

Innovations in teaching and learning for Health Professions Educators

Edited by

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Innovations in teaching and learning for Health Professions Educators

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Editorial: Innovations in teaching and learning for Health Professions Educators

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educational innovation, faculty professional development, educational research, educational training, educational research methods, simulation, artificial intelligence, health professions education

Editorial on the Research Topic

Innovations in teaching and learning for Health Professions Educators

Introduction

The health professions continue to evolve and change rapidly as more opportunities and challenges emerge (1). Hence, health professions educators are required to be adaptive and nimble in their creation and adoption of teaching and learning innovations (2–4). Scholarship related to best practices and identification of innovations is difficult because the same innovations have proven to be both engaging and burdensome (2). Simulation-based education continues to be innovative with new delivery modalities including distance simulation, while continuing to focus on effectiveness in how health professions educators are taught (5–7). However, gaps around effectiveness of training and development for health professions persist (2). Faculty effectiveness, especially as it relates to educational innovation adoption, is difficult to measure; and demonstration of related competencies is in its infancy.

This Research Topic encompasses state-of-the-art examples of scholarship in health professions education related to the awareness and appropriate adoption of innovation, which is broadly defined as an idea, practice, technology, and know-how (8). Evidence about the current state of emerging innovations including artificial intelligence, effectiveness of reflections or systems thinking as core aspects of learning, and evidence about the competencies needed for teaching in our evolving environments are included in this Research Topic. The 17 articles include quantitative and qualitative data collection, secondary data analyses, literature reviews, curriculum and assessment tool development. Covering a spectrum of health professions including medicine, nursing, pharmacy, physical therapy, and others, they reflect work conducted around the world, including US, Asia (China, Singapore), Australia, Middle East (Qatar, Saudi Arabia), and Europe (Germany). Additionally, this Research Topic includes participant samples across career stages from early trainees to continuing professional development for mid-career professionals. This Innovations in Health Professions Education Editorial organizes and highlights the articles into the following themes: (1) artificial intelligence/machine

learning/computer-based training; (2) competencies and assessment tools; (3) reflections as a core aspect of learning; and (4) systems thinking as a core aspect of learning.

Artificial intelligence/machine learning/computer-based training

From undergraduate medical education to continuing professional development, the use of AI and other technological innovations have revolutionized the ways healthcare professionals learn and practice. For best implementation, it is pertinent that the use of any forms of technology in healthcare education considers the readiness of the users—as reported by [Gharib et al.](#) Students tend to be more eager to adopt new technologies whereas educators on the contrary express more reluctance due to workload and technology efficacy concerns.

Large language models (LLM) such as GPT-4 represent perhaps one of the more transformative technological advancement in health professions education. Nevertheless, we must critically examine and mitigate the risks of using AI such as algorithmic bias, overreliance, plagiarism, misinformation, inequity, privacy, and copyright concerns in health professions education through integral and systematic use (9). These recommendations align with the structured literature review on the use of LLM in healthcare simulation provided in the series by [Maaz et al.](#) The paper offers guidance on prompt design for healthcare simulations which is particularly useful for clinical scenario development, OSCE station creation, simulated person scripting, and debriefing facilitation.

Despite the potentials of AI use in postgraduate medical education in helping residents develop critical thinking skills with algorithmic reasoning (10), careful consideration of their limitations, and the imperative to maintain human oversight in clinical education should always be incorporated. [Yang et al.](#) proposes a new paradigm of data-intensive clinical research as a pivotal strategy in medical advancement. This approach encompasses multidisciplinary integration needs, high-quality faculty, learning method transformations, assessment system updates, and awareness toward ethical concerns.

Finally, one of the published papers in this Research Topic by [Janumpally et al.](#) offers five major potential impacts of generative AI in graduate medical education which include reduced EHR documentation burden, enhanced clinical simulations, personalized educational experiences, supported research and data analysis, and improved clinical decision making. As [Masters et al.](#) (11) emphasize, technology should augment rather than replace the human elements of healthcare education—mentorship, role modeling, and professional identity formation remain irreplaceable components of developing compassionate, competent healthcare professionals. Moving forward, a balanced approach that leverages technological advantages while preserving essential human interactions will be crucial for preparing healthcare professionals to practice effectively in increasingly complex and technologically-mediated healthcare environments.

Competencies and assessment tools

In medical and health professions education, assessment is a hot topic on both macro and micro levels. On a macro level, programs strive to meet assessment requirements and standards set by accreditation bodies. Competency-based learning objectives and assessments are imperative as programs move in that direction. The dilemma is how to assess demonstrated competency and behaviors. In the article by [Williams et al.](#), there are seven literature supported tips for integrating behavioral assessments, guiding transition and compliance around competency-based medical education. The macro literature also includes a systematic review of clinical learning environment tools within nursing education ([Xu et al.](#)), highlighting nine instruments that measure the clinical learning environment and can be used for future research.

On a micro or programmatic level, programs have created assessment tools. [Mohamed et al.](#) created an assessment tool through action research to monitor weekly clinical skills progress in their nursing students and to ensure constructive feedback from key stakeholders like the nursing faculty and students. Although not directly about competency and assessment, the final article in this section by [Zhang et al.](#) highlighted methods [virtual reality technology combined with “Bridge-in, Objectives and Outcomes of Learning, Pre-assessment, Participatory learning, Post-assessment, and Summary” (BOPPPS)] that improved learning which could impact competency. In their study, they conducted a traditional educational intervention with experimental and control groups finding that the experimental group, receiving education with virtual reality technology and BOPPPS demonstrated better outcomes. These articles highlighted the innovative ways health professions educators are attempting to improve education and assessment internationally.

Reflections as core aspect of learning

Varied applications of reflection have been used as learning and assessment tools in the health professions impacting things like empathy and comfort with nuanced topics (12, 13). As a teaching and learning tool, reflection enables learning to move from theory to application (14). Several submissions in this Research Topic included reflection with some using reflection in teaching, others in assessment, and some in their methodology of investigation. A cross-sectional study by [Kinney et al.](#) found reflection on digital recordings of patient encounters for physical therapy students served as a useful educational modality. Additionally, they recommended the need for agreed upon best practices around student reflection such as frameworks or guidelines for reflection. [Schmude et al.](#) utilized an e-portfolio to assess their personal and professional curriculum within their medical doctorate. Part of their e-portfolio included reflection on learning which necessitated faculty training on previously published tools (15, 16).

In [Berri et al.](#), reflection was used as part of a post-test within an educational intervention about chemical denervation for medical residents. Their use of reflection included student self-assessment on knowledge and student intentions for future implementation. Another study used reflective exercises in a longitudinal multi-profession educational intervention on

empathy. First-year dentistry, medicine, nursing and pharmacy students participated in reflective exercises, requiring students to be personally aware of their experiences (Müller et al.). The last two studies in this section were less about using reflection for teaching and learning, but instead about using reflective experiences and writings to understand things like leadership and educational development. Leveraging constructivist learning theory and reflection, Dewsnap and Konatham explored a new and less resource intensive way of teaching and learning about leadership, moving away from lecture-based education. In the final study by Schumann et al. researchers used qualitative methods to identify and understand what motivates health professionals to participate in additional training around education, finding that intrinsic motivation, competence, collaboration and mentorship were some of the components that motivated them to pursue additional education.

Systems thinking as a core aspect of learning

Health professions education occurs at the intersection of two very complex systems (health care and education) with diverse, interacting components reflecting messy, non-linear relationships and substantial uncertainty (2). Systems thinking and complex adaptive systems (CAS) are useful frameworks for considering how stakeholders can be considered in planning and implementing health professions education programs (20) and professional development programs to train faculty (17). In this Research Topic, Cola et al. explicitly incorporated a systems thinking approach to effectively teach U.S. FDA regulatory processes to students, faculty, and staff at multiple schools of medicine and engineering in northeastern Ohio. They “highlight the effectiveness of an interdisciplinary and transdisciplinary approach to teaching and learning for biomedical education, specifically in preparing participants for the complexities of FDA regulatory processes and biomedical entrepreneurship”. They employed the principles of andragogy (18, 19) to create an applied learning experience that is relevant to a diverse mix of students. Wells et al. also described a transdisciplinary dual degree program based on andragogical principles that chronologically, experientially, and conceptually integrates biomedical topics with the goal of achieving “transformative educational outcomes”. They noted the importance of faculty willing to go beyond their disciplines’ comfortable boundaries and teach educational materials “transdisciplinarily” in order to create “physicianeers”. As noted above, Yang et al. also

touch on these themes in creating graduate educational experiences for data intensive machine learning and artificial intelligence applications.

Conclusion

The field of health professions education faces enormous challenges as we strive to keep up with emerging technology capabilities and disparate learning preferences across the spectrum of career stages. Competencies related to the use of AI-assisted clinical decision support are only beginning to be considered and studied (20, 21), posing challenges for educators who themselves need training about how to effectively utilize innovations in the service of better learning experiences and achievement of required learning outcomes. Consistently adopting systems thinking approaches combined with reflections are valuable ways to evaluate health professions education innovations. Methodological challenges associated with studying educational innovations and measuring attainment of competencies (e.g., related to AI) remain critical research needs. We hope this collection of articles inspires readers to embark on new scholarship as we learn together.

Author contributions

RE: Conceptualization, Writing – original draft, Writing – review & editing. BW: Conceptualization, Writing – original draft, Writing – review & editing. AF: Conceptualization, Writing – original draft, Writing – review & editing.

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Integrating behavioral assessment in instructional design for competency-based medical education

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As institutions continuously strive to align with the standards set forth within competency-based medical education, there is an increased need to produce evidence of learner achievement in the form of observable behaviors. However, the complexity of healthcare education and clinical environments make it challenging to generate valid and reliable behavioral assessments. In this article, we utilize our interdisciplinary knowledge from the perspectives of experts in medical education, assessment, and academic administration to provide tips to successfully incorporate behavioral assessments into instructional designs. These include tips for identifying the best assessment methods fit for purpose, guiding instructors in establishing boundaries of assessment, managing instructors, selecting raters, generating behavioral assessment guides, training raters, ensuring logistics support assessment strategies, and fostering capacity for iteration. These can be used by institutions to improve planning and implementation for longitudinal behavioral assessments.

KEYWORDS

competency-based, undergraduate, medical education, assessment, rater selection, observational ratings

Introduction

Competency-based assessment is becoming increasingly prevalent in medical education and is vital to meeting goals established in competency-based medical education (CBME) to ensure healthcare workers are adequately prepared to enter the workforce (1). CBME shifts the focus from time-based learning (e.g., a certain number of weeks in each rotation), to a progression-based method that is driven by each learners' successful demonstration of all relevant competencies (2–4). This is meant to ensure that learners are ready to enter the workforce with all relevant abilities, rather than either assuming they have been achieved based

on exposure to content or permitting excellence in some to make up for deficiencies in others.

Some often-overlooked competencies important to clinical performance in all healthcare professions are based in non-technical teamwork and communication (5). Although the impact of technical skills on patient status are often directly and clearly observable (e.g., an incorrect diagnosis will likely lead to inappropriate treatment and lack of improvement in the patient), the impact of non-technical skills such as communication may be less directly tied to patient status (e.g., failure to use closed-loop communication may or may not affect patient care depending on whether an error occurred, and/or was caught via other mechanisms before impacting the patient). Establishing and assessing progression to mastery in such non-technical competencies have been noted as both elusive and highly desirable to adequately meet the goals of CBME (5, 6). Behavioral assessments can provide insights into learner competence in such areas, and their flexibility to be applied to both simulated and clinical settings invite the potential to provide greater insights into mastery over time (6, 7). Behavioral assessments typically consist of observers rating learner performance on sets of discrete behaviors. Examples of technical skills that are often assessed in this context include establishing diagnoses and gaining patient history. In contrast, non-technical skills include behaviors associated with teamwork and communication, such as engaging in interprofessional collaboration, establishing inclusive/psychologically safe environments, and effectively communicating information to appropriate audiences.

Use of simulated settings provides an avenue to increase performance opportunities and reduce theory-practice gaps imposed by learners' inability to fully participate in patient care while still in training (8). Additionally, they present opportune mechanisms to intentionally create scenarios with progressive difficulty to demonstrate progression to mastery (6). However, there remain a dearth of studies that have successfully linked such simulation activities to performance in practice (i.e., transfer of training), which is greatly hindered by the challenges of implementing longitudinal assessments across these settings (4, 5, 9).

The purpose of this paper is to leverage our experiences in a large academic medical center quality enhancement plan (QEP), which is known as Team FIRST, to offer future educators, practitioners, and researchers some key considerations for incorporating progressive, competency-based, non-technical behavioral performance opportunities within the context of graduate and undergraduate medical education. This manuscript aims to provide prescriptive guidance on how to manage considerations to strengthen the evaluations and provide a framework to effect continual improvement in learners.

Tip 1

Not all assessments are equal: consider goals when determining methods, and clearly communicate the boundaries of these to learners, faculty instructors, and stakeholders

There are many different types and purposes of assessments in medical education, which typically range from use of more formative

methods typically aimed to understand students' current abilities for the purpose of providing feedback, to summative methods that are characterized by conferral of a pass or failure score which may be used for competence decisions (10). Oftentimes, the purpose of the assessment becomes ambiguous due to the interests of the stakeholders. This is often particularly true for non-technical skills, given that their impact on patient care is sometimes less readily visible compared to the impact of technical skills. Stakeholders are typically keenly interested in summative assessments that have potential to provide insights regarding the competence of students. Meanwhile, formative assessments are better suited for advancing the competence of learners. Lacking a clear purpose of the assessment may negatively impact both the student acceptance of the assessment, as well as the ability of the assessment to accurately reflect student competence. Heavy use and emphasis of high stakes assessments may reduce students' willingness to actively engage in those activities due to fear of potential negative scores (10, 11). Furthermore, students may begin to treat success on the assessment as the goal, as opposed to continuous improvement and true mastery in the subject matter, which may cause them to stop pursuing further improvement (10). Lastly, assessments will preclude students from learning when they lack useful, task-oriented feedback (10). These challenges may be alleviated by incorporating smaller, more frequent assessment opportunities that have both summative and formative aspects that are explicitly linked to the learner stage in their development. For instance, Maastricht medical school found success when they integrated formative and summative assessments for strengthening and evaluating professional behaviors (12). Resource costs for such programs may be reduced by incorporating methods for standardized or automatic grading and feedback, though the tradeoffs related to usefulness should be evaluated carefully in the context of overall program goals (13, 14).

Tip 2

Do not assume everyone is on the same page: ensure instructor guidance is consistent in implementation relative to assessment elements

Once the format of assessment is determined, it is vitally important to ensure that assessments are implemented and documented consistently. Variations in implementation of such interventions can alter both the ratings achieved and learning outcomes, which impact the validity of the assessment as well as the subsequent interpretation of data corresponding to their progression to mastery (15, 16). For example, having multiple instructors means that some may choose to prompt students, while others may choose to allow failure. Such variations in implementation impact the quality of the behavioral ratings received (17). Variations in ratings can be mitigated by providing scripts or guides that standardize instructors' introduction of behavioral demonstration opportunities and the expectations associated with them. This is particularly important for non-technical skills, given that behaviors such as closed-loop communication may be liberally or sparsely applied and have potential to impact patient care through either presentation. Thus, establishing and ensuring consistency in expectations for these non-technical competencies is important to ensuring accurate

assessment. Vital aspects to emphasize include language specific to assessment (e.g., how assessments may be used), what students should expect of the event (e.g., assignments of specific pairs of partners), common question responses or features of the unspoken curriculum that might otherwise vary across instructors (e.g., expected comprehensiveness of handovers and frequency of closed-loop communication), as well as scripts aimed to enhance student psychological safety (e.g., scripts that emphasize the learning-oriented purpose of assessments and confidentiality where appropriate; 18).

Tip 3

Expertise is not everything: consider a variety of perspectives and constraints when selecting raters

There are many individuals who can theoretically serve as raters for behavioral observations. However, there are also a plethora of factors that should be considered when selecting raters. Often at the forefront of these are resource constraints (e.g., financial, scheduling) which are interrelated to other factors that should influence selection, including the respective subject matter expertise and experience of raters. We have described three major types of raters, Novice, Expert/Experienced, and Subject Matter Expert (SME) in Table 1, and described their pros and cons. Standardized Patients (SPs; non-SMEs who participate in simulation sessions and are typically experienced with clinical terminology and rating systems) who have gone through training in behavioral assessment are often timely and reliable

resources for evaluation as non-SME, experienced raters (20). Given it is often challenging for SMEs to dedicate sufficient non-clinical time to rate scenarios, their time may be more efficiently utilized in developing grading rubrics and assisting in the training of such dedicated, experienced raters.

Tip 4

Even experts need guidance: establish well-defined behaviors and specific examples

Observational ratings are vulnerable to many well-known biases in assessment, including halo (aka horns, i.e., multiple ratings are based on a single observation that is either positive or negative), central tendency (i.e., the tendency to avoid either extreme of ratings), and contrast effects (i.e., ratings are anchored based on the performance of a previous learner or group) among many others (1, 23). Having clear definitions and examples helps to mitigate any ambiguity or confusion while strengthening consistency and accuracy of ratings. Thus, it is important to establish a scoring guide or rubric and a plan for how to rate unclear behaviors (15). To maximize the utility and usability of these scales and guides, faculty subject matter experts and assessment domain experts should collaborate extensively to develop them. It is very helpful to have faculty instructors begin the process of generating this scale in conjunction with assessment experts to develop and refine grading criteria. This helps ensure the rubrics developed have content validity and robustly align to the learning objectives across a multitude of instructors (24).

TABLE 1 Pros and cons of common observational rater types.

Type descriptions	Pros	Cons
Novice <i>An individual with no experience rating behaviors according to standardized assessments, and no subject matter expertise that is relevant to the domain under study.</i>	<ul style="list-style-type: none">• Generally inexpensive to recruit.• Scheduling is often flexible.• May be less vulnerable to profession-based stereotype effects (i.e., where ratings are based on the learners' inclusion in a group, such as medical student or nurse, rather than their own unique behaviors; 15).	<ul style="list-style-type: none">• May be challenging to train and retain (e.g., if the rater does not have sufficient knowledge or commitment related to the goals of the assessment).• May not be ideal for obtaining accurate, nuanced, and reliable ratings depending on the purpose of the assessment Case examples of this can be found in the following studies (19–22).
Expert/Experienced <i>An individual with moderate to extensive experience rating behaviors according to standardized assessments (preferably specific ones used in your assessment paradigm), but no subject matter expertise that is relevant to the domain under study.</i>	<ul style="list-style-type: none">• Typically, they are less expensive to recruit and retain compared to SMEs.• Have demonstrated superiority to novice raters, even when the novice raters were acclimated through basic frame-of-reference training (20).	<ul style="list-style-type: none">• Often require more resources to recruit and retain compared to novice raters.• This type of expertise may not be sufficient to establish reliable and valid ratings, particularly if the assessment is highly domain specific and may require subject matter expertise to effectively differentiate behaviors.
Subject Matter Expert (SME) <i>An individual who has subject matter expertise relevant to the domain under study (e.g., a medical degree), but typically does not have prior experience rating behaviors according to standardized assessments.</i>	<ul style="list-style-type: none">• May be more apt at discriminating nuanced behaviors relevant to their domain (21).• More readily able to grade the accuracy of behaviors that require domain expertise, such as whether an appropriate diagnosis and treatment was selected, which may be challenging for non-SMEs to recognize even when given extensive training (15).	<ul style="list-style-type: none">• Typically, they are very expensive to recruit, train, and retain.• Schedules are often highly restrictive.• Will likely still require training, as evidence demonstrates that even among SMEs, those who are also experienced raters with training in using specific observational tools are more consistent in assessments relative to SMEs who are not experienced raters (19, 22).

Guides corresponding to behaviorally anchored rating scales (BARS) can describe the key behaviors and information to be transmitted between learners, such as in the context of simulated handovers. A scale is considered behaviorally-anchored when several levels are present and are tied to specific behaviors that warrant their selection. For example, one of our rating scales addresses whether senders enact behaviors that support a psychologically safe environment. This is behaviorally anchored to response options of (1) “encouraged receiver to ask questions or provide feedback through explicit, open-ended requests (i.e., WHAT questions/feedback do you have),” (2) “made an explicit, but closed-ended, request for questions/ feedback (“DO you have any questions/feedback”),” (3) “did not make a request for questions, but allowed space (pause),” and (4) “did not request or allow space (pause) for questions.” This type of response is likely best utilized for behavioral items that have a relatively finite number of discrete options, where divisions can clearly be drawn between response options. Binary scales can be used when behaviors have minimal relevant variation and have clear distinctions between categories (e.g., “sender asked clarifying questions” is unlikely to have substantial meaningful variation outside of a “yes” or “no” response). In situations where there is disagreement about what should be considered a definitive “yes” or “no,” a neutral option (such as “sometime” or “somewhat”) could be included in a binary scale. However, it can be difficult for raters to discriminate between behaviors, especially with numerical ratings (e.g., a 2 vs. 3). Panzarella and Manyon (25) conducted a study in which a diverse team of faculty members worked closely together to create a behavioral tool and its scoring rubric (with clearly defined elements). This tool was designed to evaluate clinical competence in medical and physical therapy programs. In their study, they found the interrater agreement between raters for binary-type responses was significantly higher compared to that observed for a four-point scale. Thus, it is vital to incorporate both subject matter and assessment experts to successfully develop behavioral assessment scales that have sufficient validity and reliability to be used in high stakes assessment contexts.

Tip 5

Do not assume guides are enough: train raters thoroughly and hold them accountable for performance

Many programs will not have the ability to employ a single consistent rater for all instances, which means that multiple individuals will be rating behaviors. To ensure learners are assessed fairly and in ways that support their continual improvement, raters must grade behaviors similarly and consistently with each other and avoid the biases mentioned in the previous section. This is particularly important in the context of CBME, as competence should be unequivocally met or failed based on the student’s ability, regardless of the individual performing any given rating. Development of behavioral instruments and associated rater training has been slower for non-technical skills relative to technical skills, likely due to less shared understanding of concepts associated with non-technical skills (26). This makes targeted training even more important to effectively and consistently assess non-technical skills. Various training methods have been utilized to enhance inter-rater reliability and improve

accuracy, including rater error (i.e., inform raters of common mistakes to avoid during grading), performance dimension (i.e., familiarize raters with the assessment dimensions using definitions and descriptions), frame-of-reference (i.e., provide raters with reference cases as their benchmarks, usually examples of poor and good demonstration of the behaviors under assessment, and discuss discrepancies until shared understanding is reached), and behavioral observation training [i.e., target general observation skills to improve anticipation, detection, and grading of behavioral events; 23, 27]. Our group has had success with a training paradigm closely aligned with performance dimension, supplemented by frame-of-reference, using the training schema outlined in Figure 1.

This process can be repeated until acceptable agreement is reached on all assessment items. Ideally, debrief sessions should be held with the entire team. When this cannot occur, sessions should be recorded and provided for those who were absent from the event. If a guide has been crafted (as recommended in the previous tips), modifications can be made using tracked changes with version control, and both clean and tracked change copies sent out to all raters. This helps facilitate all raters recognizing and remaining up to date on grading criteria. Adherence to this process has enabled our QEP Team FIRST program to secure a set of experienced, standardized patient raters who are able to rate over 200 patient handovers using video review in a span of approximately 2 weeks.

Tip 6

No matter how well you have planned, it is wise to revisit: ensure the layout and logistics comprehensively support the desired assessment strategy

Administrators and faculty should devote ample resources to the logistical considerations for all phases of events, from conception through assessment, months before planned implementation. Factors that are often pertinent in the event conception phase include determining how groups may be formed and roles selected in interprofessional education sessions. These types of decisions have implications for what can be assessed (e.g., if a teamwork behavior will be observable) as well as how it can be assessed (e.g., if teamwork behaviors are exhibited, are specific behaviors expected between specific roles, etc.), and whether the planned physical space supports the comprehensive and accurate rating of these behaviors. For example, if a small group session necessitates 10 students divide into groups of two to perform handovers to each other simultaneously, live evaluation of this event would require at least five raters, depending on the sequencing of the behaviors to be assessed for each pair.

