transfusion guidelines
Konia, MR, 2018, USA	Observational	Under-graduate	Medical students	106 online/104 simulation/81 hybrid	Module, Video simulation	Level 2	MCQs	Blood donation Blood administration Transfusion reaction Laboratory practice

TABLE 2 (Continued)

Author, year, country	Study design	Level of education	Type of learners	Subjects/ controls[a]	Educational intervention	Kirkpatrick level	Evaluation methods	Topics
Lee, SC, 2019, USA	Randomized trial	Graduate/post-graduate	Physicians (residents)	17/17	Video simulation	Level 1 Level 2	Attitudes (via a survey), evaluation of the course, competency-based exam/practical exam	Transfusion consent
Lee, TC, 2019, Canada	Observational	Graduate/post-graduate	Physicians (residents)	53/50	Module	Level 2 Level 4	MCQs, change in organization practice/clinical outcomes	Blood administration PBM Transfusion reaction Laboratory practice Acute blood loss and perioperative transfusion
Mettiäinen, S, 2014, Finland	Observational	Under-graduate	Nursing/Midwifery students	190/NA	Module	Level 1 Level 2	Self-assessment, competency-based exam/practical exam	Blood administration
Michelet, D, 2019, France	Randomized trial	Undergraduate & graduate	Midwifery undergraduate students & staff in first year of training	12/12	Virtual simulation	Level 2	Competency-based exam/practical exam	Blood administration PPH
Miner, J, 2020, USA	Observational	Continued education	Nurses/midwifes	71 providers 472 nurses/NA	Module (Model)	Level 4	Change in organization practice/clinical outcomes	PPH
Molina-Arrebola MA, 2020, Spain	Observational	Continued education	Technicians, nurses, and physicians	556/NA	Module (Moodle)	Level 1	Self-evaluation	Blood administration PBM Transfusion reaction Hemovigilance Laboratory practice Immunohematology Massive transfusion
Monday, LM, 2020, USA	Observational	Under-graduate	Medical students	89/NA	Online interactive PowerPoint presentations, procedure videos and video chat and live message board	Level 1 Level 2	Self-evaluation, MCQ	Blood administration Blood component order
Narayanan, R, 2008, UK	Observational	Graduate/post-graduate	Physicians (FYI trainee)	113/NA	Module	Level 1 Level 2	Participant reaction (% attending the course), MCQ, true and false questions	Blood administration Blood component use
Pickard, K, 2019, UK	Observational	Undergraduate	Medical students	28/NA	Online PowerPoint lecture with audio simulation	Level 1 Level 2	Attitude (via a Likert scale questionnaire), Short question test	Transfusion reaction

(Continues)

TABLE 2 (Continued)

Author, year, country	Study design	Level of education	Type of learners	Subjects/ controls[a]	Educational intervention	Kirkpatrick level	Evaluation methods	Topics
Smith, A, 2014, UK	Observational mixed qualitative and quantitative methods with online survey and interviews	Continued education	Healthcare professionals (nurses, midwives, physicians, porters, and bio-medical scientists)	538/NA	Module	Level 1 Level 2	Attitude (via a Likert scale questionnaire), MCQ	Blood administration Transfusion reaction Hemovigilance Laboratory practice
Smith FC, 2010, UK	Observational	Undergraduate	Nursing/Midwifery students	31/NA	Online material	Level 1	Knowledge assessment questionnaire	Blood administration Transfusion reaction Hemovigilance
Soliman HM, 2021, Egypt	Observational	Continued education	Nurses	25/NA	Module	Level 1 Level 2	Knowledge assessment questionnaire, Competency-based exam/practical exam	Blood administration Transfusion reaction
Tsang, HC, 2020, USA	Observational, Short Communication	Undergraduate	Medical students	11/NA	Virtual simulation	NA	NA	Laboratory practice
Vaena, MMV, 2018, Brazil	Observational	Undergraduate continued education	Medical students Physicians	37/NA	Software	NA	NA	PBM Transfusion reaction Laboratory Practice Use of blood components Reversal of oral anti-coagulants
Vortman, R, 2020, USA	Observational	Continued education	Physicians	150/NA	Computer-based learning module Video-recorded simulation	Level 1	Attitude (via debriefing & education evaluation form), knowledge assessment questionnaire	Massive hemorrhage
Oja J, 2016, USA	Observational	Undergraduate	Laboratory technologists/ scientists' students	34/NA	Simulated Laboratory Course with teaching modules	Level 1 Level 2	Attitude (via a Likert scale questionnaire), competency-based exam/practical exam, mock certification exam	Laboratory practice

Abbreviations: FYI, Foundation Year-1; MCQ, multiple-choice questions; NA, not applicable; PBM, patient blood management; PPH, post-partum hemorrhage.
[a]Numbers reflect participants who completed the modules.