Additional consideration should be devoted to factors like sound quality in the evaluation space. If an assessment goal requires verbal utterances, it can be very challenging to decipher between learners in a packed room or in video recordings with only room microphones. This is especially difficult with teams, as it is increasingly difficult to decipher who is communicating based on the number of team members present and active in the room. Lapel microphones can be a useful tool for team studies, large rooms, and noisy environments, and devices or software that can identify speakers through name tagging are useful for assessing individual performance. Virtual events can

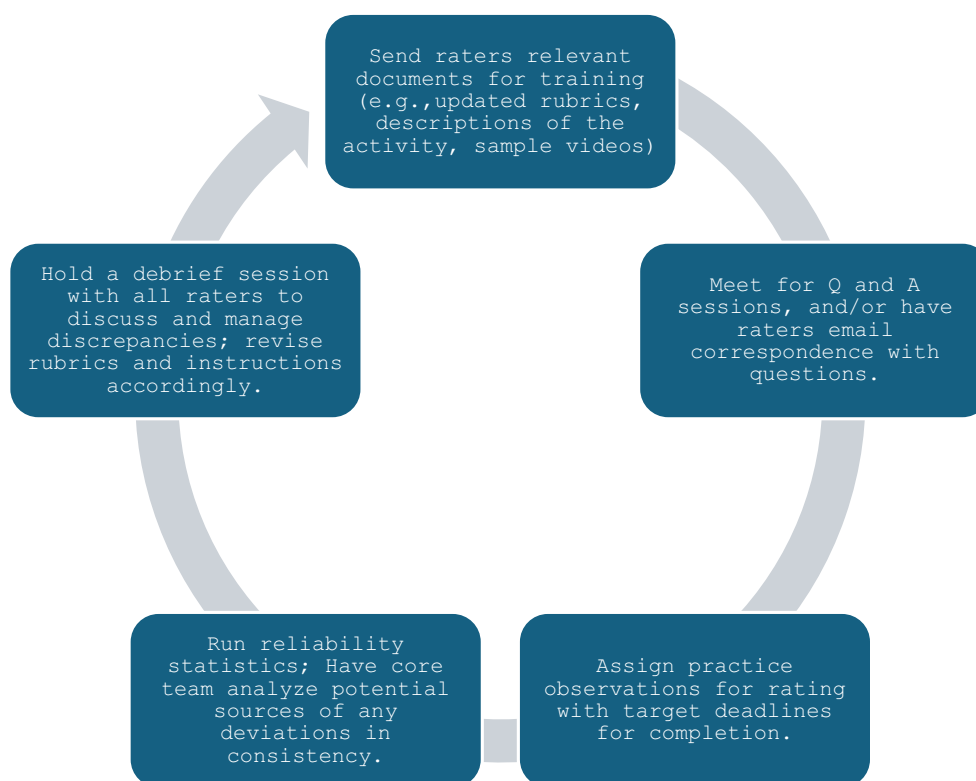


FIGURE 1
Paradigm for effective rater training to improve reliability.

mitigate many of these issues associated with behavioral assessment: When recorded, they can often be utilized to generate transcripts that are attributable to individual speakers, which enable more accurate and nuanced assessment opportunities of individual participants.

Tip 7

Development is insufficient: commit to fostering capacity for iteration, innovation, and optimization

To maintain utility, programs must remain responsive to shifts in the needs of the public, organization, incoming learners, and developing learners. Before and after each iteration, the program should be re-evaluated to ensure the same needs exist for learners at baseline, and that the curriculum continues to address these gaps by leading to improvements. It is important to continually monitor for changes to the unspoken curriculum and integrate ways to combat these as needed. Ultimately, programs should maintain awareness of the key competencies desired by national and international institutions, updating the curriculum where needed to maintain relevance. Though this can be challenging given the busy clinical schedules of most educators, it is helpful to have these individuals and assessment experts maintain an excel database of the key competencies and related aspects of curriculum and assessment instruments. This enables straightforward review when competency changes occur, and

the related aspects of the curriculum and assessment to be directly targeted to accommodate those changes in a timely manner.

When changes are made, it is beneficial to conduct piloting sessions which include both learners and faculty who have previously experienced the event as well as individuals who have not previously experienced the event. This practice enables those who are experienced to provide feedback on the changes and presents an opportunity to ensure that the content is still cohesively educational for new individuals. It is also important to consider how the structure of the curriculum and assessment may be shifted over time, such as by onboarding new aspects of the existing curriculum that had not previously been considered to further reinforce education and assessment practices (e.g., adding opportunities for assessment and constructive feedback through individual clinical clerkships where possible and appropriate).

Discussion

As institutions continue to advance assessment to conform to competency-based medical education, they must effectively generate and implement behavioral assessments in their curriculums. To be effective, these must be capable of being longitudinally assessed, clearly documented, and ultimately defensible (i.e., demonstrated as both reliable and valid) to be ethically usable in the context of advancement across stages of CBME. Such assessments have been extensively challenging to attain in terms of both feasibility as well as

reliability and validity (5). In this article, we have presented seven tips informed by the literature along with our experiences collaborating as administrative professionals, healthcare providers, medical educators, and experts in assessment which contribute to achieving these goals. These tips are summarized in Table 2, which additionally provides a list of questions that are helpful for staff to complete when integrating these tips.

Tip 1 emphasizes the importance of aligning assessment methods with specific goals and clearly communicating these to all stakeholders. By differentiating between formative and summative assessments and incorporating both aspects into the evaluation process, educators can foster a culture of continuous improvement while ensuring accurate assessments of student competence. This tip may be most simply implemented by utilizing frequent assessments wherein findings communicated to the learner are formative and anchored to the learners' current stage of development, and only summed after repeated instances of observation (e.g., learners may be formatively assessed monthly or quarterly, and this information summed yearly for advancement purposes). Identifying ways to focus on the developmental progression of the learner over time may facilitate building growth-oriented mindsets in learners and assessors, potentially reducing current barriers perceived in the transitions from UME to GME space (28).

Tip 2 outlines strategies related to consistency in assessment implementation to maintain the validity and reliability of evaluation outcomes. Standardizing instructor guidance and providing clear expectations for both students and instructors can mitigate variations in assessment practices and enhance the quality of behavioral ratings. This can most effectively be addressed by providing instructors with cheat sheets to aid their consistency and performing periodic quality checks on sessions via in person, video, or assessment score review to ensure facilitators are being consistent in their messaging. Facilitators not adhering to the appropriate messaging may be identified by comparing student assessment scores across facilitators, and targeting the faculty with the highest and lowest performing students overall to determine if their scores relate to differences in facilitator guidance.

Tip 3 highlights the necessity of considering various perspectives and constraints when selecting raters for behavioral observations. By identifying different types of raters and their respective advantages and limitations, educators can strategically allocate resources and optimize the reliability and validity of assessment results within their institution. For example, an assessment geared toward assessing nuanced non-technical skills that are unrelated to technical skills (e.g., utilizing behaviors that establish a psychologically safe environment) is likely to be an appropriate target for a novice or experienced rater, given these individuals have time to participate in more extensive training. In contrast, an assessment geared toward assessing non-technical skills that overlap with technical skills (e.g., utilizing a handover protocol to more effectively communicate patient information or utilizing closed-loop communication) may require a subject matter expert rater to ensure that non-technical aspects are appropriately paired with technical behaviors that are not the primary target, but relate to assessment.

Tip 4 emphasizes the importance of establishing well-defined behaviors and specific examples to mitigate biases and enhance the

accuracy of ratings. For assessment items where response options are relatively finite, behaviorally anchored rating scales and/or checklists are likely to be most appropriate. In contrast, assessment items where infinite types of responses are possible may be more appropriate targets for quality-based numerical scales. For example, to assess handover quality in a clinical environment, an item asking the observer to rate "How effective was the handover overall?" on a 5-point Likert type scale from "not effective at all" to "extremely effective" may be appropriate. However, such an item would likely achieve more accurate and reliable ratings from experienced subject matter experts, as they have a more practical experience base to draw from to assess handover "effectiveness" compared to raters who have never participated in handovers.

All observational assessments and raters should be verified through rater training: Accordingly, Tip 5 reflects the importance of rater training to improve inter-rater reliability and accuracy in behavioral assessments. Rater training should consider both the type of rater being used as well as the type of assessment items to ensure maximum improvement in reliability. Paradigms such as error training and performance dimension may be most effective for novice/experienced raters using behaviorally-anchored or checklist-based scales, whereas paradigms such as frame-of-reference and observational training may be more effective for subject matter experts utilizing numerical rating scales. This recommendation relates to our earlier discussion of the responses for these respective items: Whereas behaviorally-anchored and checklist-based items have clearly observable distinctions between responses that lend themselves to explicit corrections using error and performance-dimension training, numerical rating/Likert-type scales typically do not have as clear distinctions between response options and are therefore better candidates for calibration (instead of correction) using frame-of-reference and observational training. These training paradigms (frame-of-reference and observational) may also be particularly helpful for training related to assessments that occur in the clinical environment, given that there is a wide range of environments the observer may assess the learner in for any given competencies.

Tip 6 underscores the significance of logistical considerations in supporting the desired assessment strategy. The most comprehensive way to implement this tip is to establish a thorough infrastructure to generate and store video recordings of assessment occurrences. This enables continuous nuanced assessment and more widespread utility for assessment instances that is useful for collaboration between professional schools.

Tip 7 reflects the need for continuous improvement in the curriculum based on changes that will inevitably occur during a longitudinal program with repeated implementation across cohorts. Changes should not be sporadic but should be appropriately responsive to the changes that occur both within and outside the program. This process can be greatly assisted by maintaining a database of key competencies, related curriculum and assessment elements to ensure targeted evaluation of changes and corresponding corrections to the most relevant aspects of the program.

Successful implementation and sustainment of longitudinal behavioral assessments in the context of CBME is challenging, but we hope these tips will help other institutions more effectively navigate this process.

TABLE 2 Summary of tips and questions to aid implementation.

Tip #	Brief description	Questions to aid implementation
1	Not all assessments are equal: Consider goals when determining methods, and clearly communicate the boundaries of these to learners, faculty instructors, and stakeholders.	<ul style="list-style-type: none"> What do stakeholders wish to see in learners related to the curriculum? Is there a preference toward knowledge, attitudes, or behavioral demonstration? What elements of this relate most directly to program assessment and funding opportunities? What are the current attitudes of learners, faculty, and key stakeholders related to assessment? How might assessment or communication practices change to accommodate these attitudes and further promote acceptability? What existing assessments relate to the curriculum learning objectives? How might these be leveraged to reduce assessment burden?
2	Do not assume everyone is on the same page: Ensure instructor guidance is consistent in implementation relative to assessment elements.	<ul style="list-style-type: none"> What unspoken curriculum exists at the institution? Where might this support or conflict with the key learning objectives of the program? Are there specific faculty who may be strongly influencing unspoken curriculum that is detrimental to learning and performance? If so, consider whether additional training, coaching, or reduced exposure to these faculty may limit threats to the learners' achievement of the learning objectives. Are there clear instructions for facilitators guiding the learners to ensure the assessments can be consistently applied?
3	Expertise is not everything: Consider a variety of perspectives and constraints when selecting raters.	<ul style="list-style-type: none"> Does assessment of the key learning objectives require subject matter experts or experienced raters? Do faculty have sufficient time to conduct assessments? Do they have sufficient time to dedicate to training for reliability? What resources are available to compensate evaluators for their time conducting assessments?
4	Even experts need guidance: Establish well-defined behaviors and specific examples.	<ul style="list-style-type: none"> What are the ways learners can respond within the assessment environment? Are there a relatively low number of predictable response types, or are there a wide variety of possible responses? Has the most ideal rater type been selected to perform the assessment? If not, how might more ideal individuals' experience be leveraged in a more limited capacity to generate guidelines for those who will be performing the evaluations?
5	Do not assume guides are enough: Train raters thoroughly and hold them accountable for performance.	<ul style="list-style-type: none"> What are the ideal levels of agreement stakeholders expect evaluators to reach for inter-rater reliability? What are the lowest levels acceptable? How do training sessions need to be held to maximize attendance and responsiveness? Are in-person meetings appropriate, or are virtual and/or asynchronous meetings sufficient? How much time can be dedicated to training? Are there sufficient resources to meet with evaluators on a regular basis during the times they are available (e.g., are experienced training staff available after business hours if needed)? What additional resources might be needed to accommodate these schedules (e.g., additional hires, overtime pay, flexible work hour arrangements, etc.)?
6	No matter how well you have planned, it is wise to revisit: Ensure the layout and logistics comprehensively support the desired assessment strategy.	<ul style="list-style-type: none"> Are evaluators rating based off live performance or video review? Do assessment forms support completion in this environment? Are sufficient tools available to support learner identification? What is the ratio of learners to evaluators? Is this adequate for the assessment environment? What interprofessional differences are there in competency demonstration, and has this been incorporated into assessment plans? If applicable, what are plans to share assessment data across professional schools?
7	Development is insufficient: Commit to fostering capacity for iteration, innovation, and optimization.	<ul style="list-style-type: none"> How are the baseline KSAs of students changing upon entry from cohort to cohort? How has the unspoken curriculum developed over time? What changes are needed to accommodate the needs of new learners and new environments? How often do competencies change at the national or international level? What staff might be available to maintain a database of linkages between the competencies, curriculum and assessment instruments?

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

KW: Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing. EL: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. MS: Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing. NC: Investigation, Writing – original draft, Writing – review & editing. KJ: Writing – review & editing. SR: Writing – review & editing. IS: Writing – review & editing. BN: Writing – review & editing. DT: Writing – review & editing. JH: Writing – review & editing. MM: Writing – review & editing. RR: Writing – review & editing. PG: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Exploring barriers to the effective use of computer-based simulation in pharmacy education: a mixed-methods case study

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Background: At the University of Tasmania (UTAS), pharmacy education traditionally relies on placements to provide students with hands-on experience. However, these placements have become increasingly limited due to logistical challenges and growing student numbers. Computer-based simulation (CBS) has the potential to offer a scalable, effective alternative to enhance learning and critical thinking. However, integrating CBS in pharmacy education faces several barriers that must be addressed for successful implementation.

Objective: To gain insight into pharmacy educators' and students' views regarding the barriers, and potential solutions, to integrating CBS in pharmacy practice education.

Methods: This mixed-methods case study involved semi-structured interviews with pharmacy educators and quantitative surveys with pharmacy students. The data underwent thematic coding for interview transcripts and statistical analysis for survey responses. The findings were integrated by examining convergence, complementarity, and discrepancy, revealing insights into how pharmacy students and educators perceive implementation barriers and improvement strategies for CBS.

Results: Ten interviews were conducted, and 75 survey responses were collected, with a 62.5% response rate. Key barriers to CBS integration included educators' heavy workload, scepticism about CBS's educational value, and general integration challenges. Students, however, showed high acceptance of CBS, with 70.7% agreeing that CBS could assess their knowledge, 69.3% emphasising its role in developing problem-solving skills, and 80% viewing CBS as a complement to classroom study. Proposed solutions for enhancing CBS uptake included additional institutional support by appointing dedicated simulation technicians, leveraging champions to advocate for CBS, and aligning CBS with educational objectives.

Conclusion: A significant gap between students' readiness and educators' hesitancy to use CBS in pharmacy education was identified. While students are eager to adopt new technologies, educators expressed reservations, primarily due to workload concerns and uncertainties about the efficacy of CBS. The feedback from educators suggests that institutions may see improved uptake by employing dedicated support personnel and initiating targeted training programs. Future research should focus on exploring barriers and facilitators,

using larger and more diverse samples, and gaining deeper insights into decision-makers' perspectives to enhance the integration and efficacy of CBS in pharmacy education.

KEYWORDS

computer-based simulation, pharmacy education, educational technology, interprofessional learning, curriculum integration, simulation-based learning, mixed-methods, virtual patients

1 Introduction

In pharmacy education, students typically participate in workplace-integrated learning placements, which immerse them in supervised, real-world pharmacy practice scenarios. Although the educational value of these placements is widely recognised (1, 2), their availability is constrained by an increase in student numbers and the rising difficulties and costs associated with facilitating such experiences, leading to challenges in offering enough high-quality clinical placements (3). With reduced placement opportunities, increased emphasis on preparatory exercises seems prudent, but traditional classroom exercises such as paper-based cases and standardised patients (role-play) have a significant cost associated with marking and delivery on a per-student basis, which impacts the ability to scale up. This predicament underscores the importance of integrating complementary training methods, like computer-supported learning, which has demonstrated significant advantages in knowledge acquisition through its interactive and engaging approach, and which can be scaled up without a significant increase in delivery cost per student (4). Computer-supported learning aligns with Kolb's experiential learning cycle by simulating real-life challenges in a safe environment, thus enhancing students' critical thinking and collaborative skills, which are essential for their professional competency (1, 5).

At the University of Tasmania (UTAS), the demand for quality workplace-integrated learning placements in pharmacy is intensifying, exacerbated by growing student populations and logistical challenges across diverse campus locations. These issues pose a risk to maintaining educational standards and preparing a competent healthcare workforce, potentially impacting patient safety (2, 6). Innovative new educational tools such as computer-based simulation (CBS) and virtual patient training, present promising solutions that aim to enhance teaching and learning experiences by making them more engaging, efficient, and accessible, thereby enriching experiential learning opportunities and bridging the gap between theoretical knowledge and practical skills (4, 7–9). CBS, in particular, has been identified as a key tool in advancing pharmacy students' competencies in critical areas where hands-on experience may be limited (10, 11).

Despite the local development of 'Pharmacy Simulator' by the School of Pharmacy and Pharmacology at UTAS (12), which was designed to be used across several subjects within the pharmacy curriculum, including pharmacotherapy, clinical pharmacy, and pharmaceutical care. The simulator is designed to replicate various pharmacy practice scenarios, allowing students to apply theoretical knowledge in a controlled, virtual environment. It enables students to practice decision-making, patient counselling, and medication

management in both community and hospital pharmacy settings, without the risks associated with real-life errors (13, 14). However, there is limited engagement with this simulation tool among educators. This reflects a broader trend where advancements like CBS are not being fully integrated into pharmacy education, especially compared to other health disciplines (13, 14). As a result, this study investigated the perceptions of pharmacy educators and students at UTAS regarding the barriers to integrating CBS into pharmacy practice education.

2 Methods

A mixed-methods case-study design was selected for its ability to provide in-depth contextual insights and actively engage stakeholders, which is crucial for understanding the intricate dynamics between technology, pedagogy, and institutional culture (15, 16). This case study aimed to address any potential challenges to the uptake of 'Pharmacy Simulator' and other CBS systems at the School of Pharmacy and Pharmacology, University of Tasmania, Australia. 'Pharmacy Simulator' is an in-house simulator specifically designed to enhance pharmacy education by providing a realistic and interactive learning environment (12). This CBS allows students to engage in simulated clinical scenarios, fostering critical thinking and soft skills essential for pharmacy practice.

The study involved surveys and interviews conducted between March to September 2023 to gather diverse stakeholder perspectives. Surveys were administered to students, while interviews were conducted with educators. The mixed-methods approach allowed for a comprehensive understanding of both quantitative and qualitative data, providing a holistic view of the perceptions of CBS. Given the small population size, we employed a total population sampling approach, inviting all members of the study population to participate.

All UTAS pharmacy students were eligible to participate. A link to the online survey was distributed via emails, and the institution's learning management system. Participation was voluntary, with incentives including a chance to win one of ten \$50 AUD gift vouchers. Implied consent was obtained at the survey's start. The survey included questions designed to assess students' opinions on the use of CBS technology, perceived implementation barriers, and their general interest in the adoption of this technology within the curriculum. The online survey was developed and administered using LimeSurvey® (LimeSurvey GmbH, Hamburg, Germany. URL <http://www.limesurvey.org>).

The initial constructs of the survey questions and overall design were identified based on a relevant literature search (13, 14) and

scoping team meetings. Items were drafted and finalised using an iterative approach. The draft survey underwent independent content validation by two postgraduate pharmacy students and two pharmacy educators. Additionally, the survey was pre-tested with a small group of volunteers to assess its clarity and relevance, further supporting its face validity. These steps ensured that the survey was both comprehensive and aligned with the study's objectives. The survey consisted of 20 questions, primarily close-ended for quantitative analysis, along with a 6-point Likert scale to measure respondents' attitudes. The data were extracted from LimeSurvey® to IBM Statistical Package for Social Sciences (IBM SPSS® Statistics for Windows, version 26.0; IBM Corp, Armonk, NY, United States). Descriptive analysis was primarily used for the quantitative part of the study. Chi-square test was applied to make comparisons between groups, and a p -value <0.05 was considered statistically significant.

2.1 Design of the qualitative phase—educators interview

An email invitation, which included a participant information sheet and consent form, was sent to all pharmacy practice educators ($n = 16$) to participate in a semi-structured interview. These interviews aimed to examine their perspectives on CBS, discussing both the opportunities and challenges associated with its practical implementation. The interviews also explored educators' views on possible approaches to enhance the integration and use of CBS at the institution. An online 30-min interview was conducted with each educator who agreed to participate and provided written consent. The semi-structured interviews were conducted using an open-ended script to explore the participants' views on CBS and experiences with existing models. The interview format employed a 'funnel-shaped' approach, narrowing down from broad to specific inquiries (17). The script was developed based on a literature review (13, 14) and team discussions, and was pre-tested with three educators. The interview guide was designed to address several key constructs, including general perceptions of CBS, the adequacy of institutional and educator support, student engagement with CBS, and strategies for optimizing CBS implementation. Specific questions included, for instance, "What are pharmacy educators' views on incorporating CBS into pharmacy practice education?" and "Are pharmacy educators adequately skilled and willing to integrate CBS into curricula?". The full interview guide is available in [Appendix B](#).

At the completion of each interview, the audio recording was transcribed using Zoom (18), and de-identified by assigning unique codes to remove personal identifiers. The interview transcripts were analysed thematically following Braun and Clarke's (19) approach. The coding process, guided by an initial codebook, was manually conducted using NVivo (version 12.4, 2020, QSR) (20). This iterative process combined inductive and deductive strategies, allowing themes to emerge naturally while applying theoretical frameworks for depth. Researchers (AG, MS) conducted the coding, engaging in regular discussions to refine the codebook and resolve discrepancies through consensus, thereby enhancing thematic reliability. Contextual reflexivity was used to critically assess how the educational environment at UTAS and the researchers' positionality influenced the findings on CBS integration barriers. To mitigate potential biases, independent researchers cross-validated the themes, and an audit trail

of analytical decisions was maintained to ensure the trustworthiness of the findings.

Ethical approval was granted from the University of Tasmania's (UTAS) Human Research Ethics Committee (Project ID: 26897).

3 Results

3.1 Student survey

The survey had a response rate of 62.5%, with 75 out of 120 enrolled students participating. The participants represented different study years of the Bachelor of Pharmacy program, as seen in [Supplementary Table S1](#). The survey data highlighted students' access to technology resources, their positive perspectives on the integration of CBS in the curriculum, the importance of a user-friendly and engaging CBS design, and their training preferences. However, there were concerns about the expected support levels from educators and institution for CBS implementation.

Regarding the role of CBS in curriculum, a significant proportion agreed that CBS could be utilised for assessing their knowledge (70.7%), in the classroom (62.7%), and as a supplement to classroom study (80%). The students expressed strong interest in developing patient communication and counselling skills (68%), problem-solving skills (69.3%), and dispensing procedures (66.7%) through CBS (as seen in [Table 1](#)). These preferences align with the practical and interpersonal competencies required in the pharmacy profession, indicating that students recognised the potential of CBS in enhancing these essential skills.

[Table 2](#) shows students' views on perceived support for CBS integration from different stakeholder groups. A chi-square test (p -value = 0.0002) confirmed significant differences in these perceptions. Notably, 37.3% of students believed their peers were very likely to support CBS, and 52% considered it somewhat likely. In contrast, only 16% perceived strong support from educators, with 33.3% seeing it as unlikely. Institutional support was also viewed critically, with only 20% seeing strong support and 40% considering it somewhat likely. These results highlight a gap in perceived support from educators and institutions compared to their peers.

3.2 Educator interviews

Of the 16 invited, 10 pharmacy practice educators were interviewed, achieving saturation-level with no new themes or insights emerging after the tenth interview. The educators had diverse pharmacy practice teaching experience, academic roles and exposure to CBS, as summarised in [Supplementary Table S3](#). Regarding their experience with CBS, only two of the interviewees were actively using CBS in their teaching at the time of the interview. Additionally, eight educators had previous exposure to CBS, having trialled or used it in the past, but were not actively using it currently and were not necessarily updated on the changes that have occurred in CBS design features (some had not used CBS for several years). Data saturation was achieved after conducting 10 interviews, as no new themes emerged. The analysis identified three main themes: resistance to change, implementation and operational challenges, and CBS alignment with the curriculum. Additionally, several subthemes

TABLE 1 Students’ Perspectives on CBS success factors and training preferences (N = 75).

Themes	Description	CBS features	Very important, N (%)	Somewhat important, N (%)	Not important at all, N (%)	No opinion, N (%)
Important elements for successful CBS tool	Considering personal preference for elements that are crucial for CBS success	Realistic graphics	32 (42.7%)	29 (38.7%)	10 (13.3%)	4 (5.3%)
		Ease of use	60 (80%)	15 (20%)	–	–
		Bug-free experience	60 (80%)	15 (20%)	–	–
		Availability of technical support	36 (48%)	39 (52%)	–	–
		Detailed feedback	46 (61.3%)	22 (29.3%)	5 (6.7%)	2 (2.7%)
		Engaging content	52 (69.3%)	18 (24%)	3 (4%)	2 (2.7%)
		Fun/enjoyable content	43 (57.3%)	25 (33.3%)	4 (5.3%)	3 (4%)
Training preferences from a CBS tool	Considering personal views on the most suitable training focus for integrating CBS	Patient communication and counselling skills	51 (68%)	12 (16%)	8 (10.7%)	4 (5.3%)
		Problem-solving skills	52 (69.3%)	21 (28%)	1 (1.3%)	1 (1.3%)
		Dispensing procedures	50 (66.7%)	20 (26.7%)	3 (4%)	2 (2.7%)
		Interprofessional communication skills	36 (48%)	28 (37.3%)	2 (2.7%)	9 (12%)
		Hospital pharmacy practice	44 (58.7%)	26 (34.7%)	–	4 (5.3%)
		Community pharmacy practice	44 (58.7%)	22 (29.3%)	2 (2.7%)	7 (9.3%)
		Community-based clinic	30 (40%)	28 (37.3%)	2 (2.7%)	15 (20%)

CBS, computer-based simulation.

TABLE 2 Students’ views on the expected support level for CBS integration from different stakeholder groups.

Stakeholders	Expected support level for CBS integration			p-value
	Very likely, N (%)	Somewhat likely, N (%)	Not likely, N (%)	
Students	28 (37.3%)	39 (52%)	8 (10%)	0.0002
Educators	12 (16%)	38 (50.7%)	25 (33.3%)	
Institution	15 (20%)	30 (40%)	30 (40%)	

Chi-square was applied.

p < 0.05 is considered statistically significant, highlighted in bold font.

CBS, computer-based simulation.

emerged within these broader categories, each highlighting specific aspects of the educators’ experiences and concerns. The emerging themes and insights are described in [Tables 3, 4](#).

3.2.1 Theme 1: resistance to change

One of the most significant barriers to CBS uptake identified in the interviews was resistance to change, which manifested in two primary subthemes: educator resistance and student resistance.

Educators expressed a preference for traditional teaching methods and scepticism towards CBS. This reluctance to embrace new technologies reflects a broader cultural resistance within the educational environment, where innovation is often met with caution and the need for extensive testing before adoption. Additionally, some educators view CBS as lacking educational merit and perceive them as games rather than legitimate educational tools.

In addition to educator resistance, the interviews revealed concerns about student resistance, particularly among international students. Some educators noted that these students tended to view

CBS as less formal and less valuable compared to traditional methods. This highlights the importance of considering cultural perceptions and learning preferences when introducing new educational tools. Students who are accustomed to more conventional forms of instruction may find CBS challenging to accept, perceiving it as a departure from the rigour and structure they associate with effective learning.

3.2.2 Theme 2: implementation and operational challenges

The second major theme was the implementation and operational challenges associated with integrating CBS into the curriculum. This theme encompasses several subthemes, including workload and time constraints and resource limitations.

Educators cited significant time constraints and increased workload required for developing case scenarios and adapting to CBS use. Balancing the initial setup of CBS with existing educational duties was highlighted as a major challenge, as it was seen as labour-intensive,

TABLE 3 Selected quotes on barriers themes from educators' interviews.

Sub-theme and responses (n)	Representative quotes
Theme 1—resistance to change	
Educators' resistance to change Number of participants = 8 Sub-theme frequency = 11	<ul style="list-style-type: none"> - "I believe in the tried and tested. These tech solutions seem to complicate our traditional teaching methods without proven benefits."—P2 - "...organisational and educator's mindset is often difficult to change. Some people's perceptions of it as a game that does not have educational merit and do not want to engage with it."—P3 - "... some would never implement it because, you know, they do not like technology at all"—P10
Perceived Student Resistance to Change Number of participants = 5 Sub-theme frequency = 12	<ul style="list-style-type: none"> - "For some students, it is just like, 'No, that is not how I study. Especially, our international students, if told, 'You are going to play a simulation game now,' might misconstrue this as trivial rather than educational."—P1 - "I think they want authentic experiences. I think they want the real-life thing and if they are given a computer simulation instead of the real-life thing, they will see it as a cheap cop-out."—P8
Theme 2—Implementation/operational challenges	
Educators' workload and time Number of participants = 10 Sub-theme frequency = 32	<ul style="list-style-type: none"> - "It is very much about you design the whole content yourself and I know one of them used to take two to four days to develop a 15-min interaction, it's a big limiting factor."—P2 - "... this is not an easy thing, and it is very time-consuming. Everyone is extremely busy developing their courses."—P3 - "Creating those cases, testing them out, probably it will take a couple of years to perfect the cases ... we have a lot of increased workloads within the first couple of years, but it should be very minimal work from then on, once you have got a good case and it's going well."—P9
Resource Constraints Number of participants = 5 Sub-theme frequency = 7	<ul style="list-style-type: none"> - "I question if we have the correct computers that can run the sim, especially with the graphics cards that are needed. There would be a financial implication if there was not sufficient IT support up there."—P1 - "Accessing the simulations was quite the challenge. Slow devices often required the students to use their own devices, which led to compatibility and optimisation issues."—P4
Theme 3—CBS alignment with the curriculum	
Appropriateness of using CBS Number of participants = 7 Sub-theme frequency = 14	<ul style="list-style-type: none"> - "Just having a good time (for students), but absolutely achieving no educational outcomes."—P1 - "It has its place, but the amount of evidence required to implement it is quite substantial."—P8 - "Obviously, some educators do not see how it would fit in their units. So, we have got to overcome that kind of barrier before can use it."—P10
CBS design limitation Number of participants = 7 Sub-theme frequency = 12	<ul style="list-style-type: none"> - "If you are trying to teach complex communication skills, there are limitations to what the current CBS programs can offer. How do you, in a computer simulator, let a student know that they need to speak louder if the person's an older person but then do not start patronising them, like talking to them like they are a little child—and use a louder voice, but same language."—P2 - "I appreciate the potential of simulations for hands-on learning, but the one-size-fits-all approach does not account for different learning speeds and styles. A more tailored experience would help."—P4

CBS, computer-based simulation.

involving the creation of complex case scenarios, testing, and refinement. Some educators expressed concerns that these demands could detract from other important responsibilities, making CBS a daunting addition to their teaching duties. However, many acknowledged that once CBS is fully integrated, it could reduce the ongoing workload compared to traditional methods, such as standardised patients and paper-based solutions, which need to be re-implemented annually. Despite recognising the potential long-term benefits of CBS, many felt that the upfront investment in time and resources could be a significant deterrent, particularly during the early stages of adoption. Another significant subtheme was the lack of adequate resources to support CBS implementation. Educators cited issues such as underpowered or malfunctioning computers, compounded by logistical challenges when institutions have multiple sites or campuses.

3.2.3 Theme 3: CBS alignment with the curriculum

This theme includes subthemes such as curriculum integration and pedagogical effectiveness.

Some educators questioned the alignment of CBS with the existing pharmacy curriculum and its effectiveness in achieving learning objectives. They highlighted perceived gaps between the potential of CBS as an engaging tool and its actual effectiveness in delivering educational outcomes. Concerns were raised about whether CBS, in its current form, could be seamlessly integrated into the curriculum without compromising the quality of education. Educators were particularly worried that CBS might disrupt the flow of the curriculum and whether it could effectively complement other teaching methods. Additionally, design limitations were noted, such as difficulties in replicating real-life natural communication and a lack of customisation in CBS, which some educators felt could hinder the development of critical thinking and problem-solving skills.

3.3 Proposed solutions

Participants proposed several solutions that may facilitate overcoming these challenges. They emphasised the importance of communicating the benefits of CBS to stakeholders, fostering

TABLE 4 Selected quotes on proposed solutions themes and its linkage to the corresponding barriers from educators' interviews.

Sub-theme and responses (n)	Representative quotes
Solution 1—communicating CBS benefits	
Complementing placement training Number of participants = 10 Theme frequency = 18 Linked to barrier group: “CBS alignment within the pharmacy curriculum”	<ul style="list-style-type: none">- “Even before placements occur, this could give students that experience of how to deal with real-world people before they actually begin to deal with real-world people.”—P5- “I think the real-time feedback, being non-location based, non-time based, is the biggest value you get from these simulations compared to the lengthy coordination required to secure clinical placements.”—P8- “Going into the hospital for teaching students there is very useful, but human resource timewise, it is very costly. A lot of these types of cases could be incorporated into a computer simulation to complement my students’ training.”—P9- “You do not always get that (talk to patients) because they might be in isolation, grumpy, have visitors, going for a scope, or asleep. In computer simulation, cases are ready anytime, anywhere! The training quality may not be similar, but it is something better than nothing.”—P10
Interprofessional training Number of participants = 9 Theme frequency = 15 Linked to barrier group: “CBS alignment within the pharmacy curriculum”	<ul style="list-style-type: none">- “CBS can simulate a hospital situation, helping students understand what to ask a nurse or a doctor, enhancing IPL, especially when we are limited by how much IPL we can do with other disciplines because of timetabling and those sorts of things, you could see a sim environment for that being quite beneficial, particularly in a hospital situation.”—P1- “I believe that incorporating computer simulations could help how students understand patient care. It’s about seeing healthcare as a collaborative effort, where clear communication and teamwork are essential.”—P2- “Talking to a doctor, then they just want the important information in short, sharp bursts. [...] one of my roles was to help educate the nurses [...] you would talk to them in a slightly different way, and then the patients are going to be completely different again, so from an interdisciplinary point of view—computer simulation gives the students a bit of an idea of what to expect in hospital environment.”—P6
Solution 2—role of champions	
Role of champions Number of participants = 6 Theme frequency = 7 Linked to barrier group: “educators’ resistance to change”	<ul style="list-style-type: none">- “I think CBS really needs an advocate. [...] you are not going to pay someone to convince you to use something unless you want to use it.”—P4- “The role of a CBS champion is crucial in the educational landscape. [...] advocating for the use of simulations [...] providing a clear, actionable plan on how to integrate these tools seamlessly into the curriculum.”—P5- “Having a champion to showcase the direct benefits of CBS can help overcome resistance and integrate these tools into the curriculum effectively.”—P9
Solution 3—decrease educators’ workload	
Dedicated simulation technician Number of participants = 9 Theme frequency = 13 Linked to barrier group: “implementation barriers—(educators’ workload and time constraints)”	<ul style="list-style-type: none">- “If we had a dedicated Educators member who could draft the cases for us. [...] If we can say, ‘We want a case on this,’ and it could be written, then I think there is more chance that Educators will use it.”—P1- “If there was a dedicated person preferably a pharmacist to make sure that it legally meets requirements and those kinds of things who had the time to take on all of the work, and I just handed them a case and said, ‘Here you go, what do you think? Do you think that there’s aspects of this that you could put into a simulation,’ and it was not on my shoulders, then absolutely yes.”—P8- “Coming from, a pharmacist background, as I said, we know the dialogue. [...] the reaction of the avatar, I found that part really difficult to program in. so, yeah, if that’s all done for you and you just have to make the questions relevant, that would be—that would be a big timesaver.”—P10

CBS, computer-based simulation.

interprofessional learning opportunities through simulation, leveraging champions to advocate for technology integration, and alleviating educators’ workload by employing dedicated simulation technicians. Specifically, the solutions included promoting the benefits of CBS in complementing clinical placement training (18 instances, 10 participants) and employing dedicated CBS support staff, such as specialist simulation technicians (13 instances, 9 participants), to ease educator workloads.

3.3.1 Solution 1: communicating CBS benefits

One of the proposed solutions focused on communicating the benefits of CBS more effectively, particularly in how CBS can complement existing training methods and foster interprofessional learning (IPL).

Educators suggested that CBS could play a critical role in complementing clinical placements, particularly by providing students

with opportunities to practice and refine their skills in a controlled environment before interacting with real patients. This would help bridge the gap between theoretical knowledge and practical application, giving students confidence in their abilities. Additionally, CBS could offer real-time feedback, allowing students to learn from their mistakes in a safe setting. This approach would be especially valuable when traditional placements are limited or challenging to coordinate, as CBS can simulate scenarios that students might not otherwise encounter. The ability of CBS to supplement clinical placements was seen as a key factor in aligning it more closely with the pharmacy curriculum.

Another solution proposed was the use of CBS to enhance interprofessional training. By simulating real-life healthcare scenarios that involve multiple disciplines, CBS can help students understand the importance of communication and collaboration in patient care. Educators noted that IPL through CBS could overcome the logistical

challenges of coordinating in-person IPL activities across different disciplines, making it a practical and effective tool for developing these essential skills. This solution directly addresses the subtheme of CBS alignment within the curriculum by integrating CBS as a means to achieve broader educational objectives beyond the scope of traditional, discipline-specific training.

3.3.2 Solution 2: role of champions

To address resistance to change, educators proposed introducing champions—key individuals who advocate for CBS and guide its integration. Champions are seen as crucial in addressing the educators' resistance to change. By demonstrating the benefits of CBS and offering practical support, champions can help shift the cultural attitudes within the educational environment. They would lead by example, showcasing successful CBS implementations and providing mentorship to other educators who are hesitant to adopt the technology. Champions could also play a pivotal role in aligning CBS with educational goals, ensuring that its integration is seamless and effective. This approach would help build confidence in CBS and foster a more supportive environment for its adoption.

3.3.3 Solution 3: decreasing educators' workload

A final proposed solution involves reducing the workload associated with CBS by employing dedicated simulation technicians. Educators suggested that this role could alleviate their burden by managing the technical aspects of CBS, such as scenario development, system maintenance, and troubleshooting. This approach would allow educators to concentrate on the pedagogical integration of CBS without being overwhelmed by operational demands. Having a team member who understands both the technical and educational aspects of CBS would also ensure its effective use, enhancing its value as a teaching tool. This solution addresses barriers related to educators' workload and time constraints, making CBS a more viable option for curriculum integration.

4 Discussion

This case study explored the perceptions of students and educators towards using CBS in pharmacy education, uncovering several barriers impacting CBS uptake. These barriers encompassed cultural challenges, such as educators' resistance to change, and operational challenges, including limited resources and substantial workload and time constraints faced by educators. Participants proposed several solutions to mitigate these barriers and enhance the uptake of CBS.

The combined insights from students and educators revealed both challenges and benefits to the broader adoption of CBS. There was strong student support for CBS, with 70.7% affirming its value for assessing knowledge and 80% endorsing its assistive role in education. These findings align with other educational contexts where technological readiness and positive perceptions towards digital learning tools have been increasingly noted. Studies have shown that digital natives, such as the current generation of students, are generally more receptive and adaptive to using technology for learning purposes (21).

However, only 16% of students believed that strong educator support for CBS integration was likely. The interviews with educators largely supported this view, exhibiting a notable resistance to change,

potentially rooted in a preference for traditional teaching methods and concerns over the educational efficacy of new technologies. This resistance is compounded by practical barriers such as resource constraints and workload, hindering the effective deployment and integration of CBS into the curriculum. This phenomenon is well-documented in educational research, which underscores a natural hesitancy towards change (22–24). Introducing CBS requires an upfront investment and may be perceived as burdensome rather than enriching. Without adequate support, this workload can lead to burnout and resistance, despite the potential benefits for learning outcomes and longer-term workload reductions. Previous research has found that while students quickly adapt to new learning technologies, educators often lag due to factors such as resistance to change, lack of training, and perceived increase in workload (25).

This divergence in perspectives on the role of CBS in pharmacy education highlights a cultural gap that needs bridging. Overcoming faculty resistance and boosting institutional support are likely required to realise the full potential of CBS in pharmacy education. Students perceived CBS as highly valuable for improving patient communication, problem-solving abilities, and dispensing procedures. In contrast, educators expressed reservations about CBS's ability to replicate complex real-world scenarios effectively and its alignment with educational outcomes. This limited active use suggests that their practical experience might not fully reflect CBS capabilities. Their feedback should be contextualised within their hands-on experience, highlighting the need for ongoing training and support to help educators integrate and utilise CBS effectively. The literature supports the positive views of students and refutes educators' scepticism, with evidence that CBS can improve skills and knowledge, including clinical reasoning, procedural skills, and team skills (26). By integrating CBS more deeply into the curriculum, educational institutions can better prepare students for real-world clinical scenarios, enhancing their readiness for professional practice. Furthermore, the effective use of CBS can help bridge the gap between theoretical knowledge and practical application.

All interviewees supported CBS to complement placement training, recognising its value in addressing educational gaps. This support is reinforced by professional organisations such as the American Association of Colleges of Pharmacy (AACP) and the Accreditation Council for Pharmacy Education (ACPE), which advocate for using technologies like CBS as complementary teaching tools (27). CBS is also seen as having the potential to foster collaborative learning experiences and promote a culture of (IPL) within pharmacy education (28).

Our study revealed significant shortcomings in local institutional support, with nearly 40% of students questioning its adequacy. This underscores a critical gap in perceived support systems within the institution. Educators reported substantial challenges, notably heavy workloads and limited time, which hindered their ability to explore and adopt innovative teaching methods like CBS. To fully leverage the potential of CBS, schools must invest in infrastructure and provide ongoing training for educators. Such investments not only address current resistance but also empower educators with the skills and confidence needed to innovate in their teaching practices. As educators become more proficient with CBS, they can enhance the school's overall development by creating more engaging and effective learning environments, which, in turn, can attract and retain students.

The literature consistently underscores the essential role of institutional support in successfully integrating new technologies in educational settings (29). One key suggested intervention is appointing a dedicated technician for CBS integration. This technician would provide essential technical support, facilitate smooth implementation, and allow educators to focus on pedagogical innovation rather than technical matters. By doing so, educators believed that educational institutions could ensure CBS content is expertly managed and updated, enhancing both the quality and functionality of the simulations. Other targeted support measures identified in the literature may help address implementation challenges effectively (29). These include specialised training sessions for educators to grasp new technologies quickly without overwhelming them. Practical resources like customisable CBS templates and digital resource libraries can further streamline the time educators spend creating new content and integrating it into existing courses.

5 Study implications

Our study highlights the need for a strategic approach to equip both students and educators to engage effectively with CBS in pharmacy education.

For students, while their enthusiasm for CBS is evident, it is crucial to ensure they are not merely passive users but are actively developing the critical thinking and problem-solving skills that CBS can enhance. This requires carefully designed instructional strategies that integrate CBS into the curriculum in ways that align with professional practice expectations.

For educators, the study underscores the necessity of targeted faculty development initiatives. These should go beyond technical training to include pedagogical strategies for seamlessly incorporating CBS into teaching. The goal is to shift the perception of CBS from being an additional burden to a valuable tool that enhances educational outcomes. This shift can be facilitated by creating platforms for educators to share their experiences and successes with CBS, fostering a community of practice that supports continuous learning and adaptation.

Furthermore, the study suggests that institutional support plays a pivotal role in the successful adoption of CBS. This support includes not only providing the necessary infrastructure but also ensuring that educators have access to ongoing professional development and technical support. Such support structures are essential to overcoming the cultural and operational barriers identified in our study, enabling educators to innovate with confidence and effectiveness.

By addressing these implications, educational institutions can better prepare both students and educators to leverage CBS fully, ultimately enhancing the quality and effectiveness of pharmacy education. This will equip future pharmacists with the skills and knowledge needed to excel in an increasingly complex and technology-driven healthcare environment.

6 Limitations

The mixed-methods approach, combining qualitative interviews and quantitative surveys for two key stakeholders, ensured a comprehensive understanding of CBS uptake at UTAS and enhanced

the reliability of the findings. Furthermore, the high response rate and detailed thematic analysis further strengthen the study's credibility and relevance. However, the study sample, drawn from a single institution, may limit the generalisability of the findings. Nevertheless, the results are applicable in a broader context. The identified barriers and proposed solutions, such as dedicated support personnel and fostering interprofessional learning, address common issues in pharmacy education globally. These insights into overcoming challenges contribute to the wider adoption of CBS, benefiting pharmacy programs worldwide.

Additionally, the inclusion of students from different academic years may introduce bias due to uneven representation and varying levels of experience and familiarity with CBS. Moreover, there is a risk that participants might have provided socially desirable responses rather than their true perceptions, as the reliance on self-reported data from interviews and surveys may be subject to response bias. To mitigate this, we ensured the anonymity of responses, designed questions to maintain anonymity, and guaranteed that participation had no impact on students' grades or study progress.

7 Recommendations for future research

Future research should incorporate larger, more diverse samples from multiple universities. This approach would enhance the accuracy and generalisability of the findings, providing a more comprehensive understanding of the barriers and facilitators to CBS adoption in pharmacy education. Additionally, gaining deeper insights into the perspectives of decision-makers would be useful for identifying potential barriers and developing strategies to overcome them.

8 Conclusion

This mixed-methods case study reveals a complex interplay of factors influencing the adoption of CBS in pharmacy education at our university, highlighting student enthusiasm and educator reservations. Despite students valuing the adoption of CBS, educators expressed concerns over practical implementation challenges, including infrastructure needs, workloads, and the impact on traditional teaching methods. Proposed solutions emphasised the need for dedicated support personnel, targeted training, and strategic curriculum integration.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Tasmanian Human Research Ethics Committee (reference: H0026897), Australia. The studies were conducted in accordance with the local legislation

and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AG: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. GP: Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. IB: Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MS: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The University of Tasmania owns the underlying Intellectual Property for Pharmacy Simulator and makes use of it in their Bachelor of Pharmacy program. This technology has been out-licensed for commercialisation and is being actively sold as Pharmacy Simulator by Imitated Environments Pty Ltd., Hobart, Australia. ABN 71625288575. One of the authors, Ivan Bindoff is the director and major shareholder of Imitated Environments Pty Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board members of *Frontiers*, (MS and GP) at the time of submission. This had no impact on the peer review process and the final decision.

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Supplementary material

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Curriculum guide for teaching house officers and faculty: applying procedure codes effectively using chemical denervation as a model

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Introduction: The healthcare system in the United States relies heavily on physician-and house officer-driven initiation of billing and coding for collection of hospital payments and professional fees. Under the umbrella of practice management is the ever-changing and suboptimally taught concept of procedural billing and coding to house officers and faculty. Clinical providers and practitioners initiate billing and coding for performed services based on the procedural visit encounter, supported by the appropriate documentation. Correct charge capture is dependent on accurately linking CPT codes and J codes, including waste documentation, modifiers, and charge collection. We discuss a perspective regarding a new curricular methodology that teaches learners to apply an algorithmic approach for coding CPT codes, J codes, and modifiers for chemical denervation procedures involving high-cost botulinum toxin. We further recommend the use of visuals with algorithm development for other pertinent procedures that are specific to a department.

Methods: We developed a curriculum that includes algorithmic visuals, pre-and post-test questions, and reflections. It was implemented across various learner types.

Results: This chemical denervation curriculum was well-received and impactful in meeting the objectives of the course. It further expanded a learner's vision of practice management that can be applied to other procedural examples.

Discussion: The results demonstrate a clear gap in practice management education, with pre-education knowledge on applying appropriate codes being particularly low among resident physicians. Learners found the algorithm we developed especially valuable, as it serves as a practical tool for accurately accounting for all aspects of CPT codes, modifiers, and J-codes. The methodology of the algorithmic approach proved to be innovative for avoiding billing write-offs and loopbacks that were beneficial for the training process. Learners indicated that this approach can be applied to other procedural billing.

KEYWORDS

house officer curriculum, faculty education, billing and coding, medical practice management, procedural billing and coding

Introduction

In increasingly complex clinical care environments, medical trainees are inadequately prepared for billing and coding procedures. In fact, studies have shown that medical trainees and graduates believe that their training for billing procedures under practice management education was inadequate (1–3). While few studies have included aspects of billing and coding in resident education, they are largely in the fields of pediatrics (4, 5), emergency room (6), and inpatient hospital procedures common in internal medicine (7). There is currently no curriculum that teaches residents appropriate billing and coding for procedures to identify and subsequently bill for botulinum toxin chemical denervation procedures. These procedures are used for spasticity management, cervical dystonia, and migraine treatment, which are common but not limited to departments of neurology and physical medicine and rehabilitation. In fact, according to data published by the Center for Medicare and Medicaid Services, excluding commercial insurance payers, there are approximately 462,082 of these procedure codes utilized in 2022 (8). Yet, curricula that detail billing procedures in medical practice education are still overwhelmingly undertaught and not readily available. Consequently, providers initiate chemical denervation procedural billing codes for both inpatient and outpatient settings, often without an effective feedback loop to correct or optimize the coding. The Accreditation Council for Graduate Medical Education transitioned to “competency based, outcomes-oriented education (9)”. Though this educational approach recognizes practice management, this occurs, however, in the context of a changing billing and coding environment, where optimal billing requires stable attention to compliance with external and internal administrative and regulatory requirements. Some institutions may have a robust reconciliation process for charge capture, and others may not. This results in claim denials, decreased work relative value unit (RVU) compensation, and largely avoidable write-offs. Education is the first line of defense to ensure correct charge capture, which will both increase efficiency in practice management and decrease accidental underbilling. This will inevitably result in less time spent on billing errors and more time spent optimizing patient healthcare. We designed a curriculum that will enable learners to appropriately apply Current Procedural Terminology (CPT®) code(s), modifiers, and J codes to chemical denervation with botulinum toxin injection procedures. While this curriculum targets this specific procedure, its algorithmic model can be adapted to other healthcare settings with unique procedural acumen.

Through a curriculum designed to optimize coding procedures that contribute to avoidable write-offs in billing and coding procedures, our aim is to maximize efficiency in teaching such processes. It includes opportunities for residents, fellows, and faculty to determine when to use codes for specific patient care scenarios and to apply each appropriately without common errors. It will enable learners to effectively assign Common Procedural Terminology (CPT®) codes, J codes for reporting medication, and modifiers for different chemodenervation procedures. Students were presented with four different patient case scenarios with a demonstration of how practitioners should code in each different case scenario, utilizing both images and an originally developed algorithm.

Importantly, this curricular perspective is novel in two ways: first, it addresses the gap in training for billing and coding of chemodenervation procedures, specifically in physical medicine and

rehabilitation or neurology practice settings, and second, the innovative development of an algorithm for practitioners to utilize in their approach to appropriately assign CPT codes, J codes, and modifiers outside of chemodenervation procedures specifically, as all procedures utilize formats of these codes. While this curriculum focuses on billing items that contribute to payer denials and avoidable write-offs, our aim is to present methods that can both contribute to improvement in practice management education overall and expand the knowledge so that it can be applied to other procedures. This curriculum also targets learners’ pre- and post-course knowledge as a means of implementing best instructional practices in diverse learning environments.