(LIS) and e-learning management systems were reported.[32] One publication reported the impact of distributing evidence-based TM educational cards through WhatsApp, and posting them on different social media pages (Facebook and Instagram) that were created for this purpose.[24]

3.5 | Learning outcomes in TM e-learning

With the exception of two publications, all literature included information regarding the learner assessment using the Kirkpatrick levels (Table 2). In 14 publications, multiple Kirkpatrick levels were assessed. There were four publications assessed which reported either patient or PBM specific outcomes as a result of e-learning (Kirkpatrick Level 4).[9,15,24,30] These reported positive impact on outcomes, such as a reduction in blood component ordering and transfusion rates, improved traceability, and improvement in perinatal outcomes related to postpartum hemorrhage. Brunetta et al. evaluated the impact of its social media learning program and reported a reduction in RBC transfusions, and an increase in single-unit RBC used after introducing the social media program.[24] Kelly et al. introduced formal staff education including a transfusion e-learning module, then retrospectively reviewed the overall transfusion and discard rates, indication, and the hemoglobin cut-offs for transfusion orders in the emergency department.[15] The study reported a reduction in blood component ordering and transfusion, improved traceability, and a rise in the median age of the patient for whom a transfusion request was made after the introduction of the learning modalities. Lee et al. introduced an accredited self-directed training e-learning program in transfusion among medical residents,[30] and assessed the proportions of transfusions at a Hb below 80 g/L in the intervention ward study in comparison with a control ward. This publication reported a statistically significant increase in the proportion of transfusions at a hemoglobin below 80 g/L between both sites after introducing the intervention ($p = .002$). Finally, Miner et al. reported improvement in perinatal outcomes related to postpartum hemorrhage after introducing blended learning including the use of an online assessment-driven e-learning platform.[9]

One publication assessed change in behavior (Kirkpatrick Level 3) through direct observation,[20] while another assessed skill application.[32] Knowledge assessment (Kirkpatrick Level 2) was assessed in 16 publications including multiple-choice questions, written exams, quizzes, and competency-based/practical exams. One publication assessed knowledge through a mock certification exam.[13] Sixteen programs assessed reaction (Kirkpatrick Level 1) including attitudes, self-evaluation/assessment, and evaluation of the course.

Various types of evaluation measures were utilized in 10 studies, mainly focused on knowledge assessment, such as pass score ($n = 4$) and knowledge scores ($n = 2$) (Table 4). Performance and practice assessment were used in four studies,[8,27,28,31] and pass/fail was used in one.[13] In a study by Huang and colleagues, a 5-point Likert-based meta-recognition tendency questionnaire, pre- and post-test multiple-choice questions (with a pass score), a problem-solving tendency questionnaire, and a classroom engagement questionnaire were used in assessing learning outcomes of using spherical video-based virtual reality in a blood transfusion safety training course for new nurses.[33] Thirteen studies did not provide details on the criteria to define successful completion of the module.

Educational program evaluation via learners' feedback/satisfaction was reported in 18 studies (Table 4).

3.6 | Reports comparing outcomes of e-learning with more traditional modes of teaching (e.g., face-to-face)

Nine studies compared e-learning/online education with other forms of education (Table 4).[7,8,16,22,26,27,30,32,33] These studies were heterogenous in terms of type of audiences including nursing/midwifery students,[27] nursing staff,[32,33] midwives,[22] medical students,[7,26] residents,[8,30] and foundational year-I (FYI) trainee.[16] While most studies applied online education, one study utilized video-based virtual reality-based experiential flipped learning (SVVR-EFL),[33] and one combined online education with an in-person simulation.[7] All studies reported positive impact of e-learning in comparison to other modalities of education based on learners' perspective on learning achievement[16,26,33] and assessment results.[7,8,22,27,30,33]

3.7 | Knowledge gaps in the published literature

There are various gaps in the literature on e-learning in transfusion education including a lack of information on cost and resources required for module development, assessment methods used to evaluate learning outcomes, and accreditation status of the modules (Supplementary material S4). Educational theory chosen as the basis of teaching was usually not reported. The provided literature only had limited information on resources required for e-learning module development. Only two papers

TABLE 3 Characteristics of e-learning programs.