Methods

The curriculum was designed to teach learners how to apply correct CPT codes, modifiers, and J codes through an innovative algorithmic model that maximizes billing efficiency in practitioner settings and minimizes payer denials and avoidable write-offs. It was developed by a team consisting of a neurorehabilitation physician experienced in chemodenervation procedures, a Certified Professional Coder from an academic institution, and a university instructor (PhD) with focused experience in best instructional practices in pedagogy and curricular development. The pre- and post-tests (including short responses and reflections) were conducted specifically to target the most common errors in chemodenervation procedures and assess curriculum knowledge outcomes. The team met six times to revise, and the final version was ultimately reviewed and approved for use.

The curriculum was taught both over Zoom® software and in person. Given the COVID-19 pandemic restrictions and newly formed teleconference capabilities nationally, the curriculum was taught first virtually via Zoom over a cohort of three residency classes from 2020 to 2023. The curriculum was taught in person at a national conference to faculty in 2022. Facilitators prepared the slide presentation (Appendix A) that includes review information, the algorithm procedure and chart, patient scenarios, and the pre- and post-tests. Prior to the start of instruction, resident learners were emailed a course pack that included the review information, the algorithm, patient case scenarios, and pre- and post-tests (Appendix B). We also included the algorithm as a separate appendix (Appendix C). For the faculty, this was given at the beginning of the course session in person. The curriculum includes a review of J code (HCPCS) and CPT code definitions, along with which modifiers should be applied in different case scenarios. It includes four patient case scenarios of chemical denervation with botulinum toxins procedures with subsequent demonstrations on how to code and capture charges appropriately. Case studies for Zoom sessions were set up as virtual stations on the screen, allowing learners to move through them and practice the correct application of CPT codes, J codes, and modifiers in these simulations. Case studies for the faculty included a doll to aid in visual and tactile learning in an independent station. Virtual learners had the option of printing the course pack of materials and scanning (and emailing) their responses back or use any other software that enabled them to markup the pdf form directly and return it to the facilitators. Faculty in the in-person course had the opportunity to write down responses on paper and submit them back to the facilitator.

Learners were given a pretest to assess prior knowledge, followed by a posttest at the end of the lesson. Additionally, the posttest incorporated reflection responses on new knowledge. Studies across various domains of medicine have shown that assessing learners' prior knowledge—in this case through the pretest at the start of training material—can help instructors determine knowledge gaps and better target instruction (10). Furthermore, studies have shown that implementing reflection in medical students' training is not only a means of self-assessment but also an effective instructional practice in ensuring students can synthesize prior knowledge with their new understandings (11–13). In fact, one study that implemented reflection to measure the efficacy of medical students' training for teaching notes that “Narratives [produced through reflection] revealed candid self-assessments and detailed descriptions of their experiences and what they valued most from the course (13)”. As such, in the posttest, learners were asked to reflect on the overall course and the ways they might apply their knowledge in practice management to optimize charge capture and billing procedures. Reflection responses were also used to evaluate course effectiveness.

Implementation

The study was implemented by the revenue physician lead for the Department of Physical Medicine and Rehabilitation.

Equipment and delivery

To effectively deliver the course material, the following equipment was needed: computer equipment, a slide show presentation, and course packs (either downloaded or printed as needed). For the in-person conference session, dolls were provided for marking practice.

Activating prior knowledge and pretest session (5 min)

The course began with activating the learners' prior knowledge. In a brief paragraph for each, learners were asked to respond to three questions that essentially asked what they already knew and what they wanted to gain from the session regarding CPT codes and denervation procedures. Learners were then given three additional content-based questions that targeted content directly covered in the curriculum. These same questions would be repeated in the posttest session, which would not only serve as an assessment tool but also as a measure of the effectiveness of the curriculum.

Review of CPT codes and modifiers (15 min)

We reviewed chemical denervation CPT code definitions. We also reviewed when to apply modifiers and common mistakes providers make when assigning trunk, neck, and extremity codes. The CPT codes used were: 64612, 64615, 64616, and 64642–7. Review cards were included in the learner course packet and displayed on the screen.

Patient care scenario simulation (30 min)

After review, learners were introduced to the algorithmic model that physicians can utilize to effectively determine which modifier to use in CPT procedures. They were presented with four different patient case scenarios. The virtual session included stations with visual diagrams to practice the correct application of CPT codes and modifiers in the setting of real-case examples, which included details such as muscles injected, units of botulinum toxin utilized, and wasted. Learners completed stations independently and through real-time participation. The hands-on session for faculty learners included the same materials as the virtual teaching, but the content was printed out and a doll was set up to mark and map out case scenarios (see [Appendix D](#)).

Posttest and reflection

The posttest was administered immediately after the patient scenario simulation. The same knowledge-based questions given in the pretest were asked in the posttest. Learners were then asked to reflect on what they learned and how they would utilize this knowledge on CPT coding procedures in their anticipated practice settings. Learners were asked to write out responses in the form of a brief paragraph.

Whole group discussion and conclusion

A brief wrap-up with a whole group discussion was then facilitated, and learners shared responses to the posttest and shared reflective responses.

Results

The results reflect data collected over 26 learners ($n=26$). The curriculum was administered in an average of 75-min lesson sessions on three different dates. They were administered to house officers in separate ACGME-accredited residency and fellowship programs (11 and 12 learners ranging from PGY2 to PGY5, respectively). It was administered again to three faculty in a national conference. All learners (except 1 faculty member) completed the pretest activating prior knowledge assessment, as well as the posttest and short response reflections. They were sent back to the course instructor.

The impact of the curriculum was measured twofold: quantitatively and qualitatively. First, through comparative results of the knowledge-based pre- and post-test questions. That is, learners were asked the same questions in the pre- and post-tests to measure student comprehension and efficacy of curriculum material. Prior to this curriculum, only 20% of students ($n=5$) knew when to use modifier 50. Additionally, less than half of the class (44%, $N=11$) could correctly name a muscle that could be considered UE and trunk muscle when coding ($N=0$ in faculty). Finally, less than half of the class (40%, $N=10$) knew that more than one guidance type could be assigned to a claim with the use of ultrasound. These percentages

changed drastically in the posttest, increasing to 100% after the curriculum was taught, demonstrating efficacy in methodology and curriculum (Figure 1).

An analysis was conducted to examine whether the proportion of correct responses to the three questions changed from pretest to posttest. Chi-square analyses with related samples, specifically McNemar's change tests, were conducted. The results are presented in

Figure 2. For all three questions, the proportion of correct answers was significantly higher at posttest than pretest.

The impact of the curriculum on learning was also measured qualitatively through pre-and post-test reflection responses. In the pretest, these questions complemented those of the short answer pretest but asked learners to reflect on their current knowledge of chemodenervation procedures. The pretest reflection questions were

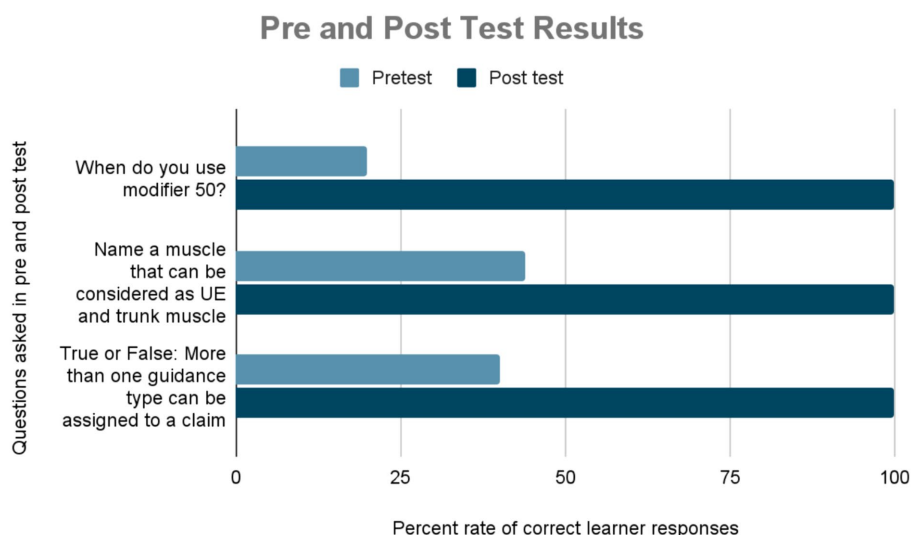


FIGURE 1
Results of pre-and posttests.

1. When do you use modifier 50?

		Posttest		
		Correct	Incorrect	
		n (%)	n (%)	
Pretest	Correct	5 (20)	0 (0)	$\chi^2(1, N=25) = 18.05, p < .0001$
	Incorrect	20 (80)	0 (0)	

2. Name a muscle that can be considered as UE and trunk muscle when coding.

		Posttest		
		Correct	Incorrect	
		n (%)	n (%)	
Pretest	Correct	11 (44)	0 (0)	$\chi^2(1, N=25) = 12.07, p < .0001$
	Incorrect	14 (56)	0 (0)	

3. True or false: More than one guidance type can be assigned to a claim.

		Posttest		
		Correct	Incorrect	
		n (%)	n (%)	
Pretest	Correct	10 (40)	0 (0)	$\chi^2(1, N=25) = 13.07, p < .0001$
	Incorrect	15 (60)	0 (0)	

FIGURE 2
Results of Chi-square analyses with related samples, specifically McNemar's change tests.

intended to invite the learner to begin to assess their knowledge base. Responses indicated knowledge gaps and uncertainty among students in various domains of CPT procedures in practice management. Questions with all their reflective responses were typed into a Word document to identify common themes. These questions elicited open-ended answers to learners' current knowledge of chemical denervation procedures and their codes. The themes included a majority of responses that indicated low to no knowledge and frustrations with the lack of knowledge.

Question 1: What do you know about billing and coding for chemodenervation procedures?

- "I know I may not be coding correctly."
- "We start doing Botox as a PGY-4. I do not know anything about it."
- "At this time, my knowledge is limited. However, I understand that it is \$1,500 per 100u of Botox. It is prepaid to the administrator."
- "I know there is a sheet in the clinic with codes. No one truly taught us how to use it but we try to code them based on definition. I do not know if my coding is ever wrong or incorrect because no one cross checks my work or gives me feedback. Its great we are asking this question because I have felt not confident in this area. There are no websites or books to teach us this."

Question 2: What billing codes would you typically use for Chemical denervation procedures?

- "99214, 99215 are encounter codes-I'm not sure maybe they start with 994... something"
- "I do not know any of the codes."
- "I do not know what codes are used but I believe there is a procedure modifier code that is added to a visit level code."
- "I do not know which billing codes are used for denervation. I believe it depends on EMG guidance or lack thereof. It depends on how many muscles are injected as well."

Question 3: When considering practice management in medicine, what knowledge gaps do you have with CPT codes, J codes, and/or modifiers?

- "I find that there are nuances which can be frustrating especially when learning those on my own. I have not yet used J codes and rarely used modifiers for chemodenervation toxin procedures."
- "At this time, as a PGY3, I have not been in a situation where I have learned about CPT codes, J Codes, or modifiers."
- "I feel I am slightly exposed to this when in clinic but typically the attending chooses the code and it is not emphasized why later in residency. I feel I currently have significant gaps in coding and billing."
- "I have heard of CPT codes and modifiers but I am not sure what they mean."

Accordingly, in Question 1, students expressed clear uncertainty and knowledge gaps in billing and coding. One student indicated that they were unsure of where to go to learn this information. For Question 2, when asked about specific codes, students did not know which set of codes was for denervation procedures. For Question 3, the common theme was, again, overall uncertainty with respect to coding and billing in practice management. One student was

frustrated by the knowledge gap and noted that they have to learn this on their own, while another noted they depend on the attending provider to tell them which code, and they are often uncertain why a specific code was chosen. Overall, the pretest indicated significant deficiencies in the billing and coding curriculum.

The posttest reflection questions were intended to invite students to assess their knowledge gained after the course and envision how this might impact their practice moving forward. All responses were typed out into a Word document to obtain informal themes. Learners' comments indicated that they found both the case studies and the algorithm particularly helpful. Many indicated they would use the algorithm in their future practice. Furthermore, this curriculum substantially increased their understanding of billing aspects of practice management. The reflections indicated intended application in their future practice. The questions and responses included:

Question 1: Which parts of the course were most effective in increasing your understanding of CPT billing procedures?

- "The use of the algorithm along with most, if not all, CPT codes we utilize. The discussion of modifier especially J and JW codes as this was unbeknownst to myself and most others."
- "The entire course was outstanding. The explanations and reference tables for codes were very helpful but the case examples were very useful critical thinking/application of learned knowledge."
- "The algorithm was incredibly helpful to use through the cases, and something I plan to use moving forward."
- "The intro laid a solid foundation for other broad strokes regarding definitions of CPT codes (like office visit), and modifier GC (for teaching physician staffing). Then it moved into specific for chemodenervation but the principles can be applied to other general procedures. The cases included medical knowledge and were interactive regarding muscle pathophysiology and innervation while presenting the billing and coding component in a simple and easy to apply manner. The algorithm was the star of the course!"
- "I thought this presentation was very well put together. Good amount of explanation of the codes at the beginning of the lecture, the algorithm was a helpful flow sheet, and the practice cases helped to bring it together for understanding and application."

Question 2: In what ways do you think this information will aid you in practice management?

- "I think it will help me advocate appropriate billing for what I know at this time throughout my fellowship and beyond. Knowing this information may help peek interest of practices where I may apply for jobs."
- "This is my first real exposure to billing and will serve as the framework for my future billing."
- "It broadened my understanding on practice management. I am more aware of how easy it is to code incorrectly and how important it is to be fluent in applying these codes. The billing and coding generated by a physician is legally and ethically our responsibility."
- "As a PGY2 with very little experience with CPT codes at this point, I found this very helpful in thinking about codes and the major impact it can/will have on my future practice."

Question 3: How will you change your approach to appropriately applying CPT to denervation injections? What impact do you think this lesson will have in your approach to billing and coding in practice management overall?

- “I will hopefully take this training into all of my chemodenervation coding in the future.”
- “I now will be placing the appropriate codes for these procedures. The impact might be large enough for our program to consider hiring more faculty which may give us more time for educational endeavors as residents on inpatient rehab. Overall, I think I may be questioning procedural codes moving forward.”
- “This will alter/formulate my style and billing practices for my future. This course will help me daily in my future practice.”
- “Initially, I did not have an approach as I did not have clinical experience to appropriately applying CPT to denervation injections, so this has impacted my practice tremendously.”
- “My new approach will not always include this algorithm and as I place the coding into the EMR I will cross check it against this course material. I will also teach others the correct so we do not continue to make the same mistakes in our department.”
- “I would like make my own flowsheet to use with knee and shoulder injections so I can visualize and not miss anything in charge entry.”

Student reflections in the posttest indicated an overall increase in knowledge and application for denervation procedures and billing and coding. The overall tone from learners was strikingly similar, and there was no seemingly unfavorable reflection/response eliminated from the examples above. For the first question, where learners were asked about the most effective parts of the curriculum, they expressed that the algorithm and case studies in particular were most helpful. For the second question, learners were asked to reflect on application in practice management, to which many expressed that it strengthened their understanding of billing and coding substantially. Finally, the last question asked learners to reflect on the broader implications of the lesson to their practice. Most learners reported an

increased knowledge that they believe will alter their billing approach in the future. One learner even noted they would potentially create their own flowsheet (or algorithm) for other parts of the body.

Discussion

Our results reveal a clear gap in practice management education, with both house officers and faculty demonstrating suboptimal knowledge in applying appropriate procedural charge capture. Most students had expressed little to no exposure to billing and coding well into their residency training, and this extended into faculty responses during the course as well. This curriculum not only addresses the gaps in CPT coding education for chemodenervation procedures but also invites learners to think about the importance of billing and coding in their future and current practices as it applies to other procedures.

The curriculum and algorithm (Figure 3) stressed the importance of capturing all units of neurotoxin injected, including wasted units, to ensure accurate reimbursement for high-cost neurotoxins. It also maximized billing RVUs by applying the appropriate modifiers. Future considerations on this topic include completing a scoping review to understand the lay of the land in the overall setting of billing and coding education, procedure, or otherwise, in order to understand the starting points for these major gaps.

Our evaluation method for the course relied heavily on student reflection rather than quantitative surveys, which hardly encouraged practitioners to think critically. By implementing reflection, learners were given opportunities to self-assess their prior knowledge and revisit what they had learned. Importantly, they drew connections between pre- and post-course content knowledge and envisioned how this might impact their practice moving forward—to which all learners indicated specific ways they would implement the course, including using the algorithm and case examples with visuals.

Learners indicated that the algorithm, which we developed as a tool practitioners can utilize to accurately assign CPT codes, modifies, and J

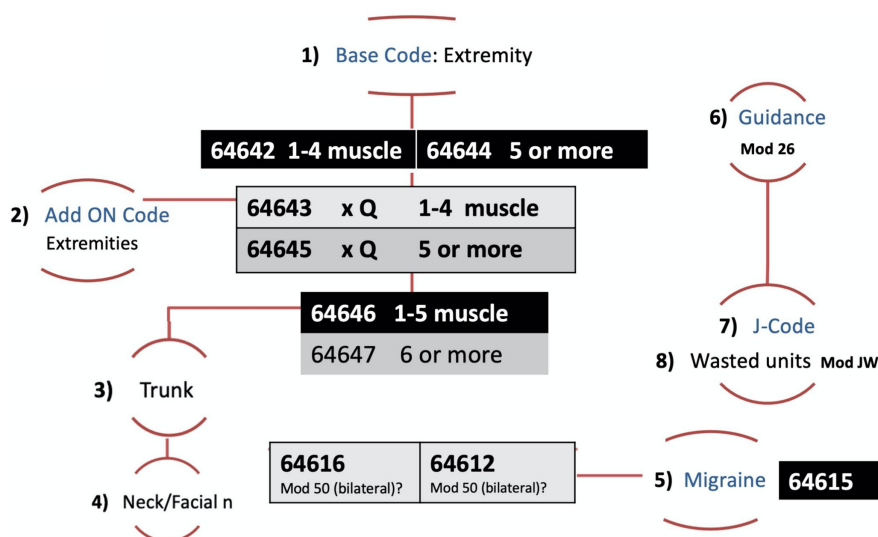


FIGURE 3
Algorithm for chemical denervation procedural charge capture.

codes, was especially valuable. The algorithm proved to be an innovative approach for avoiding billing write-offs and loopbacks. It was beneficial for training and, as learners indicated, also applicable to other procedures.

A major limitation of this study is that it was conducted on a smaller sample of students, ranging from PG2 to PG4 residents. Notably, the faculty course was held during a COVID-19 spike as well, with fewer attendees than expected. Nevertheless, the consistent results that showed substantial knowledge growth in every student suggest that it could be adapted effectively in larger sections when applicable.

Another limitation is the timing of the posttest assessments. Since the posttest was administered nearly immediately after the patient care scenario, we acknowledge the question of long-term knowledge retention. That is, the posttest timing likely assessed recall rather than practical application in different contexts. Nevertheless, the results do indicate increased knowledge, while the reflections envisioned where such implementation might occur in their own future practice.

In addition, future sessions could include a review of Medicare's coverage policy [LCD-local coverage determination-L33458] and other payer guidelines, which include indications, limitations, and medical necessity for coverage. If a procedure is performed without meeting the payer's criteria, charges may be denied and ultimately may result in write-offs, another major contributor.

We envision that this curriculum can continue to be easily adapted to in-person settings with the case scenarios set up with models/or dolls to increase visual and tactile learning as restrictions continue to lessen. We also envision that this approach to teaching and developing an algorithm with visual case studies that includes all components of procedural billing needs (J codes, modifiers, and reporting waste) can be applied to other practice management teaching activities in the future.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

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Author contributions

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Supplementary material

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Developing empathy in healthcare professions students: protocol of a mixed-methods non-controlled longitudinal intervention study

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Despite the necessary focus on clinical skills and knowledge during the tertiary education of healthcare professionals, the literature highlights the importance of developing psycho-social competencies. Empathy, a cognitive-behavioral attribute linked to various benefits for patients and healthcare professionals, is one such competency. Pedagogical approaches to successfully develop empathy in tertiary healthcare students are available. However, these approaches are often integrated piecemeal throughout the tertiary education journey. Research on a more empathy-focused curriculum is scarce. This manuscript describes the design of a study that aims to examine the effects of a more empathy-focused curriculum on empathy in tertiary healthcare profession students in Singapore. Freshmen dentistry, medicine, nursing, and pharmacy students enrolled in a novel curriculum with a strong empathy focus will be recruited for the study and followed for the program's extent. Mixed-methods data collection at various time points will be conducted. Quantitative data will be collected on cognitive-behavioral empathy, intentions to provide empathic care, and engagement in courses of the curriculum. Qualitative data on perceptions of patient care and empathy in relation to relevant courses of the curriculum will be collected to provide context for quantitative findings. Ethics approval was granted by the Departmental Ethics Review Committee of the Saw Swee Hock School of Public Health, National University of Singapore (Ethics ID: SSHSPH-214).

KEYWORDS

interdisciplinary instruction, healthcare education, psycho-social competencies, healthcare professionalism, compassion

Introduction

In addition to clinical skills and knowledge, healthcare professionals need a range of psycho-social competencies to provide quality care (not merely cure) to patients. One of these professional competencies is empathy (1, 2). Although empathy has been widely studied in healthcare and healthcare education, there is considerable debate about its definition in the context of patient care (3, 4). Recently, however, the literature has converged toward a cognitive-behavioral view of empathy.

This view can be illustrated by Hojat who, after much research, defined empathy in the context of patient care as "...a predominantly cognitive attribute that involves an understanding of experiences, concerns, and perspectives of the patient, combined with a capacity to communicate this understanding, and an intention to help" (3). This definition, along with others (2, 5, 6) emphasizes the cognitive aspect of empathy, which is argued to be the most relevant in patient-healthcare provider relationships. Cognition is emphasized because understanding requires advanced mental activities of perception, analysis and appraisal of information, and response generation (7). This process often involves recognizing as well as understanding of and responding to patients' feelings, while regulating one's own emotions to prevent burnout and maintain accuracy in judgment, among others (2, 8, 9).

Such higher-order cognitive processing allows health care professionals to gain a more accurate and non-judgemental understanding of patients leading to more appropriate responses. Consequently, supportive connections between healthcare professionals and patients are formed. These connections have various health- and well-being promoting effects driven by psycho- and socio-physiological processes occurring in supportive interpersonal relationships (3, 10–12). Empathic connections also translate into trust, leading to better cooperation between healthcare professionals and patients, facilitating early diagnosis, and treatment adherence as well as success (13–16). For healthcare professionals, meaningful empathic relationships can improve the sense of accomplishment and job satisfaction (8), while reducing stress and burnout (17–20), all of which are crucial for wellbeing. Given the high-stress working conditions of healthcare professionals and the associated negative outcomes such as exhaustion and burnout (21), the positive effects of empathic care are also essential in the context of protecting the healthcare system as a whole.

The myriad benefits of empathic engagement between healthcare professionals and patients highlight the need to develop and maintain empathy-related attitudes and competencies across all healthcare professional groups. Fortunately, empathy as we introduced it above, is a cognitive-behavioral attribute which can be developed through education (3, 6, 20, 22). Ideally, such education should begin early in training of healthcare professionals, with empathy-promoting elements to further nurture empathic care interspersed throughout the curriculum and beyond (23, 24). Since many healthcare profession students enroll in their courses to help others (3), it is crucial to capitalize on this teachable moment by incorporating empathy-promoting instruction early on. Further exposure to empathy education throughout training may increase competencies and prevent the drop in empathy observed in some healthcare professional students and in some contexts (25, 26). Reductions in empathy have been reported among medical students in the United States, the United Kingdom (27), New Zealand (28) and Iran (29), dental students in the United States (30) and Canada (31), nursing students in the United States (32) as well

as medical, dental and nursing students in Trinidad and Tobago (33). In Singapore, where the study described in this manuscript is conducted, previous research revealed no significant changes in empathy among medical students throughout their 5 years of training (34).

Some evidence on effective pedagogical strategies to cultivate empathy in healthcare professionals and students is available. Generally, these strategies focus on understanding people, their circumstances, and needs, and developing interpersonal skills (3). Despite the importance of empathy and the availability of pedagogies to develop it, empathy is usually not explicitly targeted in the curricula for healthcare professional students (20, 27, 35). Instead, opportunities to develop socio-cognitive attitudes and skills related to empathy are offered throughout the education journey. This reality is reflected in the research literature as studies primarily report on the effects of short to medium-term interventions such as workshops or training modules (20, 22, 36). Research on a more empathy-focussed curriculum spanning several semesters at the beginning of tertiary healthcare training is currently scarce.

The research is also limited by the fact that the available scientific literature on empathy interventions in healthcare professions students is primarily from high-income countries in North America and Europe (35). Relevant research from Asia is notably scarce, with a recent review (20) identifying only one such study, conducted in China (37). A later review focusing on qualitative aspects of empathy education interventions (38) identified another study, also from China (39). We are aware of only one relevant intervention study conducted in Singapore; this work involved an evaluation of a short empathy-training course for pharmacy students (40).

Lastly, intervention studies are typically conducted in students from a single healthcare discipline (20, 22, 36, 38). For instance, Winter's review (2020) identified only one study that included healthcare students from multiple disciplines (41). Relatedly, most studies focused on medical and nursing students, with less research on pharmacy students and very little on dental students (42).

We responded to the call for mixed-methods longitudinal intervention research on empathy in healthcare professions students (3, 6, 35) and conceived a study recruiting freshmen dentistry, medicine, nursing and pharmacy students at the National University of Singapore. The primary aim of our study is to examine the effects of consecutive courses of a novel Common Core Curriculum for healthcare professions students that emphasize understanding patients, communication, and other critical areas of professionalism on empathy. Our secondary aims are: (a) Examining the effects of the novel curriculum on intentions to provide empathic care, (b) Studying the association between engagement in courses of the novel Common Core Curriculum and empathy as well as intentions to provide empathy care, (c) Exploring perspectives on and experiences with courses of the new Common Curriculum in relation to empathy and patient care, and (d) Examining trajectories of empathy and intentions to provide empathy care beyond the novel Common Core Curriculum.

Materials and methods

The study involves multiple units within the National University of Singapore (NUS), including the Yong Loo Lin School of Medicine, the Alice Lee Centre for Nursing Studies, the Department of Pharmacy and Pharmaceutical Sciences and the Faculty of Dentistry.

We received ethics approval for this study from the Departmental Ethics Review Committee of the Saw Swee Hock School of Public Health, National University of Singapore (Ethics ID: SSHSPH-214).

Design

This study is a longitudinal intervention study without a control group. We will use a mixed-methods approach, utilizing both quantitative and qualitative data to achieve our research objectives (43). Such an approach has been advocated for in healthcare education research (44). It is also warranted to account for the complexity of evaluating educational programs in general. Quantitative data will provide insights into the potential effects of the intervention on predefined outcomes (i.e., empathy), while qualitative research will provide context. Additionally, qualitative data can inform teaching practice of subsequent iterations of the Common Core Curriculum to improve the educational impact related to empathy.

The study began in August of 2023 with the first wave of recruitment and will run for 6 years. Data collection time points are scheduled along the duration of the study programs: between 2 and 5 years depending on the program. Figure 1 provides an overview of the study, including information on study enrolment, delivery of intervention courses, and data collection time points as well as data collection methods.

Participants

Participants in this study are freshmen dentistry, medicine, nursing, and pharmacy students at the National University of Singapore. There are no other inclusion criteria. All students enrolled

in the respective programs will be invited to participate in this study ($n=900$ per Academic Year). Participant Information Sheets are provided to all eligible students interested in joining the study. Students must provide consent before formally enrolling in each component of the research.

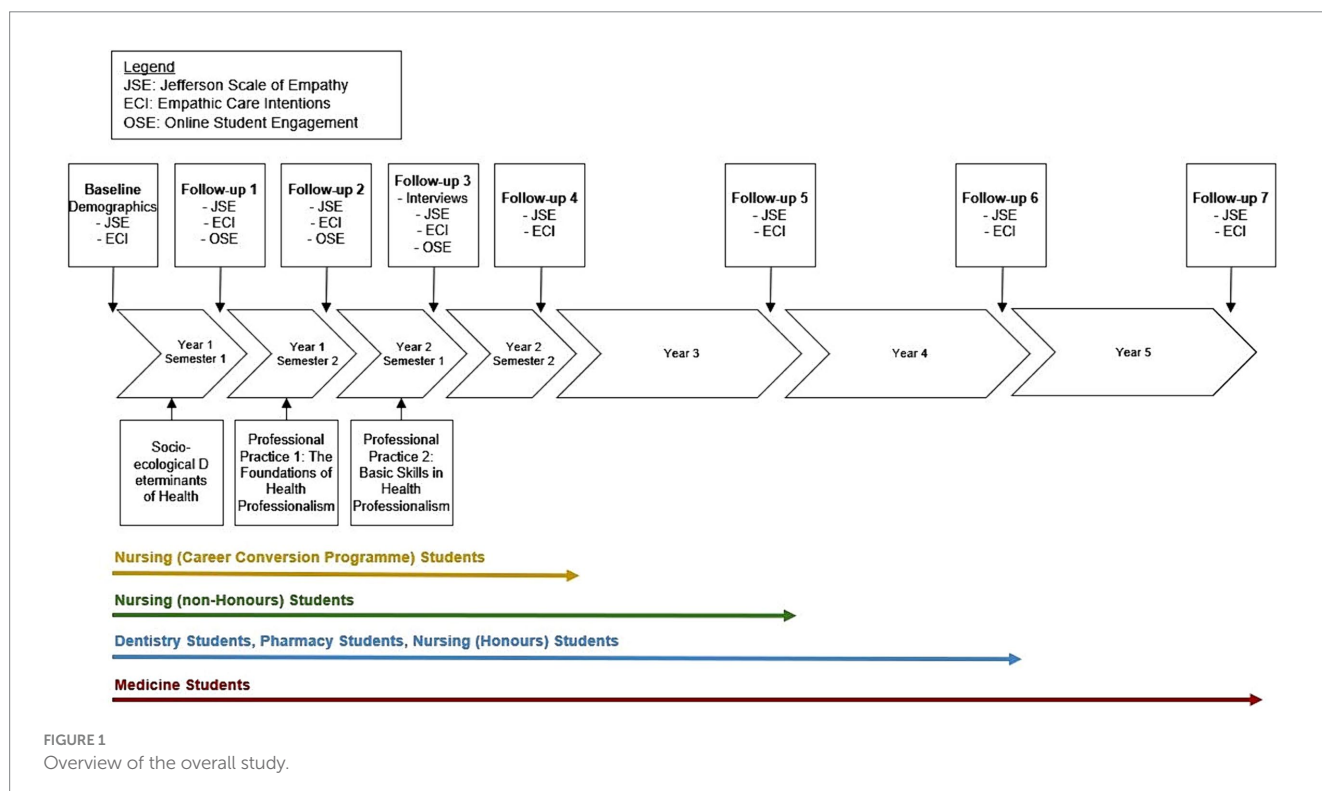
For the survey component, students will be enrolled in the study until their projected graduation. This means nursing, pharmacy and dentistry, and medical students will be enrolled for two to four, four, four and five years, respectively. For the interview component, a separate recruitment within the entire student cohort will be conducted, and consenting students will enroll for a single interview.

Intervention

Overview

The intervention comprises three consecutive courses of the Common Core Curriculum for Health Professions Students which was fully implemented in August 2023. Course 1 is called Socio-ecological Determinants of Health; Course 2 is called Professional Practice 1: The Foundations of Health Professionalism; Course 3 is called Professional Practice 2: Basic Skills in Health Professionalism. All freshmen dentistry, medicine, nursing and pharmacy students enroll together in Course 1 in Semester 1 of their healthcare training; Courses 2 and 3 are conducted in subsequent semesters. Each course spans one semester of 13 weeks.

The three courses are explicitly and implicitly designed to enhance empathy-related attitudes and skills in students. Considering the cognitive-behavioral attributes and skills required for empathic engagement and the evidence on how these could be developed in healthcare professionals and students (3, 6, 26), important goals of the



courses are to enhance students' understanding of patients, professional identity formation, and interpersonal skills. The courses are sequenced to progressively deepen students' understanding and skills related to empathy throughout their healthcare training. Course 1 focuses on understanding patients and their circumstances while Courses 2 and 3 are meant to develop interpersonal skills which are crucial to gain insights into patients and their lives (35). Various teaching and learning activities are designed to achieve the relevant goals in each course. In the next section we describe pedagogies implemented to develop empathy.

Pedagogies employed to develop empathy

Didactic training

Didactic training, commonly delivered in empathy development programs (26, 45) covers a range of topics that underscore the importance of empathy in healthcare professions. We introduce the socio-ecological view, communication strategies, ethical frameworks, and professional attributes. Collectively, these topics emphasize the need to understand and acknowledge the individuality of each patient, their circumstances, and perspectives to deliver effective care. Additional materials that reinforce the importance of empathy for healthcare professionals are also provided. Some evidence of efficacy of didactic training in this context is available (46).

Perspective taking exercises

To foster empathic understanding, we primarily use perspective taking exercises. These exercises involve scenarios such as personal stories or recorded encounters with healthcare professionals. Students are encouraged to imagine the experiences and feelings of the people involved, effectively stepping into their shoes. Additional strategies include reflecting on students' own experiences in healthcare settings, a concept known as the 'wounded-healer effect' (47). We also conduct role-playing activities to enhance perspective-taking capacity. For instance, students take on the roles of a healthcare professional who interview a patient struggling with a lifestyle behavior.

Taking the perspective of others not only builds capacity for understanding and empathizing with people who have diverse stories (48), but it also reduces the distance between patient and healthcare professional, laying the groundwork for empathic engagement. Studies involving healthcare professionals and students have provided evidence on the effects of perspective-taking exercises on empathic understanding and response (3, 49).

Communication and interpersonal skills training

Training in communication and interpersonal skills has frequently been linked to improvements in empathy among healthcare professions students (6, 20, 50). Our courses involve several aspects of communication training.

Understanding verbal and non-verbal expressions includes training students to listen, observe and recognize opportunities for empathic engagement. It also involves identifying the meanings of expressions such as change of gaze, silence and laughter. A common method for training is asking students to analyze patient-healthcare professional interactions.

Empathic communication tasks include activities where students are asked to communicate their understanding of the needs, concerns and feelings as expressed by others. This involves training of

non-verbal and verbal expression that communicate understanding and empathy. Additionally, we explore the impact of one's own personal biases and attitudes on the interpretation of a patient's needs.

Exposure to arts and literature

We provide students with access to some forms of literature and arts such as fiction, poetry, drama and other works. The purpose of such exposure is for students to gain insights into human experiences, emotions, perceptions, values and cultures, and to understand the many ways in which feelings and experiences can be expressed (51). For example, students can read about patients' complex emotional journeys through illness or the daily-life experiences of people with disabilities. Such stories are often less familiar to young students (52). Exposure to these materials, along with related reflective prompts, prepares students to listen to patients' stories with curiosity, take their perspective, and engage empathically (52, 53).

Reflective exercises

We incorporate various activities that require students to contemplate their approach or viewpoint on caring for people. Reflective exercises encourage students to be cognisant of their experiences and potential biases. Engaging students in empathic reflection has been used in various empathy development programs and interventions (54), and has shown to be important to empathy development (20, 46).

Empathy strategies and the three courses of the Common Core Curriculum

Course 1: Socio-ecological Determinants of Health

This course focusses on the socio-ecological factors that influence a person's health and wellbeing (55). The aim is to provide students with a solid understanding of the various circumstances that relate to people's health, and in doing so, develop empathy toward people in different situations. The premise of teaching the socio-ecological view is that knowledge of diverse factors impacting health, can motivate students to ask and listen carefully to fully understand the people they are serving. This understanding might also enable them to take the perspective of others. Students are also exposed to ways to support people based on their understanding of circumstances, feelings and experiences. Course 1 primarily focuses on the cognitive aspect of empathy, that is perspective taking. [Supplementary Table S1](#) introduces teaching and learning activities related to the development of empathy incorporated into Course 1.

Courses 2 and 3: Professional Practice 1 and 2

These courses focus on equipping students with core learning related to professional practice: ethical analytic skills, legal knowledge, communication and team working skills, and the required components for individual professional identity formation. The courses operate as two, sequential parts to provide a common foundation for all health professional students. Further learning in professional practice is then spiraled upwards in the remaining years of students' training, once they return to their uniprofessional educational contexts.

Developing empathy lies front and centre in these courses. Students are to develop an understanding of how empathy features as one core attribute of a healthcare professional's identity. To develop such an understanding, fundamentals of therapeutic relationships

with patients are explored through observation of recorded interactions with real patients, among others.

Furthermore, students are encouraged to act with empathy in the undertaking of specific learning activities; particularly regarding how they conduct themselves as learners in the classroom and within learning groups. In this sense, the premise of developing a basic understanding of professional practice is to cultivate certain attributes in how students behave in their learning roles. In this way, we expect students to develop the cognitive dimensions of empathy, taking the perspective of a future healthcare practitioner and understanding what empathy demands in that role.

Lastly, behavioral aspects of empathy are expected to develop through interpersonal communication training elements. This involves discussing biases that could inhibit empathic relationships and how to overcome these. Additionally, verbal and nonverbal communication techniques that enable empathic interactions are introduced and practiced. [Supplementary Table S2](#) introduces teaching and learning activities related to the development of empathy incorporated into Course 2.

Data collection—survey questionnaire

Survey questionnaire data will be collected at baseline and at various other time points: following the conclusions of Courses 1, 2 and 3, and annually until student graduation. Students will self-administer the instruments through the online platform, Qualtrics.

Demographic information

At baseline, we collect the following demographic information from study participants: course of study, gender (male, female, other), age in years, ethnicity (Chinese, Indian, Malay, Other), and housing type as a proxy for socio-economic status of the family (private property or large government housing unit, to medium size government housing unit, small-size government housing unit).

Empathy

The primary outcome of our study is cognitive empathy, as measured by the Jefferson Scale of Empathy, Healthcare Professions Student version (JSE-HPS). It appears to be the only available instrument designed specifically to measure empathy among healthcare professions students that is psychometrically sound (3). It is also the most commonly used instrument in this context (35). After conducting face and content validity assessments, the developers performed psychometric testing on a generic version intended for medical students. Using a sample of medical students, they established criterion validity, and the internal consistency was found to be desirable with a Cronbach's alpha coefficient of 0.87 (56). Based on the generic version, three versions of the JSE were developed to allow administration in different populations: medical students, physicians and other healthcare professionals, and healthcare profession students. The psychometric properties of all versions were found to be reasonably comparable across locations (3). The JSE for medical students has been utilized in Singapore (34).

The JSE-HPS has been validated and used in students of various healthcare professions across geographical locations, including Asia (57–61). Students need to respond to 20 items using a 7-point Likert scale ranging from strongly disagree to

strongly agree. To ensure the validity of responses, half of these items are negatively worded. The instrument measures three factors related to cognitive empathy: Perspective Taking-10 items, Compassionate Care-8 items, Standing in Patient's Shoes-2 items. The JSE-HPS has been utilized in pharmacy students in Singapore (40).

To measure students' intentions to provide empathic care, we drew from two existing instruments. First, the 12-item Reynolds Empathy Scale was developed in the United Kingdom for the nursing context (62). Scale development was based on patients' perceptions of nurses' behaviors that are helpful and unhelpful in showing empathy. Validity and reliability has been examined in terms of encounters with nurses (63, 64). Second, the 10-item CARE measure was developed to allow patients to assess their healthcare professionals' empathic engagement (65, 66). The validity and internal consistency have been established in the United Kingdom (for medical doctors) by the developers of the instrument (66).

We developed our 7-item instrument as follows. First, we chose items that are directly related to key behavioral aspects of empathy as per the empathy definition introduced earlier (3). These are trying to understand patients (i.e., exploring feelings, giving space to communicate, listening; 3 items), communicating understanding (1 item) and acting upon understanding (i.e., ignoring feelings and views when providing care, support based on needs, focus only on data and facts; 3 items). Second, we used the stem 'when I work as a healthcare professional, I will/want to' to indicate future-directed self-assessment (i.e., intentions). Third, we adopted a 7-point Likert scale ranging from strongly disagree to strongly agree to align answering options with the JSE-HPS and allow for more granularity. An example item reads 'When I work as a healthcare professional, I want to give patients space to tell their stories.'

Engagement in teaching and learning activities

Following each of the three courses, we administer an instrument to assess students learning engagement in various domains. The importance of engagement beyond the cognitive domain to achieve significant learning has been described (67, 68). For example, connecting with fellow learners can raise confidence and contribute to more positive attitudes toward a course. This, in turn, can raise the emotional desire to learn, resulting in more time and effort being invested in engaging with learning materials, ultimately impacting learning outcomes (69–71). Some suggestive evidence for the link between engagement and empathy has been reported in the context of medical students' learning communities (72). Researchers observed that valuing aspects of social, collaborative and behavioral engagement was associated with empathy. As such, engagement in one or more domains may impact the development of empathy.

We drew 12 items from the Online Student Engagement Scale (OSE) and made minor modifications for our purpose (73). The instrument will enquire about the following domains of learner engagement: behavioral and cognitive engagement (learning efforts-5 items), emotional engagement (interest and commitment-4 items), social and collaborative engagement (contributing and connecting-3 items). Students will assess how well certain behaviors, thoughts and feelings describe them in relation to each course on a 5-point Likert scale ranging from 'describes me perfectly' to 'does not describe me at all'. An example item reads 'Participating actively in group-project discussions.' Validity and internal consistency ($\alpha=0.91$) of the

OSE are satisfactory as assessed in university students in the United States.

Free-text items

During data collection following each of the three courses under investigation, we include an open-ended question inviting students to share how the courses have impacted their views and skills around patient care. Survey questionnaires for Follow-ups 4–7 include the following open-ended question: ‘What makes a good healthcare professional, please describe.’ Free-text responses are meant to provide some context to the quantitative findings.

Sample size and data analysis—survey questionnaires

Sample size calculation

We conducted sample size calculations to estimate the number of participants required for an adequately powered analysis of the effect of the three courses under investigation on empathy as measured with the JSE-HPS. Considering a small effect size of 0.2 (20), a power of 80% and a two-tailed significance level of 0.05 we would need 199 participants at Follow-up 3. To account for an expected significant drop-out of >50% over time we aim to recruit 400 students into the study.

Data analysis

To estimate the overall effect of the three courses on empathy and empathic care intentions across all students, we plan to conduct within-group t-tests. Repeated measures ANOVAs are planned to investigate the interactions between time and socio-demographic variables as well as engagement in teaching and learning activities on empathy and empathic care intentions. Significant interaction effects will be followed up with post-hoc tests and simple effects analysis as appropriate. Significant main effects will be followed up with post-hoc tests. The significance level will be set at 0.05. Data will also be plotted to visualize the results.

Free-text comments will be analyzed using qualitative thematic analysis (74). We will employ an inductive approach allowing the data to guide the generation of categories, themes and subthemes. We will first familiarize ourselves with the data by reading responses multiple times. Following this, we will conduct open coding of responses to capture all relevant content. We will then organize the codes into categories based on the overall topic they reflect. Within categories, we will identify themes and subthemes before crafting a narrative that will be supported by excerpts from the responses.

Data collection—interviews

Interview procedures and reporting were guided by the Consolidated Criteria for Reporting Qualitative Research (COREQ) checklist (75).

Experienced qualitative researchers working in the healthcare or education sector will conduct semi-structured interviews following the completion of Course 3, marking the end of the Common Core Curriculum. Utilizing a pre-piloted interview guide, open-ended questions and prompts will be used to explore three broad areas with research participants: reasons for selecting their healthcare profession and experiences with the study program, perceptions and skills pertaining to patient care and empathy, and the contributions of the

Common Curriculum courses on perceptions and skills related to patient care and empathy. Throughout the data collection period, the interview guide will be iteratively refined to explore emerging themes and topics previously not considered.

Interviews will be conducted in English via widely used videoconferencing platforms such as MS Teams or Zoom. Interviews will be audio-recorded using platforms built-in features. Field notes of interviews will supplement the audio recordings.

Sampling

We will employ a purposive sampling strategy to ensure diversity in experiences and perspectives are captured. We aim to recruit dentistry, medicine, nursing and pharmacy students until saturation is achieved within each student group. We project that 30 students in total will be sufficient. However, we are mindful that more participants may be needed to draw a rich picture.

Data analysis

Verbatim transcripts of interviews will be used for a primarily inductive thematic analysis (74). Briefly, following line-by-line coding of transcripts, we will develop and iteratively refine broad analytical categories, within which we will identify themes and subthemes. Representative quotes from participants will be selected to illustrate the findings. Depending on the data, we will highlight differences of themes and subthemes across students from different programs.

Conclusion

Empathy as a cognitive-behavioral attribute is important across healthcare disciplines and should be developed throughout tertiary healthcare training. Pedagogical strategies to do this are widely available and most scientific studies point to desirable effects when such strategies are being examined, often in isolation (35). Researchers also suggest that empathy-related education is acceptable to healthcare professions students with many reporting related instruction to be valuable. Unfortunately, many curricula lack a distinct focus on developing the essential socio-cognitive competency of empathy, leaving much to be desired (35). This observation prompted a growing number of educators and education researchers to call for a meaningful integration of empathy training into the curriculum so as to nurture healthcare professionals who have the skills to cure, but also the attitudes and competencies to care (76–78).

With the mixed-methods longitudinal intervention study described in this manuscript, we will examine the effects of three consecutive courses of a novel Common Core Curriculum for Healthcare Professions Students on empathy in freshmen dentistry, medicine, nursing and pharmacy students enrolled at the National University of Singapore. Findings will provide insights into the potential of integrating empathy-related education into the curriculum for healthcare professions students and inform us about iterative changes we might need to make to enhance an anticipated impact.

Author contributions

AM: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original

draft. NN: Methodology, Writing – review & editing. MD: Methodology, Writing – review & editing. DS: Conceptualization, Methodology, Writing – review & editing. BG: Methodology, Writing – review & editing. CG: Methodology, Writing – review & editing. AT: Conceptualization, Methodology, Project administration, Writing – review & editing. JL: Conceptualization, Investigation, Methodology, Resources, Writing – review & editing. W-PY: Formal analysis, Supervision, Writing – review & editing. LL: Conceptualization, Investigation, Methodology, Writing – review & editing. PG: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Collaborative teaching among ultrasonographers, anesthesiologists, and vascular surgeons: its unique role in specialty training for vascular surgeons in developing countries

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This study explored the unique role of collaborative teaching among ultrasonographers, anesthesiologists, and vascular surgeons in the training of vascular surgeons in developing countries. Using qualitative research methods, data were collected through in-depth interviews and observations to analyze the improvement in ultrasound operational skills and basic anesthesia skills among trainees, as well as their satisfaction with collaborative teaching. The results indicate that collaborative teaching significantly enhances trainees' professional skills and interdisciplinary collaboration abilities, gaining widespread recognition from trainees. This teaching model provides trainees with a comprehensive learning experience through interdisciplinary cooperation, hands-on practice, contributing to the cultivation of vascular surgeons with comprehensive qualities and professional competencies. This study offers new ideas and methods for the training of vascular surgeons in developing countries, holding significant implications for the development of medical education.

KEYWORDS

collaborative teaching, training of vascular surgeons, developing countries, ultrasound technology, anesthesia skills, interdisciplinary cooperation

1 Introduction

With the rapid development of global medical technology, the field of vascular surgery has undergone unprecedented changes. From initially relying primarily on hemostasis and basic open surgery methods to the widespread application of minimally invasive techniques such as in endovascular surgery, the treatment modalities in vascular surgery have achieved a qualitative leap (1). Simultaneously, the application of 3D printing technology in vascular surgery has provided new solutions for surgical planning and simulations (2). Especially in the 21st century, these changes have become even more pronounced, not only improving the precision and safety of surgeries but also bringing better treatment outcomes and quality of life to patients. However, the widespread application of these advanced technologies and equipment also poses a series of challenges, particularly for developing countries with relatively limited medical resources.

In developing countries, due to insufficient hardware facilities and constraints on medical costs, many hospitals may not be able to equip themselves with expensive Digital Subtraction Angiography (DSA) operating rooms or other high-end medical equipment. This results in doctors facing different conditions and limitations when dealing with the same medical issues. Therefore, how to improve the clinical skills and professional competence of vascular surgeons under limited resources has become an important issue before us.

Ultrasound technology, as a non-invasive and relatively low-cost diagnostic and therapeutic tool, holds unique advantages in the field of vascular surgery. It plays a crucial role not only in the diagnosis of vascular surgical diseases but also as an essential guidance tool during surgery, helping doctors accurately locate vascular lesions, assess blood flow conditions, and guide surgical operations (3, 4). Additionally, ultrasound holds irreplaceable value in post-surgical monitoring. Through postoperative ultrasound examinations, doctors can conveniently and promptly evaluate surgical outcomes, observe the healing of surgical sites, and detect and manage postoperative complications (5).

In vascular surgery, nerve block anesthesia is a commonly used anesthesia method. Examples include femoral nerve block in lower extremity vascular surgery and brachial plexus block in upper extremity arterial thrombectomy (6). Ultrasound-guided nerve block anesthesia can accurately locate the target nerve and inject local anesthetics around the nerve under direct vision, thereby effectively blocking nerve impulse conduction and achieving anesthesia. Compared with traditional nerve block methods, ultrasound-guided nerve block anesthesia has higher success rates and safety, and can reduce the dosage of local anesthetics and the risk of nerve damage. However, vascular surgeons often lack the skills for simple nerve block anesthesia and often require the assistance of anesthesiologists. Mastering these skills, however, would enable surgeons to perform certain simple surgeries without the presence of anesthesiologists, thereby reducing staffing requirements and medical expenses for patients. This is particularly crucial for hospitals in low- and middle-income countries with limited medical resources.

Despite the widespread application of ultrasound technology in vascular surgery, many vascular surgeons, especially those in primary hospitals, still lack proficiency in ultrasound operation skills and basic anesthesia skills based on ultrasound (7). This limitation, to a certain extent, constrains their ability to independently handle cases in clinical practice. Therefore, exploring an effective training model to enhance the ultrasound operation skills and basic anesthesia skills of vascular surgeons has become an urgent issue.

Against this backdrop, we propose this collaborative teaching research. Collaborative teaching, a method where professionals from different disciplines work together to educate trainees, has gained recognition for its potential to enhance healthcare education and improve patient care quality (8). This method leverages the diverse expertise of various professionals to provide a more comprehensive and practical learning experience for trainees. In the context of vascular surgery training, especially in developing countries, the integration of ultrasonographers, anesthesiologists, and vascular surgeons through collaborative teaching can address critical gaps in resources and expertise.