Author, year, country	Name/link provided?	Source	Type of learning	Mode of delivery
Aloweni, F, 2021	No	In-house developed	Solo	Web-based Integrated platform to the LIS
Bhaskar, A, 2014	Yes (Nobel Prize website)	External	Part of a blended learning	Web-based
Brunetta, DM, 2021	Yes	In-house developed	Solo	Social media; Facebook, Instagram, WhatsApp, emails
Cottrell, S, 2013	Yes (LearnBloodTransfusion)	External	Solo	Web-based
Gouifrane, R, 2020	No	In-house developed	Part of a blended learning	Web-based through CANVAS e-learning management system
Huang, H, 2021	No	In-house developed	Part of a blended learning	Web-based (for the pre-class content) Mobile phone or VR glasses with headsets (for the VVR content)
Joyce, KM, 2015	No	In-house developed	Part of a blended learning	Simulated computer-based patients
Kato, C, 2017	No[a]	In-house developed	Part of a blended learning	Web-based Low-fidelity mannequins with patient-actors
Kelly, SL, 2013	Yes	External	Part of a blended learning	ND
Konia, MR, 2018	No	In-house developed	Part of a blended learning	Web-based
Lee, SC, 2019	No	In-house developed	Part of a blended learning	ND
Lee, TC, 2019	Yes (Bloody Easy Lite for Physicians)	External	Part of a blended learning	Web-based
Mettiäinen, S, 2014	No	ND	Part of a blended learning	Web-based
Michelet, D, 2019	Yes (*PerinatSims*)	External	Part of a blended learning	Point-and-click screen-based simulation
Miner, J, 2020	Yes (*Relias OB*)	External	Part of a blended learning	Web-based
Molina-Arrebola MA, 2020	Yes (www.ephpo.es,https://www.juntadeandalucia.es/ep-hospitalponientealmeria/Moodle)	In-house developed	Part of a blended learning	Web-based
Monday, LM, 2020	Yes (Canvas online management system)	In-house developed	Part of a blended learning	Web-based

TABLE 3 (Continued)

Author, year, country	Name/link provided?	Source	Type of learning	Mode of delivery
Narayanan, R, 2008	Yes (http://www.learnbloodtransfusion.org.uk)	External	Solo	Web-based
Pickard, K, 2019	No	In-house developed	Part of a blended learning	Web-based
Smith, A, 2014	No	External	Solo	Web-based
Smith FC, 2010	Yes [SafeTransfusion Practice (Module. One) Student Programme]	External	Part of a blended learning	ND
Soliman HM. 2021	No	In-house developed	Part of a blended learning	ND
Tsan, HC, 2020	Yes	In-house developed	ND	Web-based accessed by PC or mobile browser
Vaena, MMV, 2018	Yes (Sciences; an animated way of learning)	In-house developed	ND	Desktop, tablets, smartphone
Vortman, R, 2020	NA	In-house developed	Part of a blended learning	ND
Oja, J, 2016	No	In-house developed	Part of a blended learning	LIS

[a]A reference to a publication in Japanese was provided.

Abbreviations: LIS, laboratory information system; NA, not applicable; ND, no details; PC, personal computer; VR, virtual reality; VVR, video-based virtual reality.

described such resources.[11,25] Tsang et al. described the use of interactive, educational 360° virtual reality simulation walkthrough tours of the laboratories using commercially available cameras and software,[11] while another paper described an in-house developed software for TM teaching and learning.[25] None of these studies described the cost or resources required for the development of these learning modalities. Overall, the included literature in this review provided inadequate reporting of the time required to complete the educational material, making it challenging to summarize.

4 | DISCUSSION

E-learning is widely offered in TM education, but there has been no systematic evaluation of its scope and impact. E-learning/digital programs described in the literature were very diverse, in terms of the level of education and target audience, as well as the topics covered. Blood component administration, transfusion reactions, laboratory practices, hemovigilance, and PBM were frequently addressed, while other topics such as blood component production and massive hemorrhage were less frequently covered. While there is a broad literature available describing the characteristics and types of e-learning programs, the quality and quantity of research into its value and effectiveness are highly varied. There are no comparisons between different types of e-learning and very few studies comparing e-learning to other modes of education.