In many developing low- and middle-income countries (LMICs), healthcare systems often face significant challenges, including limited resources and a shortage of specialized medical professionals (9). The World Health Organization (WHO) has highlighted the importance of task shifting and collaborative approaches in these

settings to maximize the use of available resources and enhance the quality of care (10, 11). Task shifting involves delegating tasks traditionally performed by specialized professionals to those with less training but adequate skills, thereby optimizing the workforce's efficiency (12).

The aim of this study is to evaluate the effectiveness of collaborative teaching among ultrasonographers, anesthesiologists, and vascular surgeons in the specialty training of vascular surgeons in developing countries. Specifically, we sought to determine the impact of this teaching method on trainees' skills in ultrasonography and anesthesia, as well as their overall satisfaction with the training program.

Objectives of the study include:

- 1 Assessing the improvement in ultrasonography skills among vascular surgery trainees.
- 2 Evaluating the enhancement of basic anesthesia skills in the trainees.
- 3 Measuring the trainees' satisfaction with the collaborative teaching approach.
- 4 Identifying the benefits and challenges associated with implementing collaborative teaching in vascular surgery training programs in developing countries.

By addressing these objectives, we aim to provide evidence on the feasibility and effectiveness of collaborative teaching as a strategy to improve the training and capabilities of vascular surgeons in resource-limited settings.

2 Methods

2.1 Study aim and objectives

The aim of this study is to evaluate the effectiveness of collaborative teaching among ultrasonographers, anesthesiologists, and vascular surgeons in the specialty training of vascular surgeons in developing countries. The objectives are to assess improvements in ultrasonography and basic anesthesia skills among trainees, measure their overall satisfaction, and identify the benefits and challenges of implementing this teaching approach.

2.2 Research design

This study employed a mixed-methods approach with a pre-test post-test quasi-experimental design, without a control group. The design was chosen to measure the impact of the collaborative teaching intervention on trainees' skills and satisfaction levels.

2.3 Participants

The participants were vascular surgery trainees from developing country, affiliated with the Department of Vascular Surgery at Sichuan Provincial People's Hospital in Chengdu, China.

Inclusion criteria were:

- 1 Enrollment in a vascular surgery training program.

- 2 Willingness to participate in the study and provide informed consent.

Exclusion criteria included:

- 1 Previous extensive training in ultrasonography or anesthesia.
- 2 Inability to attend the entire training program.

A total sample population of 30 trainees was recruited, with 30 completing the study.

2.4 Recruitment methods

Participants were recruited through announcements at medical institutions. Interested trainees completed a screening questionnaire to confirm eligibility.

2.5 Pre-test post-test quasi-experimental design

Participants underwent pre-test and post-test assessments to evaluate their baseline skills in ultrasonography and anesthesia and to measure any improvements following the intervention. The assessment process involved both theoretical exams and practical operations tailored specifically for the trainees' level of knowledge and experience in vascular surgery.

2.5.1 Skill assessment tests

2.5.1.1 Ultrasound skills assessment

The ultrasound skills assessment was designed to evaluate trainees' proficiency in basic ultrasound operation techniques and image interpretation relevant to vascular surgery. The test included both a written component, covering ultrasound principles and vascular anatomy, and a practical component, where trainees were asked to perform ultrasound scans on standardized phantoms or volunteer patients under supervision. A standardized scoring system was developed based on the ability to correctly identify anatomical structures, manipulate the ultrasound machine, and interpret images accurately. This scoring system was reviewed and validated by a panel of experienced ultrasonographers prior to the study.

2.5.1.2 Anesthesia skills assessment

The anesthesia skills assessment focused on trainees' knowledge and proficiency in basic anesthesia techniques, particularly nerve block anesthesia relevant to vascular surgeries. Similar to the ultrasound assessment, this test comprised both a written exam covering anesthesia principles, local anesthetic agents, and procedural steps, as well as a practical component where trainees performed simulated nerve blocks under the supervision of anesthesiologists. The scoring system was also standardized and validated by a team of anesthesiologists experienced in teaching and assessing anesthesia skills.

These assessments were designed to be challenging but achievable for trainees with varying levels of experience, ensuring that improvements in skills could be accurately measured over the course of the intervention. The lack of a control group is acknowledged as a

limitation affecting internal validity but was necessary due to practical constraints.

2.6 Data collection tools

Data collection involved tests, questionnaires, and interviews. These instruments were developed by the research team and validated through pilot testing. The tests assessed practical skills, while the questionnaires gathered demographic information and satisfaction levels. Interviews provided qualitative insights into the trainees' experiences.

2.6.1 Examples of data collection tools

- 1 Skill assessment test: A practical test to measure proficiency in ultrasonography and basic anesthesia techniques.
- 2 Satisfaction questionnaire: A Likert-scale questionnaire assessing trainees' satisfaction with the collaborative teaching approach.
- 3 Interview guide: A semi-structured guide for conducting qualitative interviews with participants. We conducted in-depth interviews with the participating ultrasonographers, anesthesiologists, and vascular surgeons. The interview content primarily focused on their views on collaborative teaching, experience sharing, and suggestions for future teaching. Through these interviews, we aimed to gain a deeper understanding of the actual operation and potential issues of collaborative teaching, providing a basis for subsequent improvement and optimization.

2.7 Inter-rater reliability and baseline assessments

To ensure inter-rater reliability, multiple assessors were trained to use standardized criteria for evaluating skills. Baseline assessments were conducted by experienced faculty members using predefined criteria for ultrasonography and anesthesia skills.

2.8 Curriculum delivery timetable

An example timetable for the curriculum delivery was as follows:

Week 1–2: Intensive workshops on ultrasonography and anesthesia basics.

Week 3–4: Hands-on practice sessions under supervision.

Week 5–6: Case studies and collaborative problem-solving exercises.

2.9 Teaching implementation and case presentation

During the teaching implementation phase, we designed a systematic collaborative teaching curriculum. The curriculum content includes but is not limited to ultrasound operation techniques, image interpretation, diagnostic thinking, nerve blocks, and local anesthesia skills. We utilized various teaching methods such as case analysis, hands-on practice and

group discussions, and simulated surgeries to enhance the trainees' practical operation abilities and interdisciplinary collaboration skills.

During the teaching process, the ultrasonographers were responsible for teaching ultrasound operation techniques and image interpretation skills to ensure that trainees could master the usage of ultrasound equipment and image interpretation techniques. The anesthesiologists taught nerve block and local anesthesia techniques to help trainees grasp the key points of anesthesia management during surgery. The vascular surgeons integrated ultrasound and anesthesia knowledge, guiding trainees in practical operations and surgical simulations to improve their clinical practice abilities and interdisciplinary collaboration skills.

2.9.1 Case presentation

Taking lower extremity varicose veins, the most common surgical disease in vascular surgery, as an example. During high ligation and stripping surgery of the great saphenous vein, femoral nerve block anesthesia can be performed under ultrasound guidance, thus replacing general anesthesia or spinal anesthesia. This enables the surgeon to complete the surgery independently. The specific implementation process and effects of this training model can be described in detail as follows. Firstly, the ultrasonographer uses ultrasound equipment to locate the target femoral nerve, explains the regional structures in the images, and enables learners to clearly understand the specific meanings of the ultrasound images, identifying the femoral nerve, femoral arteriovenous, muscle tissue, and possible variations. Then, under the guidance of the ultrasonographer, the anesthesiologist performs the nerve block, explaining the ratio of local anesthetics, dosage, drug delivery techniques, and methods for managing possible complications. Finally, the vascular surgeon instructor performs high ligation and stripping surgery on the great saphenous vein, explaining and guiding the entire process. This collaborative teaching model allows learners to learn and master ultrasound-guided femoral nerve block techniques through practical operations. They can then independently complete high ligation and stripping surgery of the great saphenous vein without the involvement of ultrasonographers and anesthesiologists, which is particularly significant for hospitals in rural areas or developing countries lacking equipment and medical personnel.

2.10 Analysis methods and software

Quantitative data were analyzed using GraphPad Prism software, employing statistical tests such as paired t-tests to compare pre- and post-test scores. For the interview content, we conducted thematic analysis, summarizing and extracting the interviewees' viewpoints and suggestions to identify the characteristics, advantages, and potential issues and improvement directions of collaborative teaching.

3 Results

3.1 Participant demographics

A total of 30 trainees were recruited for this study, including 6 vascular surgery interns, 18 resident physicians, and 6 specialist doctors. The average age of the trainees was 27.3 years old, with males accounting for 83.3% and females accounting for 16.7%. Their professional experience in vascular surgery ranged from 0 to 10 years.

3.2 Improvement in trainees' skills

By comparing the skill test data of trainees before and after teaching, we found significant improvements in their ultrasound operation skills and basic anesthesia skills. The following Table 1 details the skill improvements of the trainees:

For the ultrasound and anesthesia skills assessments, we specifically designed scoring systems that took into account the training objectives and the knowledge and experience levels of the trainees. These systems aim to comprehensively evaluate the proficiency of trainees in their respective skills and ensure consistency in scoring across all participants.

3.2.1 Ultrasound skills assessment scoring system

3.2.1.1 Written component (50% of total score)

This part assesses trainees' knowledge of ultrasound principles, vascular anatomy, and basic ultrasound machine operation. It consists of multiple-choice and single-choice questions. Each correct answer is awarded a fixed number of points, with a maximum of 50 points achievable.

3.2.1.2 Practical component (50% of total score)

The practical component evaluates trainees' ability to correctly identify anatomical structures, manipulate the ultrasound machine, and interpret images accurately. The assessment is conducted on volunteer patients under supervision. The scoring criteria include:

- 1 Accurate identification of anatomical structures (e.g., vessels, muscles, nerves).
- 2 Proper machine settings and manipulation (e.g., depth, gain adjustments).
- 3 Clear and accurate image interpretation.
- 4 Time taken to complete the task.

A standardized checklist is used to score the practical component, with a maximum of 50 points achievable.

3.2.2 Anesthesia skills assessment scoring system

3.2.2.1 Written component (50% of total score)

Similar to the ultrasound assessment, this part evaluates trainees' knowledge of anesthesia principles, local anesthetic agents, procedural steps, and possible complications. It comprises multiple-choice and single-choice questions, with a maximum of 50 points achievable.

3.2.2.2 Practical component (50% of total score)

The practical assessment focuses on trainees' proficiency in performing simulated nerve blocks under ultrasound guidance. The assessment criteria encompass:

- 1 Correct selection and preparation of equipment and medications.
- 2 Accurate localization of the target nerve under ultrasound guidance.
- 3 Appropriate injection technique and local anesthetic spread.
- 4 Ability to manage potential complications.

TABLE 1 Students' skill improvement status.

Skill	Pre-teaching skill score (N = 30)	Post-teaching skill score (N = 30)	Skill improvement score (N = 30)	R square	p
Ultrasound skills	39.03 ± 2.093	72.67 ± 1.674	33.63 ± 2.680	0.8516	<0.0001
Anesthesia skills	39.03 ± 1.782	73.00 ± 1.165	33.97 ± 2.129	0.9299	<0.0001

TABLE 2 Statistical analysis results of skill improvement among different professional experience groups.

Analysis item	Group	Mean improvement in ultrasound skills	Mean improvement in basic anesthesia skills	Significant difference (p-value)
Descriptive statistics	Interns group	50.00	35.00	–
	Residents group	30.50	36.00	–
	Fellow doctors group	22.50	30.00	–
ANOVA	Improvement in ultrasound skills	–	–	0.001* (Interns vs. fellow doctors)
	improvement in basic anesthesia skills	–	–	0.256 (No significant difference)

A standardized checklist is used to score the practical component, with a maximum of 50 points achievable.

Prior to the study, both scoring systems were reviewed and validated by panels of experienced ultrasonographers and anesthesiologists, respectively, to ensure their reliability and validity.

The statistical analysis results of skill improvement among different professional experience groups (Table 2) indicate that: 1. the ultrasound skills and basic anesthesia skills of each professional experience group have been significantly improved after the training, and 2. ANOVA results show that there is a significant difference in the improvement of ultrasound skills between the Interns group and the Fellow Doctors group ($p=0.001$). This may be related to their lower skill levels before the training, which provided them with greater potential for improvement. There is no significant difference in the improvement of basic anesthesia skills among the groups ($p=0.256$).

3.3 Trainee satisfaction evaluation

The results of the questionnaire survey revealed that trainees were satisfied with the collaborative teaching model. The following Table 3 summarizes the trainees' satisfaction evaluation of collaborative teaching:

3.4 Characteristics and advantages of collaborative teaching

Through thematic analysis of the in-depth interviews with the participating ultrasonographers, anesthesiologists, and vascular surgeons, we have identified the following characteristics and advantages of collaborative teaching:

- 1 Interdisciplinary cooperation: Collaborative teaching integrates knowledge and skills from multiple disciplines such as ultrasound, anesthesia, and vascular surgery, enabling interdisciplinary cooperation and exchange.
- 2 Strong practical orientation: The teaching process emphasizes hands-on practice and simulated surgeries, allowing trainees to experience and learn firsthand, thus enhancing their clinical practice abilities.

TABLE 3 Students' satisfaction evaluation of collaborative teaching.

Satisfaction evaluation	Number of respondents	Percentage
Very satisfied	20	67%
Satisfied	8	27%
Neutral	1	3%
Dissatisfied	1	3%

- 3 Positive feedback from trainees: Trainees generally express that the collaborative teaching model helps improve their professional skills and interdisciplinary collaboration abilities, and they are satisfied with the teaching effect.

These characteristics and advantages demonstrate the unique role and value of collaborative teaching in training vascular surgeons in developing countries. In the future, we can further promote and optimize this teaching model to enhance the quality and effectiveness of vascular surgeon training.

4 Discussion

This study delved into the unique role and value of collaborative teaching in training vascular surgeons in developing countries through its implementation. In the results section, we presented significant improvements in trainees' ultrasound operation skills and basic anesthesia skills, along with their satisfaction evaluations of collaborative teaching. These data provide compelling evidence supporting the effectiveness of the collaborative teaching model in vascular surgeon training.

Collaborative teaching has been increasingly recognized as an effective educational approach in various healthcare disciplines (13). Recent studies have demonstrated its potential to enhance learning outcomes, improve interprofessional collaboration, and optimize the use of limited resources, particularly in developing low- and middle-income countries. The World Health Organization (WHO) has emphasized the importance of task shifting and collaborative approaches to address the shortage of

specialized healthcare professionals in low- and middle-income countries (11, 14).

Task shifting involves reallocating tasks from highly trained health workers to those with less training but sufficient skills. This strategy has been shown to enhance workforce efficiency and improve healthcare delivery (15, 16). For example, a study by Callaghan, Ford, and Schneider systematically reviewed task-shifting initiatives for HIV treatment in Africa and found significant improvements in patient outcomes and healthcare accessibility (17). Similarly, Mullan and Frehywot highlighted the effectiveness of non-physician clinicians in sub-Saharan Africa in addressing the healthcare workforce crisis (18).

In the context of vascular surgery training, integrating ultrasonographers, anesthesiologists, and vascular surgeons through collaborative teaching can significantly enhance trainees' skills and knowledge. Previous studies have shown that interprofessional education (IPE) can improve communication, teamwork, and clinical competencies among healthcare trainees (19, 20). However, the application of collaborative teaching in vascular surgery training remains underexplored. Our study aims to fill this gap by evaluating the impact of a collaborative teaching model on the skills and satisfaction of vascular surgery trainees in developing countries.

The critical appraisal of the literature indicates that while task shifting and collaborative approaches are beneficial, their implementation requires careful planning and support. Challenges such as resistance to change, the need for standardized training, and ensuring the quality of care must be addressed (10, 16).

Our study contributes to the growing body of evidence supporting collaborative teaching in healthcare education. It provides insights into its feasibility and effectiveness in resource-limited settings and offers recommendations for future research and practice.

Firstly, the collaborative teaching model integrates knowledge and skills from multiple disciplines such as ultrasound, anesthesia, and vascular surgery through interdisciplinary cooperation and exchange. This integration not only enables trainees to comprehensively grasp relevant knowledge in the field of vascular surgery but also provides them with opportunities to collaborate with doctors from different professional backgrounds. In clinical practice in vascular surgery, interdisciplinary cooperation is crucial. For example, during complex vascular surgeries, ultrasonographers can provide precise vascular images and blood flow information, anesthesiologists ensure the stability of patients' vital signs, and vascular surgeons formulate surgical plans and perform surgeries based on this information. Through collaborative teaching, trainees can develop a sense of interdisciplinary collaboration during their learning process, laying a solid foundation for their future clinical practice.

Secondly, the collaborative teaching model emphasizes hands-on practice, allowing trainees to experience and learn firsthand. This teaching method is more engaging than traditional theoretical lectures, stimulating trainees' interest and enthusiasm for learning (21). Through practical operations, trainees can gain a deeper understanding of theoretical knowledge, master operational skills, and enhance their clinical practice abilities (22).

Moreover, trainees' satisfaction evaluations of collaborative teaching indicate that this teaching model meets their learning needs and improves their professional skills and interdisciplinary collaboration abilities. Trainees generally express that through collaborative teaching, they have not only acquired more knowledge and skills but also learned how to collaborate with doctors from other

professional backgrounds, enhancing the efficiency and quality of clinical work. The positive feedback on this teaching model provides valuable experience and insights for our future teaching work.

Finally, the collaborative teaching model is particularly significant for developing countries, where access to advanced medical equipment and professional technology is often limited (10, 16). By training vascular surgeons in ultrasound techniques, image interpretation, and anesthesia skills, this approach equips them with essential tools and skills to provide more comprehensive and effective treatment for patients under limited equipment and human resources. Additionally, promoting interdisciplinary collaboration enables trainees to effectively work with multidisciplinary teams, improving the overall quality of treatment in these countries (23).

However, this study also has some limitations. Firstly, due to time and resource constraints, the number of trainees recruited was limited, which may affect the generalizability of the results. Future studies can expand the sample size to further validate the effectiveness of the collaborative teaching model. Secondly, this study primarily employed qualitative research methods, which can deeply explore the characteristics and advantages of collaborative teaching but lack quantitative data support. Future studies can combine quantitative research methods to collect more data for analysis and validation.

5 Conclusion

The collaborative teaching model plays a unique role and value in training vascular surgeons in developing countries. Through interdisciplinary cooperation and exchange, emphasis on hands-on practice and simulated surgeries, and positive feedback from trainees, this teaching model can comprehensively improve trainees' professional skills and interdisciplinary collaboration abilities. In the future, we can further promote and optimize this teaching model to cultivate more outstanding vascular surgical talents in developing countries, providing patients with higher-quality and more efficient medical services. Simultaneously, we need to pay attention to the limitations and deficiencies of the study, continuously improving and refining research methods and approaches to promote the continuous development and progress of medical education.

To maximize the benefits and overcome the challenges associated with this teaching model, the following recommendations are proposed: Medical institutions should provide strong support for the implementation of collaborative teaching models, including administrative backing and resource allocation. Developing standardized training protocols and guidelines can ensure consistency and uniformity in the delivery of training across different sessions and instructors. Regular assessment and feedback mechanisms should be established to monitor the progress of trainees and the effectiveness of the training program, allowing for timely adjustments and improvements. Training programs for faculty members should be conducted to familiarize them with the collaborative teaching model and address any resistance to change. This can help in creating a supportive and conducive learning environment. Organizing interdisciplinary workshops and seminars can further enhance communication, teamwork, and mutual understanding among different specialties, fostering a culture of collaboration. Finally, the collaborative teaching model should be designed to be scalable and adaptable to different contexts and settings, allowing for broader implementation and impact.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the ethical requirements of the research Ethics Committee of Sichuan Provincial People's Hospital. Written informed consent to participate in this study was provided by the participants.

Author contributions

PZ: Data curation, Writing – original draft. MZ: Writing – original draft. QZ: Investigation, Supervision, Writing – original draft. WH: Writing – review & editing.

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Use of an electronic portfolio for longitudinal assessment of personal and professional development in undergraduate medical education

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Introduction

Assessing the professionalism competency in undergraduate medical education

Contemporary medical education is increasingly competency-based and requires a curricular framework to support individual students' professional identity formation concurrently with defined and benchmarked competencies (1, 2). The transition to a competency-based curriculum requires both longitudinal and integrated assessments (Schmude et al., unpublished),¹ which are challenging to deliver on an individual level (2–4). Much has been written regarding the evaluation of professionalism, especially among medical students and residents (5). Expert consensus about professionalism assessment is that “Professionalism should be assessed longitudinally. It requires combinations of different approaches, assessing professionalism at individual, interpersonal, and societal/institutional levels” (6). The challenge to medical educators in the longitudinal assessment of professionalism involves integrating a large and dispersed amount of data into an organized and easily accessible format (7, 8, 29, 30). Our work focuses on promoting adult learners' professional identity formation through a longitudinal Personal and Professional Development curriculum in undergraduate medical education.

ePortfolios in higher education and medical education

ePortfolios have been identified as a high-impact practice for education and are widely used by colleges and universities in the United States (9). Developing an ePortfolio allows adult learners to cultivate their skills as master learners and participate actively in their education, a key tenet of adult learning theory (11). The Association of American Colleges and Universities has worked to promote the value of portfolios in

1 Schmude, M., Adonizio, T., Ellison, H. B., Weber, R., Arnott, J., and Koestler, J. (unpublished). “Teaching Professionalism,” in *Medical Education and Fostering Professionals in Medicine*, eds. A. Fornari and N. Deming (New York, NY: Springer).

assessing student learning through their Valid Assessment of Learning in Undergraduate Education (VALUE) project (<https://www.aacu.org/initiatives/value>). Scholars who study student assessments have evaluated ePortfolios to promote and assess student learning (7, 9). These researchers similarly conclude that professionalism is not a solitary pursuit; student self-reflection and self-assessment without external guidance are suboptimal (12). Faculty increasingly realize the value of implementing ePortfolios for students to demonstrate competence, while students appreciate the value of reflecting on what they learn throughout their medical education (9). Researchers have reported that ePortfolios promote students' reflection and learning; one group reported that "ePortfolios are currently celebrated as a way to facilitate and document more authentic forms of assessment" (13, 14). Subsequent studies have reported positive student perceptions of using portfolios, particularly the utility of reflective learning (15–17).

Although ePortfolio use in medical education continues to grow, documented use within a medical school curriculum is still developing (10, 18). Early descriptions of ePortfolio use included how portfolios could be utilized in medical education (7, 8, 30), yet few medical schools have used ePortfolios to assess professionalism.

Our goals for incorporating an ePortfolio

At Geisinger Commonwealth School of Medicine (GCSOM), we defined the ePortfolio as a student-assembled electronic portfolio that displays academic accomplishments, essays, videos, samples of work, and volunteer and extracurricular activities in required and optional, student-driven artifacts. This tool can monitor and promote each student's curricular progress through course assignments tied to these ePortfolio artifacts related to competency development (11, 19). Comprehensive ePortfolio assessment data for Doctor of Medicine (MD) program evaluation can highlight opportunities for continuous quality improvement. Therefore, developing and implementing an ePortfolio may be applied to any competency-based educational setting, such as health professions and medical education (16).

We felt that using an ePortfolio to assess professionalism could have several benefits, including (1) enabling multidimensional assessment by facilitating longitudinal integration of students' assignments, termed artifacts, (2) highlighting opportunities for continuous quality improvement within our curriculum and (3) serving as an example for educators using an ePortfolio in any competency-based educational setting. Therefore, we aim to share our experience with developing and implementing an ePortfolio for longitudinal assessment of professionalism within undergraduate medical education.

Methods

Development and implementation of the ePortfolio

The GCSOM Total Health Curriculum includes personal and professional development as one of the six programmatic

objectives woven throughout the MD curriculum (Appendix A). The personal and professional development curriculum, one of six longitudinal curricular themes, is used to demonstrate achievement in meeting the learning objectives of the MD curriculum (see text footnote 1). The development and implementation of the ePortfolio assessment at GCSOM was based on Design Thinking, which incorporates organizational and systems theory with social psychology and practical research through inspiration, ideation, and implementation (20). By reflecting on their learning, students practiced collective generation of ideas, rapid prototyping, and continuous testing to align technologically based tools with users' needs (20). In this manner, we engaged student leaders and faculty champions to review the implementation and provide timely feedback for improving the ePortfolio (21). Partnering with a faculty member, students engaged in ePortfolio development while strengthening their professional identity formation (20, 22, 23).

To begin the implementation of the ePortfolio, we evaluated the curriculum to identify assessments that would be appropriate to use as evidence of individual student growth and achievement in the curriculum's personal and professional development programmatic learning objectives (10, 24). The step-by-step inventory process included:

1. Assemble faculty members responsible for assessment within the MD curriculum.
2. Create an inventory of MD curricular assessments by course and class session.
3. Identify gaps in MD curricular assessments related to the programmatic learning objectives that the ePortfolio could address.
4. Propose assessments to address the gaps to meet programmatic learning objectives.
5. Link and map identified assessments to the programmatic learning objectives.
6. Create labels for ePortfolio evidence to track students' growth in reflection and professionalism.

Three GCSOM medical students developed several ePortfolio prototypes. One was selected based on its ability to track students' progress toward achieving programmatic learning objectives (25).

Current processes and continuous quality improvement for the ePortfolio

All first-year students attend a session that explains the programmatic requirements, introduces the personal and professional development curriculum, and provides an overview of the ePortfolio. Students are also given an ePortfolio manual so they have the necessary educational guidance to construct their ePortfolio correctly. In addition, an active learning workshop is conducted so students can build confidence in using the ePortfolio within the Portfolium platform and upload evidence in real time while receiving feedback from faculty members.

The longitudinal personal and professional development ePortfolio was created in Portfolium (<https://portfolium.com>) and

embedded as a curricular requirement for all students. Students completed ePortfolio entries for corresponding assignments that reinforced what they learned in basic science and doctoring courses and themes related to professionalism, social justice, health equity, and community engagement (19, 25). Personal and Professional Development theme faculty members evaluated student submissions, termed evidence, within the ePortfolios and provided feedback regarding student growth in the personal and professional development curriculum. These faculty members also mentored students' reflective skills and construction of the ePortfolio. In addition, courses throughout the MD curriculum support the student's growth for reflective practice. Students submitted data were used to determine if curricular requirements were achieved.

Reflective writing and practices are embedded throughout the MD curriculum, providing formative feedback to students for future incorporation into their learning. Students were given a document that contained the specific ePortfolio evidence needed by class year, assignment name, name to be used in Portfolium for the type of evidence, and the specific labels to assign to the evidence. ePortfolio labels can be assigned at the individual student level (personal use), theme level (evidence for the personal and professional development theme), and programmatic level (evidence for programmatic objectives). Labels allowed for ePortfolio assessment data to be used by faculty in institutional research for MD program evaluation and to identify opportunities for continuous quality improvement. Students were periodically reminded via announcements in the Canvas Learning Management System (www.instructure.com/canvas) about ePortfolio deadlines and requirements. At the end of the academic year, students were required to upload their completed ePortfolio from Portfolium into a designated assignment in Canvas for individual student evaluation by faculty.

One example of an educational activity within the personal and professional development theme is viewing the Association of American Medical College virtual seminar Legacy of Medicine in the Holocaust. After watching the seminar, students must complete a reflective writing assignment, which they are required to submit as an ePortfolio assignment. The reflective writing submission links directly to MD program outcomes and is contained as evidence within the ePortfolio. The associated ePortfolio "skills" document the MD program outcomes directly related to the students' achieved competency (26).

Results

Each required personal and professional development curriculum assignment for the ePortfolio has labels, known within Portfolium as *skills*, that are linked back to the MD programmatic objectives. Creating labels allows for the tracking of individual student growth and assessing the personal and professional development curriculum. These results can be tracked at the individual student level annually and longitudinally. Annual curricular review allows faculty and students to evaluate the breadth of program objectives covered in that year's assignments. The data contained within the ePortfolio can be used to generate theme content maps relevant to each phase of the

curriculum to address particular educational program objectives and provide precision education to enhance student learning and outcomes.

Faculty are trained to use the REFLECT rubric and Began Model (27, 28) to assess assigned reflections within the ePortfolio. These assessment tools (27, 28) provide a standardized process for evaluating students' reflections and providing formative feedback regarding their achievement of learning outcomes (see text footnote 1). Based on the individual assessment of student learning throughout the MD program, artifacts contained within the ePortfolio linked to longitudinal student learning, and the skills associated with achieving MD programmatic outcomes, we believe the ePortfolio achieved the goals.

Discussion

In 2021, GCSOM expanded its use of the data warehousing and visualization software One45 Analytics. The Analytics modules included data related to prematriculation, student performance on local assessments, and nationally normed gateway exams. One45 Analytics software modules allowed GCSOM staff to access and label curricular data points for more detailed tracking and visualization on data dashboards. MD program objectives and personal and professional development curricula can be labeled in Canvas, and data that flow from Canvas assignments into Analytics can thus be used for data-driven decision-making. Assignments completed in fulfillment of the personal and professional development curriculum, including success in the ePortfolio, can be identified so that a student's academic advisor can intervene if there are concerns about the student's progress in this area of the curriculum.

In addition, ePortfolio entries created as Canvas assignments allow students to label their posts with the appropriate program objective and personal and professional development curriculum assignment. In this manner, ePortfolios create a collection of academic artifacts for students and concurrently display a diversified array of skills that can be valuable during residency interviews. Standardized labels can streamline communication between students and faculty; however, students can create their own labeling schema for the personal and professional development curriculum use. This allows students to showcase special skills or experiences that they feel can contribute significantly to the residency programs they apply to.

The next steps for our ePortfolio initiative include optimizing Analytics reporting capabilities and further staff development. For example, GCSOM hopes to give course directors access to course-specific data and faculty advisors access to their advisees' data. Currently, all data are requested by faculty and then collected, synthesized, and disseminated by the Office of Institutional Research, facilitated by the ability to create standard reports within Analytics. Granting course directors and faculty advisors this level of access requires refined data tables to ensure that faculty can view only assessment data related to a student's performance in the faculty member's purview and not the student's overall

record of achievement, thus avoiding a potential source of bias in assessment.

As access evolves during the maturation of ePortfolio use, the need for faculty development will increase. Concerning One45 Analytics, we will implement a *train-the-trainer* model starting with those who work closely with the curriculum, academic progress, and assessment data, progressing to course leadership, and then to other faculty and staff as necessary. Faculty and staff who regularly use Portfolium will share their successes and promote using the ePortfolio product in tracking MD programmatic requirements while providing precision education to learners. The ePortfolio has become an essential part of the longitudinal assessment of the personal and professional development curriculum and students' performance throughout the curriculum as a whole. By integrating numerous systems and assessment types, GCSOM can create a more holistic picture of student performance that benefits not only the institution's ability to report accurate data but, more importantly, helps students reflect upon their experiences in a way that guides them in taking the next step in their careers.

Author contributions

MS: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. IM: Formal analysis, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing. TA: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. HE: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing, Project administration. AH: Writing – original draft, Writing – review & editing. AC: Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Data curation, Formal analysis.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

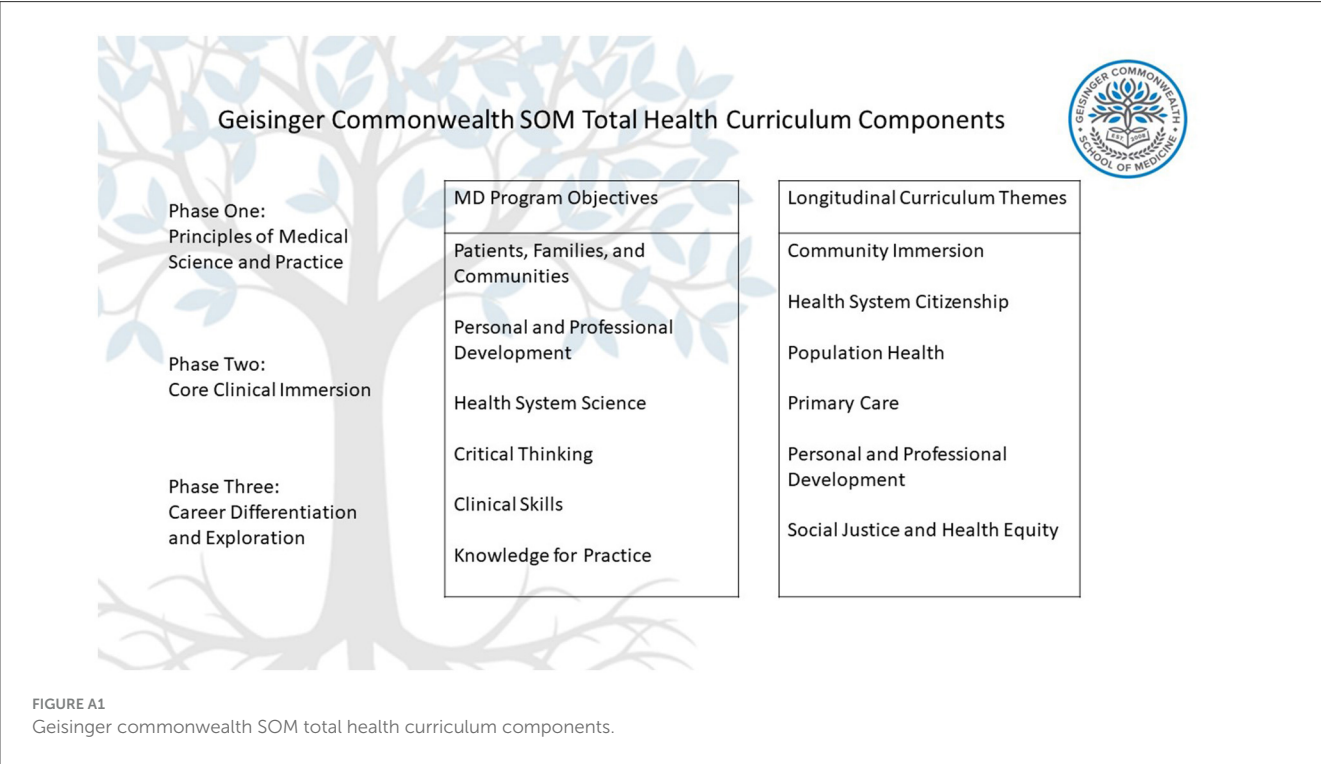
The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Appendix A





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Generative artificial intelligence in graduate medical education

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Generative artificial intelligence (GenAI) is rapidly transforming various sectors, including healthcare and education. This paper explores the potential opportunities and risks of GenAI in graduate medical education (GME). We review the existing literature and provide commentary on how GenAI could impact GME, including five key areas of opportunity: electronic health record (EHR) workload reduction, clinical simulation, individualized education, research and analytics support, and clinical decision support. We then discuss significant risks, including inaccuracy and overreliance on AI-generated content, challenges to authenticity and academic integrity, potential biases in AI outputs, and privacy concerns. As GenAI technology matures, it will likely come to have an important role in the future of GME, but its integration should be guided by a thorough understanding of both its benefits and limitations.

KEYWORDS

Generative AI, LLM, GPT, GME, graduate medical education, ChatGPT, artificial intelligence, education

1 Introduction

Generative artificial intelligence (GenAI) is a relatively new technology that uses advanced machine learning models to generate humanlike expression. Large language models (LLMs) like ChatGPT (OpenAI, San Francisco, United States) rely on a machine learning architecture called a “transformer.” A key feature of transformers is their self-attention mechanism, which allows the model to assess the importance of words in a sequence relative to one another, enhancing its ability to understand context and, when trained on vast amounts of data, resulting in a remarkable ability to understand and generate humanlike text (1). Such models excel at tasks like document summarization, sentiment analysis, question answering, text classification, translation, text generation, and as conversational chatbots. Related models called large vision models (LVMs), Vision-Language Models (VLMs), large multimodal models (LMMs), diffusion models, and generative adversarial networks (GANs) provide similar or overlapping functionality for image, audio, and video processing and generation. It is widely believed that GenAI will have far-reaching societal impact and will be incorporated into multiple aspects of our daily lives (2, 3). GenAI has the potential to revolutionize multiple industries, with healthcare and education among the likely targets.

In healthcare, GenAI has shown promise in a broad range of applications such as clinical decision support, medical education, clinical documentation, research support, and as a communication tool (4). GenAI models like ChatGPT, even without special fine-tuning for medical knowledge, achieve performance at or near the passing threshold on all three United States Medical Licensing Examination (USMLE) Step exams (5). Studies evaluating performance on medical specialty board examination or in-service examination-level questions have shown mixed results, but in some cases LLM performance has approached that of senior medical trainees (6–9). GenAI-powered tools are deployed in production clinical

environments today, most notably in the patient care-adjacent domains of clinical documentation (10) and provider-patient communication, where they have shown promise in improving EHR-related provider inefficiency and burnout (11, 12).

In the medical educational setting, GenAI potentially offers multiple benefits such as easy personalization of learning experiences, simulation of real-world scenarios and patient interactions, and practicing communication skills (13). These potential gains are balanced by meaningful risks, such as the trustworthiness of AI-generated content, the deepening of socioeconomic inequalities, and challenges to academic integrity (14, 15).

Graduate medical education (GME) shares many characteristics with undergraduate medical education and with other types of healthcare education. As adult learners, medical trainees are theorized to learn best when self-motivated, self-directed, and engaged with task-centered, practical topics (16). Historically, medical education used time spent in the training environment as a proxy for learning success. More recently, there has been renewed interest in competency-based medical education (CBME), a paradigm that uses achievement of specific competencies rather than time spent (or other structural measures) as the key measure of learning success (17, 18). CBME serves as the foundation of the Accreditation Council for Graduate Medical Education (ACGME)'s accreditation model, and is the key theory underpinning the formative "Milestones" used by ACGME-accredited programs to assess trainee development and to improve education (19).

Having built a foundation in medical sciences and basic clinical skills in medical school, GME trainees spend little time in the classroom, with most of their learning occurring with real patients as they function as members of the healthcare team. A core tenet of GME is "graded authority and responsibility," where trainees progressively gain autonomy until they achieve the skills to practice independently. Additionally, trainees are expected to become "physician scholars"; participants in ACGME-accredited GME programs participate in scholarly pursuits like research, academic writing, quality improvement, and creation of educational curricula (20).

In this paper, we present concise summary of the existing literature (Table 1) and commentary on the potential opportunities and risks of GenAI in the GME setting.

2 Opportunities

2.1 EHR workload reduction

Given their long work hours and stressful work environment, GME trainees are particularly susceptible to burnout, with rates higher than their age-matched peers in non-medical careers and higher than early-career attending physicians (21). Burnout among the academic physicians who comprise most GME faculty also occurs, and may impact the quality of training they are able to deliver (22, 23). Thus, innovations that prevent overwork and burnout have the potential to benefit GME trainees and faculty.

One unintended consequence of the adoption of electronic health records (EHRs) has been a dramatic increase in time spent in documenting clinical encounters. Many physicians now spend as much time documenting in the EHR as they do in patient-facing activities (24). This documentation burden can result in medical

errors, threats to patient safety, poor quality documentation, and attrition, and is a major cause of physician burnout (25). Various strategies have been tried to reduce physician documentation burden, including medical scribes and various educational interventions, workflow improvements, and other strategies (26). Given its ability to summarize, translate and generate text, GenAI demonstrates clear potential as a technological aid to alleviate the burden of clinical documentation. The most notable current application is ambient listening tools that use GenAI to transcribe and analyze patient-doctor conversations, converting them into structured draft clinical notes that the physician would theoretically only then need to review for accuracy. Numerous organizations are piloting such technology as of the time of this writing (27), though the few results published so far about real-world performance have been mixed (10, 28, 29). Examples of other less commercially mature concepts for how GenAI could reduce clinical documentation burden include tools to improve medical coding accuracy (30), to generate clinical summary documentation like discharge summaries (31), and to draft GME faculty supervisory notes (32).

In addition to documenting clinical encounters, physicians (including GME trainees) spend large amounts of time in the EHR managing inbox messages, including patient messages, information about tests results, requests for refills, requests to sign clinical orders, and various administrative messages (33). As another major contributor to workload, EHR inbox management is also a cause of burnout (34, 35). This problem came to be of particular importance during the COVID-19 pandemic, where patient messaging increased by 157% compared to pre-pandemic levels (35). LLMs have shown the ability to draft high-quality, "empathetic" responses to patient questions (36). Early efforts to use LLMs for drafting replies to patient inbox messages have shown promising results, with multiple studies showing that LLMs can draft responses of good quality (37, 38) and at least one study showing good provider adoption with significant reductions in provider assessment of multiple burnout-related metrics (11). Multiple health information technology companies, including the largest United States EHR vendor, have already brought GenAI functionality for EHR inbox management to market (39–41).

2.2 Clinical simulation

Simulation-based medical education (SBME) has evolved significantly since the early use of mannequins for basic life support training 60 years ago, and simulation using high-fidelity mannequins and virtual and augmented reality tools are now a vital component of GME. There is a substantial body of evidence confirming the benefits of simulation-based training and the successful transfer of these skills to real patients (42, 43). Simulations are used both to educate and to assess performance in GME. For example, the American Board of Anesthesiology incorporates an Objective Structured Clinical Examination (OSCE) meant to assess communication and professionalism, as well as technical skills, into the board examination process for anesthesiology residents (44). Many of the current applications of SBME in GME are targeted at procedural skills like complex surgical techniques, bridging the gap for trainees' experiential

TABLE 1 Literature on GenAI in the GME setting.

Specialty	First author (Publication date)	Title (Citation)	Brief description
Administration	Mangold, S (2024)	Artificial Intelligence in Graduate Medical Education Applications (101)	Commentary on the use of GenAI in GME application materials.
Administration	Quinonez, S (2024)	ChatGPT and Artificial Intelligence in Graduate Medical Education Program Applications	Commentary on the use of GenAI in GME application materials.
Administration	Zumsteg, J (2023)	Will ChatGPT Match to Your Program? (97)	Commentary on the use of GenAI in GME application materials.
Anesthesiology	Sardesai, N (2023)	Utilizing Generative Conversational Artificial Intelligence to Create Simulated Patient Encounters: A Pilot Study for Anaesthesia Training (48)	Study using an LLM to simulate patient conversations for trainees regarding certain anesthesia procedures. The tool showed good accuracy in simulating patient responses and behavior.
Dermatology	Ayub, I (2023)	Exploring the Potential and Limitations of Chat Generative Pre-trained Transformer (ChatGPT) in Generating Board-Style Dermatology Questions: A Qualitative Analysis	Study using an LLM to generate board exam-style dermatology questions, showing poor performance of the model in generating accurate and appropriate questions.
Dermatology	Breslavets, M (2024)	Advancing dermatology education with AI-generated images.	Commentary with examples using a GAN to generate synthetic clinical images for dermatology training.
Dermatology	Lim, S (2024)	Exploring the Potential of DALL-E 2 in Pediatric Dermatology: A Critical Analysis	Study using a diffusion model to generate synthetic clinical images of dermatologic conditions for dermatology training, showing poor performance of the model for most tested conditions.
Emergency Medicine	Barak-Corren, Y (2024)	Harnessing the Power of Generative AI for Clinical Summaries: Perspectives From Emergency Physicians (32)	Study using an LLM to generate clinical supervisory notes, showing a significant reduction in time and effort required to create notes, without any reduction in note quality on simpler notes.
Emergency Medicine	Webb, J (2023)	Proof of Concept: Using ChatGPT to Teach Emergency Physicians How to Break Bad News (49)	Proof-of-concept study using ChatGPT to roleplay breaking bad news to patients.
Neurosurgery	Arfaie, S (2024)	ChatGPT and Neurosurgical Education: A Crossroads of Innovation and Opportunity (90)	Review of the literature and summary of the uses of GenAI for educating neurosurgical trainees.
Neurosurgery	Bartoli, A (2024)	Probing Artificial Intelligence in Neurosurgical Training: ChatGPT Takes a Neurosurgical Resident's Written Exam (111)	Study evaluating the performance of an LLM in generating board examination-style questions, showing poor performance of the LLM in generating a small trial set of exam-quality questions.
Neurosurgery	McLean, A (2024)	Application of Transformer Architectures in Generative Video Modeling for Neurosurgical Education (112)	Detailed description of a planned study that would use a diffusion model to create synthetic neurosurgical training videos.
Ophthalmology	Sevgi, M (2024)	Medical Education with Large Language Models in Ophthalmology: Custom Instructions and Enhanced Retrieval Capabilities (113)	Description of tools using LLMs to teach clinical guidelines in ophthalmology and to summarize current ophthalmology research.
Orthopedic Surgery	DeCook, R (2024)	AI-Generated Graduate Medical Education Content for Total Joint Arthroplasty: Comparing ChatGPT Against Orthopedic Fellows (114)	Study using an LLM to generate educational summaries of total joint arthroplasty-related topics, showing that the LLM created better orthopedic training content than orthopedic fellows across several topics and domains.
Pathology	Cecchini, M (2024)	Harnessing the Power of Generative Artificial Intelligence in Pathology Education (18)	Review of the literature and summary of the uses of GenAI for educating pathology trainees.
Pediatrics	Ba, H (2024)	Enhancing Clinical Skills in Pediatric Trainees: A Comparative Study of ChatGPT-Assisted and Traditional Teaching Methods (115)	Study comparing LLM-assisted instruction with traditional instruction on pediatric clinical skill education, showing comparable or better performance of the LLM-assisted method.

(Continued)

TABLE 1 (Continued)

Specialty	First author (Publication date)	Title (Citation)	Brief description
Pediatrics	Suresh, S (2024)	Large Language Models in Pediatric Education: Current Uses and Future Potential (116)	Review of the literature and summary of the uses of GenAI for educating pediatrics trainees, showing that LLM-assisted instruction did not affect theoretical knowledge application but did enhance practical clinical skills.
Pediatrics	Waikel, R (2023)	Generative Methods for Pediatric Genetics Education (56)	Study using synthetic images of individuals with uncommon genetic conditions to train pediatric residents, showing that the synthetic images performed similarly but were slightly less helpful than real patient images.
Primary Care	Parente, D (2024)	Generative Artificial Intelligence and Large Language Models in Primary Care Medical Education (59)	Review of the literature and summary of the uses of GenAI for educating primary care trainees.
Radiology	Lyo, S (2024)	From Revisions to Insights: Converting Radiology Report Revisions into Actionable Educational Feedback Using Generative AI Models (60)	Study using an LLM to compare preliminary (trainee) and finalized radiology reports, identify discrepancies, and suggest review topics. The LLM consistently and accurately identified discrepancies and suggested relevant feedback.
Radiology	Meşe, I (2024)	Educating the Next Generation of Radiologists: A Comparative Report of ChatGPT and E-Learning Resources (117)	Review of the literature and summary of the uses of GenAI for educating radiology trainees.
Radiology	Mistry, N (2024)	Large Language Models as Tools to Generate Radiology Board-Style Multiple-Choice Questions (61)	Study using two LLMs to generate board exam-style radiology questions, demonstrating that one LLM generated questions of equivalent quality to real American College of Radiology in-service exam questions.
Surgery	Lia, H (2024)	Cross-Industry Thematic Analysis of Generative AI Best Practices: Applications and Implications for Surgical Education and Training (118)	Analysis of ethical considerations when integrating GenAI into surgical education, with example use cases.
Surgery	Sathe, T (2024)	How I GPT It: Development of Custom Artificial Intelligence (AI) Chatbots for Surgical Education (119)	Commentary on the use of GenAI chatbots for surgical education with description of several potential use cases.

Summary of existing literature of which we are aware focusing on GenAI in GME. The summary excludes papers focused on mainly on testing LLM performance on medical knowledge tasks, papers on non-GME-specific clinical, educational or academic applications of GenAI, and papers about artificial intelligence in general.

learning on invasive, uncommon, or high-acuity procedures (45). The integration of artificial intelligence into clinical simulations would theoretically allow for the customization of scenarios based on a trainee’s skill level and performance data, providing a personalized learning experience and potentially opening the door to new types of patient simulation (43). Accordingly, there has been interest in using conversational GenAI to simulate patient encounters to practice cognitive and communication skills, though this application is more often focused on undergraduate medical education (15, 33, 46–49).

Among the most interesting potential applications of GenAI in GME is the concept of using synthetic data as training material for visual diagnosis. GANs and diffusion models have shown promise in generating realistic images of pathology findings (50, 51), skin lesions (52–54), chest X-rays (55), genetic syndromes (56), and ophthalmological conditions (57). The synthetic data approach may ultimately address important limitations in image-based training data

sets, such as underrepresentation of certain patient demographics and adequate demonstration of rare findings.

2.3 Individual education

Individualized tutoring produces better academic outcomes than learning in a traditional classroom setting (58). Skilled teachers can guide learners at different levels through complex topics, offering tailored and accessible explanations. One-on-one tutoring delivered by humans is costly, and skilled teachers are not available everywhere, but GenAI tools may have some of the same benefits at a fraction of the cost. LLMs show promise as a tool for explaining challenging concepts to graduate medical trainees in a manner tailored to the learner’s level (18), and LLMs could be configured to act as personalized tutors (59). In one study, an LLM successfully reviewed trainee-generated radiology reports and generated relevant

educational feedback, a concept which could be extended to other types of clinical documentation (60).

GME trainees preparing for board examinations often use question banks to study, and GME programs use board-exam style questions to assess trainee progress. Question generation can be a costly and labor-intensive proposition (61). Authors report mixed success with using LLMs to generate board exam-style questions (61, 62), but as the technology matures, it seems likely that LLMs will be used by trainees and educators alike to create high-quality self-directed study materials and test questions.

2.4 Research and analytics support

LLMs are powerful tools for academic research and writing, and can assist in idea generation, processing complex background information, and proposing testable hypotheses (63, 64). LLMs readily summarize complex academic papers and draft academic text, abilities that can accelerate academic productivity (65). When paired with reliable academic databases and search engines and/or when fine-tuned with specific knowledge, LLMs do a serviceable job of conducting literature reviews (66, 67), synthesizing findings from existing literature, and drafting new scientific text with accurate literature citations (68). LLMs have great utility in assisting non-native English speakers with academic writing, representing a cost-effective and always-available alternative to commercial editing and proofreading services or to searching for native English-speaking collaborators (69).

Among the competencies listed in the ACGME's Common Program Requirements is the ability to "systematically analyze practice using quality improvement (QI) methods" (20). GME trainees are required to participate in QI projects, which typically require quantitative data analysis. Trainees are often underrepresented in organizational quality improvement activities, with one potential reason being the substantial time and effort needed for data collection and analysis (70). LLMs have some ability to facilitate straightforward data analysis and can generate serviceable code for statistical and programming tasks (71). LLMs are also adept at natural language processing tasks like extracting structured data from unstructured medical text (72).