The description of assessment methods and criteria for meeting competency or knowledge level attainment is inconsistent in the reviewed literature. The most commonly used measures are knowledge assessment (Kirkpatrick level 2) and learner feedback (Kirkpatrick level 1). There is limited literature on the assessment methods used to evaluate the effectiveness of e-learning modules, and the impact of the e-learning educational interventions on transfusion practices and patient outcomes (Kirkpatrick levels 3 and 4). There remains a need for further investigation into the impact on knowledge retention, sustainable practice transformation, and patient outcomes. Our findings are in alignment with a recent comprehensive evaluation of digital learning's application within healthcare, spanning domains like nursing and surgery.[2] The study underscored that the primary focus of assessed learning outcomes in the published literature revolves around participants' skill and knowledge acquisition, as well as learners' satisfaction.

The range of formats employed for e-learning education in the reviewed literature is extensive and includes modules, models, simulation, and online presentations/lectures. Many of the e-learning packages are integrated as part of blended learning, incorporating these components with more traditional educational approaches. The use of social media and virtual reality in some e-learning programs highlights the potential for innovative and unconventional methods to be used. The use of social media to expand the reach of virtual learning to a broader audience and to offer networking opportunities gained prominence during the COVID-19 pandemic.[34,35] Moreover, the capacity to organize large webinars has proven highly valuable to rapidly disseminate consensus and expert opinions by major medical organizations.[34] This tool has also proven effective in sharing guidelines, protocols, and standardized operative procedures across international borders. In recent years, virtual reality has emerged as a novel approach for delivering simulation-based training, offering standardized and on-demand clinical training experiences.[36]

Many e-learning programs were set in academic or university-affiliated institutions, and many were developed in-house. This observation suggests better resources within these institutions to develop e-learning programs. However, it does raise concerns regarding the generalizability to non-academic centers and hospitals. Notably, there was a paucity of information regarding the sharing of programs among different institutions in the summarized literature. Furthermore, our review of literature has revealed a dearth of information on the costs and resources required for the development and the maintenance of e-learning modules and programs. This aspect is of particular significance, especially when considering the scarcity of studies focusing on the utilization of e-learning in low- and middle-income countries in general,[2] and in our review. It is worth noting that the majority of the documented programs are of a small scale and have many limitations.[37]

In light of these findings, it is imperative that forthcoming studies provide insights into the financial implications and resources required for establishment and implementation of e-learning initiatives. Additionally, fostering increased collaboration may assist in enhancing accessibility and improving quality in e-learning education, particularly in countries with limited resources.

Evaluating the quality of online and open education is crucial for enhancing learners' experiences, but faces challenges due to the complexity of online learning and varying interpretations by educators and learners. Various organizations have incorporated certification, benchmarking, and accreditation within their quality models for open, distance, and online education, with accreditation serving as a form of mandatory certification granting access to support or award recognition.[38] We report here two programs that are accredited. Accreditation is typically managed by formal bodies like ministries,

TABLE 4 Outcome assessment/impact of e-learning programs.

Author, year	Method used for assessing learning outcomes (based on Kirkpatrick model)	Criteria to define successful completion of the module	Learner's feedback in cooperated?	Compared with other forms of learning?
Aloweni, F, 2021	Multiple levels such as knowledge, comprehension, and skill application Level 2: knowledge assessment using quizzes with real life scenarios Level 3: Skill application	ND	Yes	Yes (traditional method of conducting nursing skills competency, using question and answer, and multiple-choice questions)
Bhaskar, A, 2014	Level 1: Evaluation of the course	ND	Yes	Yes (lectures)
Brunetta, DM, 2021	Level 1: Evaluation questionnaire Level 4: Change in organization practice/clinical outcomes	NA	Yes	No
Cottrell, S, 2013	Level 1: Attitude	ND	Yes	No
Gouifrane, R, 2020	Level 2: Multiple-choice questions Level 2: Written exam	Performance score	No	Yes (traditional class room)
Huang, H, 2021	Level 1: Attitude Level 2: Multiple-choice questions Level 2: Likert scale questions	Pass score Meta-recognition tendency questionnaire Problem-solving tendency questionnaire Pre- and post-test learning achievement	No	Yes (conventional flipped learning)
Joyce, KM, 2015	Level 2: Competency-based exam/practical exam Level 3: Direct observation for any change in behavior/practice	ND	No	No
Kato, C, 2017	Level 1: Self evaluation Level 2: Multiple-choice questions Level 2: Competency-based exam/practical exam	Knowledge score Performance score	No	No
Kelly, SL, 2013	Level 4: Change in organization practice/clinical outcomes	ND	No	No
Konia, MR, 2018	Level 2: Multiple-choice questions	ND	Yes	Yes (in-person simulation, hybrid and online learning)
Lee, SC, 2019	Level 1: Attitudes Level 1: Evaluation of the course Level 2: Competency-based exam/practical exam	Performance score	Yes	Yes (observation of peers)
Lee, TC, 2019	Level 2: Multiple-choice questions Level 4: Change in organization practice/clinical outcomes	Pass score	Yes	Yes (lectures)

(Continues)

TABLE 4 (Continued)

Author, year	Method used for assessing learning outcomes (based on Kirkpatrick model)	Criteria to define successful completion of the module	Learner's feedback in cooperated?	Compared with other forms of learning?
Mettiäinen, S, 2014	Level 1: Self-assessment Level 2: Competency-based exam/practical exam	ND	Yes	No
Michelet, D, 2019	Level 2: Competency-based exam/practical exam	Anesthesia non-technical skills (ANTS) scores Number of verbal exchanges between the midwife and peers	No	Yes (basic screen-based simulation (without Non-technical skill training)
Julya Miner, 2020	Level 4: Change in organization practice/clinical outcomes	ND	No	No
Molina-Arrebola MA, 2020	Level 1: Self evaluation	Pass score	Yes	No
Monday, LM, 2020	Level 1: Self evaluation Level 2: Multiple-choice questions	ND	Yes	No
Narayanan, R, 2008	Level 1: Participant reaction (% attending the course) Level 2: Multiple-choice questions Leve 2: True and false questions	Pass score	Yes	Yes (face-to-face and text-based learning)
Pickard, K, 2019	Level 1: Attitude Level 2: Short question test	ND	Yes	No
Smith, A, 2014	Level 1: Attitude Level 2: Multiple-choice questions	ND	Yes	No
Smith FC, 2010	Level 1: Knowledge assessment questionnaire	ND	No	No
Soliman HM, 2021	Level 1: Knowledge assessment questionnaire Level 2: Competency-based exam/practical exam	Knowledge score Practice score	Yes	No
Tsang, HC, 2020	NA	NA	Yes	No
Vaena, MMV, 2018	NA	NA	Yes	No
Vortman, R, 2020	Level 1: Knowledge assessment questionnaire Level 1: Attitude	ND	Yes	No
Oja J, 2016	Level 1: Attitude Level 2: Competency-based exam/practical exam Level 2: Mock certification exam	Pass/fail	Yes	No

Abbreviations: NA, not applicable; ND, no details.

quality assurance agencies, and third party professional bodies. However, there exists a considerable gap in understanding the efficacy of these quality approaches. Given the diverse range of quality tools available, institutions need guidance in designing personalized quality management systems for their e-learning programs, ideally integrated into higher education's institutional quality assurance and aligned with regulatory requirements.[38]

To enhance the quality of research in e-learning for transfusion education, it is also necessary to standardize reporting by developing well-designed studies and validated assessment tools (as per the Kirkpatrick's Four-Level Model) with standardized criteria for successful completion (e.g., using qualitative pre- and post-testing).[39] Long-term retention and actual practice change should be the focus of these studies (e.g., change in the rates of organizational transfusion errors). To achieve this, researchers should choose appropriate assessment methods and report their results to enable meaningful comparisons across studies. Additionally, the sustainability of acquired knowledge should be assessed, and the need for repeated education to reinforce knowledge retention should be investigated.

In conclusion, we summarize here the existing literature on the use of e-learning in TM education. This review has provided insights into the characteristics of TM e-learning programs used in healthcare education, highlights areas where further research is needed, and can inform the development of effective e-learning programs in the future. There appears to be a disconnect between the amount of digital/e-learning education available internationally[4] and a demonstration of the effectiveness of these e-learning programs to deliver impactful, cost-effective, and sustainable education in transfusion. Further studies are necessary to compare e-learning with other teaching modes and evaluate its effectiveness alone and within the context of blended learning with other learning methods, and to evaluate the long-term retention of knowledge and impact on practice outcomes.

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CONFLICT OF INTEREST STATEMENT

YL works for the Canadian Blood Services and Octapharma on research grounds. She serves as a consultant for Choosing Wisely Canada. AZA, JVB, NR-L, SD, BS, and SJS have disclosed no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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