2.5 Clinical decision support

Computer-based clinical decision support (CDS) systems are among the most effective tools for guiding good clinical decision-making (73). For GME trainees, CDS that provides authoritative, evidence-based guidance has both great practical clinical and educational utility (73). CDS that delivers evidence-based clinical guidance based on relevant patient data is a required feature for EHR systems certified by the United States government (74). A widely accepted CDS framework explains that CDS should be delivered according to the "five rights": the right information, to the right person, in the right format, through the right channel, at the right time (75). Most current CDS consists of rule-based expert systems that display alerts to providers. While such systems are effective, rule-based alerts often suffer from practical problems such as a lack of specificity, poor timing, and incomplete characterization of clinical context (76).

The potential for intelligent, interactive, authoritative, LLMs to serve as always-available clinical consultants and educators has generated compelling speculation (77). LLMs can provide context-sensitive and specific guidance incorporating clinical context and patient data, they can be accessed through readily available communication channels, and--in contrast to rule-based alerts--they are interactive. However, studies done to evaluate the potential of LLMs for clinical decision support in various clinical contexts (78–83) have shown mixed results so far, with limitations in their ability to handle nuanced judgment and highly specialized decision-making. Thus, while GenAI for CDS is an area of great potential and ways to improve performance are under development, GME faculty and trainees cannot yet rely on LLMs to directly guide clinical care.

3 Risks

Despite its recent public availability, GenAI use is widespread and continues to grow quickly in both business and personal contexts. ChatGPT has the fastest-growing user base of any consumer web application in history (84), and a McKinsey & Company survey in early 2024 reported that 65% of businesses are regularly using generative AI, a rate nearly twice the year before (85). In another McKinsey report, more than 70% of healthcare leaders say they are using or pursuing GenAI technologies in their organizations (86). This explosive growth will undoubtedly have many benefits, but there are practical risks associated with GenAI that should temper optimism. Below we summarize the principal known risks as applicable in the GME setting:

3.1 Inaccuracy and overreliance

In essence, LLMs are statistical models that predict the most likely continuation of a given input sequence, based on their training data. Sometimes this approach results in plausible sounding but factually incorrect outputs, a phenomenon called "hallucination." This problem can be especially difficult when dealing with topics requiring nuanced understanding of context or specialized knowledge, conditions very common in healthcare and specialized academic settings. For example, a biomedical researcher recently reported a cautionary tale in which ChatGPT generated incorrect information about tick ecology, complete with an entirely fake but plausible-appearing source document citation (87). In clinical settings, LLMs have been found to occasionally add fabricated information to clinical documentation (88) and to provide incorrect clinical recommendations (89).

In GME, trainees learn in a real clinical environment where accuracy and context are critical. There is a risk that overreliance on LLMs can result in an incomplete or incorrect understanding of complex topics, contributing to a poor educational outcomes, loss of critical thinking skills, and/or to suboptimal care and patient harm (15, 90, 91). Techniques like retrieval augmented generation, fine-tuning and prompt engineering show promise in reducing or eliminating the problems of inaccuracy and hallucination (92–94), but at present, reliance on GenAI as a source of factual information in any important clinical or academic context is risky. In our view, assertions made by GenAI should be validated by the user to avoid

misinformation, and GME trainees should not use GenAI to directly guide patient care decisions outside of a controlled research context. GenAI users should be aware of automation bias, a cognitive bias in which people tend to excessively trust automated systems (95).

3.2 Authenticity and integrity

In reviewing applications for GME positions, personal statements are one of the most important elements that program directors review (96), especially in modern era where in-person residency and fellowship interviews are less common. Personal statements allow program directors to assess an applicant's interest in their program and the clarity, organization and effectiveness of their written communication (97). There have long been concerns about plagiarism in personal statements (98, 99), and these concerns are magnified by GenAI tools that can readily produce writing that is clear, well-structured and compelling but that lacks an applicant's unique voice, style and values (100, 101). Similarly, through letters of recommendation (LORs), faculty advocate for applicants by highlighting qualities observed in longitudinal relationships; using GenAI to draft LORs may have benefits but raises similar concerns about authenticity (102). GenAI-written content can be difficult to detect, even with software assistance (103). Some authors recommend that program draft policies for the use of GenAI in personal statements and LORs, with a common recommendation being that the use of GenAI be disclosed by the writer (97, 101).

As noted above, GME trainees are also expected to participate in research, academic writing, quality improvement summaries, creation of educational curricula, and similar academic activities. There are currently no consensus standards for using GenAI in academic medicine, but a recent review synthesized existing papers into a proposed set of guidelines, paraphrased as: (1) LLMs should not be cited as coauthors in academic works, (2) LLMs should not be used to produce the entirety of manuscript text, (3) authors should have an understanding of how LLMs work, (4) humans are accountable for content created by the LLM, and (5) use of an LLM should be clearly acknowledged in any resulting manuscripts (104).

3.3 Bias

GenAI tools are typically trained on huge corpora of data from the internet such as informational web sites, public forums, books, research literature, and other digitized media. Given the uncontrolled nature of the training data, it is unsurprising that they can exhibit social bias and stereotypes in their output (105). If unmanaged, these biases have the potential to reinforce detrimental beliefs and behaviors (106). In healthcare, GenAI may overrepresent, underrepresent or mis-characterize certain groups of people or certain medical conditions (18).

3.4 Privacy and security

GenAI is computationally intensive and expensive to operate. Thus, many resource-limited healthcare organizations or individual

physicians may rely on third-party, external GenAI tools (107). Given the great utility of GenAI, knowledge workers may be sorely tempted to upload confidential information, despite significant risks (108). In healthcare, such risks are legal as well as ethical in nature, and transgressions can have implications for professional development.

4 Conclusion

Though the timeline is uncertain, GenAI technology will continue to advance. There is little question that GenAI will come to have a key role in the medical education landscape. We are optimistic about the potential of GenAI to enhance GME for both learners and educators, but enthusiasm should be tempered by a realistic understanding of the risks and limitations of this technology. We believe specific education on artificial intelligence should be included in medical curricula, and that research should continue on the risks and benefits of artificial intelligence as a tool for medical education (109, 110).

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Conflict of interest

Authors RJ, SN, AN and KY were employed by company Baylor Scott & White Health.

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Generative AI statement

The authors declare that Generative AI was used in the creation of this manuscript. GPT 4o (version 2024-08-06, OpenAI) was used to refine each individual contributor's section(s) of the manuscript draft into a more cohesive writing style.

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A guide to prompt design: foundations and applications for healthcare simulationists

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Large Language Models (LLMs) like ChatGPT, Gemini, and Claude gain traction in healthcare simulation; this paper offers simulationists a practical guide to effective prompt design. Grounded in a structured literature review and iterative prompt testing, this paper proposes best practices for developing calibrated prompts, explores various prompt types and techniques with use cases, and addresses the challenges, including ethical considerations for using LLMs in healthcare simulation. This guide helps bridge the knowledge gap for simulationists on LLM use in simulation-based education, offering tailored guidance on prompt design. Examples were created through iterative testing to ensure alignment with simulation objectives, covering use cases such as clinical scenario development, OSCE station creation, simulated person scripting, and debriefing facilitation. These use cases provide easy-to-apply methods to enhance realism, engagement, and educational alignment in simulations. Key challenges associated with LLM integration, including bias, privacy concerns, hallucinations, lack of transparency, and the need for robust oversight and evaluation, are discussed alongside ethical considerations unique to healthcare education. Recommendations are provided to help simulationists craft prompts that align with educational objectives while mitigating these challenges. By offering these insights, this paper contributes valuable, timely knowledge for simulationists seeking to leverage generative AI's capabilities in healthcare education responsibly.

KEYWORDS

prompt, prompt engineering, healthcare simulation, ChatGPT, artificial intelligence, large language models, LLM, generative AI

1 Introduction

AI will be a ubiquitous technology during the forthcoming industrial revolution, since it enables entities and processes to become smart. Organizations and economies adopting AI strategically, will enjoy a competitive advantage over those who do not incorporate this technology timely and adequately.

-Velarde (1). Artificial intelligence and its impact on the Fourth Industrial Revolution: A review.

Artificial intelligence (AI) has slowly been infused into the workflow of society since Turing first posed the question, "Can machines think?" in the 1950s (2, 3). The transformative potential of AI enhances human productivity. It catalyzes future advancements in all fields of life, including healthcare (4), as evidenced by internet discussions, social media, news outlets,

everyday conversations, literature, and academia. What Velarde predicted in 2020 is coming true, considering today’s digital landscape in which terms and acronyms such as “ChatGPT,” “large language models (LLMs),” “natural language processing (NLP),” “machine learning (ML),” “deep learning (DL),” “generative AI (genAI),” and “prompt engineering” are common and expected to be understood by all healthcare educators including simulationists (5, 6). In this concept paper, we explore prompt design in healthcare simulation—a foundational element for unlocking the potential of genAI and LLMs—by examining the interrelationship of the terms, as mentioned earlier, to help readers contextualize and critique prompts effectively.

Grounded in literature, this paper aims to propose the best practices for developing calibrated prompts for LLMs, explores various prompt types and techniques with use cases, and addresses the challenges, including ethical considerations for using LLMs for healthcare simulation. Prompts are commands entered into an LLM to produce user-desired responses or output (4). The quality of the output received from an LLM highly depends on the prompt quality (5). For this reason, this paper defines calibrated prompts as clear, precise, and contextual input for genAI that is sufficiently broad to produce relevant answers, thereby enhancing the reliability and quality of the output (4, 5, 7–10, 78) (Table 1 for definitions related to prompt design).

Using appropriate prompting techniques, simulationists can interact with LLMs more effectively for education and training for the latest treatments, procedures, research, administrative support, and public health (4). The potential for LLM use in simulation-based education (SBE) is vast and continues to evolve as LLMs evolve. Simulationists are often short on time and manage numerous responsibilities; leveraging LLMs with calibrated prompts can enhance scalability, productivity, and efficiency (4). Hence, prompt design is becoming a valuable skill for simulationists.

1.1 Large language models and artificial intelligence

Artificial intelligence is a field in computer science that creates and studies technology that enables machines to exhibit intelligent human behavior (11). A subset of AI, machine learning (ML), focuses on developing algorithms that allow computers to learn from data and make predictions (12). When ML uses multiple hidden layers of algorithms, called deep neural networks, to simulate complex patterns between the multiple layers, it is known as “deep learning” (DL) (13, 14). Natural language processing (NLP) is a specific application of DL that uses machine learning to enable computers to understand and communicate with human language (15). NLP enables applications like conversational agents, e.g., Apple Siri (16), Amazon Alexa (17), and others (18) and automatic translation (Figure 1).

GenAI, another AI subset, uses NLP to create new content such as text, images, music, or videos from existing data (19). LLMs such as ChatGPT (20), Gemini [Bard] (21), CoPilot (22), and Claude (23) employ genAI and NLP to produce coherent, contextually relevant text (5, 24). LLMs are statistical models with computational abilities programmed to read, write, and converse in natural language (8, 14). LLMs have been integrated into almost all educational applications, improving communication platforms, experiential learning, automated assessment, and healthcare simulation technologies (4, 8). Several commercial applications, including computer-based simulations (CBS) (25), now

TABLE 1 Definitions of essential terms.

Term	Definition
Prompt	The initial input given to a language model (LM) to generate a response. This input guides the model to produce the desired output (34).
Prompt design	Prompt design is the process of creating prompts that elicit the desired response from language models (28).
Prompt engineering	The practice of designing, refining, and implementing prompts or instructions that guide the output of LLMs to help in various tasks (4, 9, 24).
Context	Additional information or text provided in the prompt to help the language model generate more relevant or accurate responses (10, 24)
Instruction/Task	Explicit directions or commands are included in the prompt to guide the model’s response (10, 24).
Input data	The input or question that we want the model to process and provide a response for (5).
Output Indicator/ Form of output	Specifies the type or format of the desired output (ex. paragraph, short response, dialogue or list) (5).
Template	A pre-defined structure for prompts that can be filled in with specific variables or content to generate consistent outputs (75).
Bias	A tendency of the language model to produce outputs that reflect certain prejudices or skewed perspectives (76)
Meta-prompting	Using prompts that instruct the model on how to generate other prompts, creating a hierarchical structure of prompt generation (77)
Use Case	In the context of this paper, a use case is a specific, practical application of prompt engineering techniques in various tasks within simulation-based education.

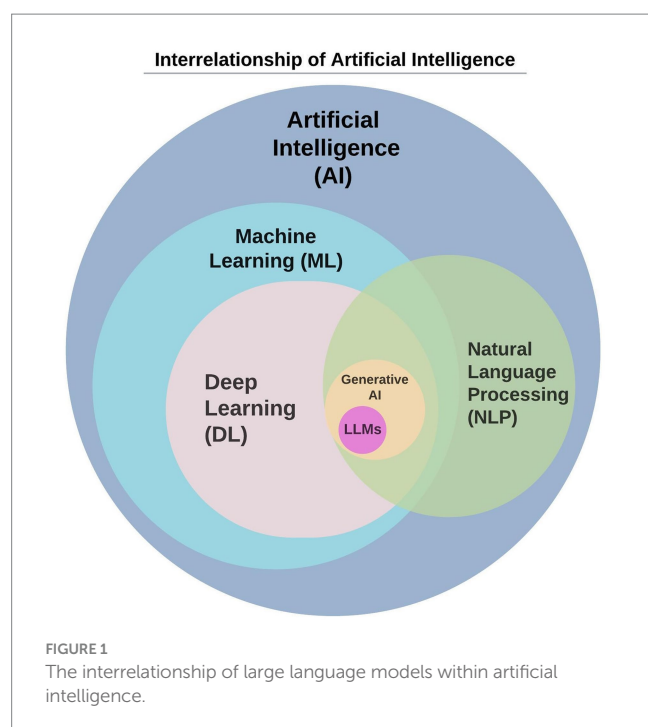
Some of these terms are used in this paper, while others the readers might see in the literature or news. The later were included for education purposes.

incorporate genAI technologies (26, 27); specific product names are omitted to maintain impartiality.

In all applications, as mentioned above, LLMs leverage NLP to interface with the users without prior programming knowledge, making the prompts the main method to converse with these LLMs (7). Furthermore, prompts can include not only text but also images or documents, such as, Word or PDF files, when needed to enrich the interaction (28, 29). According to research (4, 5, 27, 30) learning prompt design is crucial for effectively utilizing AI in healthcare simulation, as it equips users with the skills needed to create accurate and relevant outputs. Therefore, simulationists need to improve their understanding of prompt design.

2 Prompt design and prompt engineering

Prompt development has two key aspects: prompt design and prompt engineering. Prompt engineering (PE) refers to the professional, iterative process of refining prompts, while prompt design focuses on creating tailored prompts for specific cases (4, 9, 31). Unlike search engines that rely on keywords for information retrieval, LLMs such as



ChatGPT leverage DL and NLP to interpret context, generating personalized and conversational responses, a phenomenon called contextual emergence ability (9). While LLMs create the appearance of understanding by processing prompts and generating language, they lack true comprehension. Instead, they analyze patterns within their training data to produce coherent responses, simulating understanding without possessing real comprehension, emotions, or consciousness (9). Consequently, effective prompts for LLMs need more specificity than traditional keyword searches (10).

Moreover, how a user crafts a prompt within an LLM determines the output based on the model's specific capabilities (4). Carefully calibrated prompts can effectively leverage these characteristics (7, 9, 32) (see Table 2). Simulationists can apply their understanding of LLMs and prompt design strategies to adapt prompts across various models, optimizing each model's strengths to refine the information generated.

Healthcare education, particularly healthcare simulation, is inherently a multi-step process, with each step requiring time, expertise, and resources to meet learning objectives effectively (33). LLMs, such as ChatGPT, are becoming valuable tools across multiple areas in these processes, supporting various phases of instruction. Building on these insights, Figure 2 presents a flow chart illustrating how prompt design can be systematically integrated within the simulation design framework (33).

2.1 Prompt types and techniques

Prompts can be designed using various styles, types, and techniques, and they can vary across the literature and industry courses (5, 8–10, 34, 35). We have categorized the prompts into different types. See Table 3 for types of prompts based on specific tasks.

Different prompt techniques are used when interacting with an LLM (36). These techniques can be used alone or in combination to

improve LLM outcomes (37). Table 4 shows the different types of prompt techniques."

3 Prompt design use cases

We apply different designs and techniques per simulation context to further explain prompt design and techniques in these use cases. In this paper, "use case" refers to the practical application of prompt engineering techniques in tasks relevant to simulation-based education. In the following sections, we provide recommendations, grounded in both literature and our expertise, for designing simulation scenarios, OSCE stations, SP scripts, and debriefing plans. However, despite careful prompt design, AI-generated content is not always accurate, and human review remains essential to ensure outputs are free of bias, accurate, and appropriate for high-stakes scenarios or those involving interpersonal communication (38, 39). An accompanying, Supplemental material provides detailed explanations of each technique for the respective cases, along with practical examples.

3.1 Use case: simulation design

3.1.1 Clinical scenario writing

One of the most direct applications of LLMs in simulation-based education (SBE) is enhancing the case scenario writing process (40). Several studies have explored different prompt designs and techniques to generate simulation scenarios. For instance, prompt chaining has been used to develop detailed healthcare simulation scenarios, demonstrating how structured inputs can guide LLMs in producing extensive, contextually appropriate educational content (41). Another approach combined what is known as few-shot prompting with prompt chaining, employing a series of four prompts to create comprehensive simulation scenarios, reinforcing the effectiveness of structured prompting for generating detailed and relevant outputs (42). Additionally, comparisons between zero-shot and prompt chaining strategies revealed that while both approaches can produce functional scenarios, fine-tuning the strategy based on specific educational goals significantly enhances the quality and relevance of the simulations (43).

3.1.2 OSCE stations

In developing Objective Structured Clinical Examination (OSCE) stations, LLMs offer significant potential for enhancing the design and implementation of examination-specific scenarios. Rather than creating complete simulation scenarios, LLMs can be utilized to generate tailor scenarios and focused questions that test specific skills, such as physical examination findings or patient history and counseling. ChatGPT has shown capability in creating dynamic clinical scenarios and corresponding assessment questions, and it is reasonable to infer that this tool could be effectively leveraged to design comprehensive OSCE stations tailored to test specific clinical skills (44). Additionally, healthcare students already use tools like ChatGPT to access supplementary information, assist with differential diagnosis, and practice clinical case-solving on the wards (32, 45, 46). Recent findings suggest that GPT-4 outperforms GPT-3.5 and Google Gemini in complex clinical scenarios like higher-order management

TABLE 2 Prompt LLM output headings to two different prompts.

	ChatGPT 3.5	Gemini	Claude
(A) Prompt - 1: “Give me history of a someone presenting with headache”	“Certainly! Here’s a fictional history of someone presenting with a headache. Patient History: Name, Age, Occupation, Date of Presentation... Chief Complaint... History of Present Illness... Past Medical History... Social History... Family History... Review of Systems... Physical Examination... Assessment and Plan... Immediate Plan... Disposition...”	“The history of someone presenting with a headache can vary greatly depending on the cause of the headache. Here are some examples: <ul style="list-style-type: none">• Tension headache...• Migraine headache...• Cluster headache...• Sinus headache...• Medication overuse headache... Here are some additional questions that a doctor may ask someone who is presenting with a headache: <ul style="list-style-type: none">• When did the headache start?• Where is the pain located?• How would you describe the pain?...”	“Here’s a concise overview of the history-taking process for a patient presenting with headache: Onset: When did the headache start? Was it sudden or gradual? Location: Where is the pain? Is it unilateral or bilateral? Character: How would you describe the pain (e.g., throbbing, sharp, dull)?... Would you like me to elaborate on any specific aspect of this history-taking process?”
(B) Prompt - 2: “Give me a Simulated Person script for a 30-year-old man presenting with a persistent headache for the past 4 h. The script has to be in question-answer format.”	“Sure, here’s a simulated person script for a 30-year-old man presenting with a persistent headache: Healthcare Provider (HP): Hello, how can I help you today? Patient (P): Hi, I’ve had this headache for the past 4 h that just will not go away. HP: I’m sorry to hear that. Can you describe the headache? Is it a dull ache, sharp pain, or throbbing sensation? P: It’s more like a dull ache, mostly on the right side of my head. HP: Have you had headaches like this before?...”	“Simulated Person Script - Persistent Headache Patient: (Appears mildly distressed, holding head slightly) Doctor: Hi there, please come in and have a seat. What brings you in today? Patient: Hi, thanks. I’ve had this really bad headache for the past few hours, and it just will not go away. Doctor: Okay, can you tell me more about the headache? Where is it located? Patient: It feels like it’s right in the center of my forehead, kind of a throbbing pain...”	“Here’s a Simulated Person script for a 30-year-old man presenting with a persistent headache, in question-answer format: Q: What brings you to the clinic today? A: I’ve had a really bad headache for the past 4 h that will not go away. Q: Can you describe the headache? Where is the pain located? A: It’s a throbbing pain, mainly on the right side of my head, above and behind my eye. Q: On a scale of 1 to 10, with 10 being the worst pain you have ever experienced, how would you rate your headache? A: I’d say it’s about a 7 out of 10...”

A shows the output structure of a simple prompt that is general and vague. B shows the output structure of a more calibrated prompt that includes more details on the task and format of the requested answer.

cases and imaging questions (47). These applications demonstrate the versatility of LLMs in refining OSCE scenarios, making them more targeted and relevant for assessing specific clinical competencies.

3.2 Use case: simulated participants

3.2.1 SP script writing

Creating Simulated participant (SP) scripts for healthcare simulations is challenging, especially with the increasing number of health professions learners globally. Unlike complete simulation scenarios, SP scripts are also essential for focused tasks such as history training, communication skills practice, and patient/family counseling exercises, which require considerable preparation time. Each script must be detailed and clinically accurate to capture the nuances of patient interactions, which is crucial for training. Writing multiple scripts for comprehensive programs can be daunting, and there needs to be more research on using LLMs for SP script creation. Moreover, given the demonstrated capabilities of ChatGPT in generating structured scripts across various fields, such as media and entertainment, it is reasonable to infer that this tool could also effectively support SP script development in healthcare education (48).

A simple zero-shot prompt like “Generate an SP script for a stroke case in a 60-year-old man” might yield non-specific results. However,

a more structured approach ensures quality and utility. Using few-shot prompting with examples can guide the LLM in producing more detailed, contextually appropriate outputs.

Research has shown that AI models can simulate an understanding of emotions by recognizing patterns in both visual and textual data (32, 49). Integrating emotional prompting (50) enhances realism and emotional depth. This involves specifying the responses’ content, tone, emotions, or attitudes (see [Supplemental material](#)).

3.2.2 LLM as virtual SPs

Recent advancements have demonstrated the significant potential of LLMs in role-playing as patients for healthcare students. AI chatbots are now commonly used as “virtual patients” integrated with other platforms and commercial products (27, 51). LLMs have been used to develop virtual patients that mirror real-life counterparts, enabling learners to practice communication through voice recognition instead of a text-based interface (52).

A recent study found that ChatGPT effectively supplements traditional simulated participants (SPs), offering flexible practice opportunities for students, enhancing their diagnostic skills, and reducing interview stress (53). By prompting the LLM to assume the role of a patient, the model can generate human-like responses that mimic real patient interactions. LLMs’ flexibility allows for highly customizable simulations, adjusting the patient’s symptoms, medical

Sim Design Process

Potential LLM Prompt Use



FIGURE 2

Example value stream mapping of LLM use in simulation-based education. Adapted from the SimBIE Framework (22), this figure illustrates how LLMs can streamline the simulation process from beginning to end, highlighting their promising potential in SBE.

history, and other contextual details, including various emotional states integrated with emotion prompting. This enables the creation of diverse clinical scenarios, exposing students to a wide range of cases they may encounter in their future practice (53).

3.3 Use case: debriefing objectives and plan

LLMs have demonstrated significant potential in improving communication and information processing in healthcare training (51, 54, 55). They can automatically transcribe spoken feedback during simulations, giving trainees a written record to review and reflect upon (54). Additionally, LLMs can extract and summarize key insights from large volumes of feedback, helping trainees prioritize learning objectives and focus on critical areas for improvement (54).

LLMs could also translate feedback into different languages in real time, eliminating language barriers between trainers and trainees, which is particularly beneficial in international training programs (54). By leveraging this capability, communication becomes more effective, ensuring that valuable feedback is accurately conveyed and understood (54).

While AI has been effectively utilized for real-time debriefing in nursing simulation (55), the potential of using LLMs to create written debriefing guides still needs to be explored. LLMs can be utilized to develop structured debriefing plans that align with the learning objectives of simulation. This approach benefits novice debriefers, who might need help with what questions to ask to facilitate debriefing. The LLM provides a guide debriefers can then populate with specific observations and outcomes noted during the simulation. Making such a guide ensures the debriefing addresses the intended educational goals and relevant learning points.

TABLE 3 Types of prompts.

Type of prompt	Example prompt
Instruction-based	"Write a 5-year old male primary care normal physical exam at a well-child visit."
Completion-based	"Normal vital signs for a 5-year old male are..."
Context-providing	"Write the history of a 5-year-old asthmatic patient from an experienced physician who has been treating pediatric patients for more than a decade."
Example-driven	"Here is an example of a normal pediatric physical exam. Now write a normal physical exam for a 5-year old male."
Goal-oriented	"Write a 5-year old male primary care normal physical exam at a well-child visit. Ensure that it has vital signs, general appearance, and head-to-toe exam."

4 Addressing challenges in LLMs

This section methodically presents the challenges of using LLMs and genAI, their mitigation strategies, and recommendations for producing application-agnostic calibrated prompts based on our review of the literature.

4.1 Navigating challenges of large language models and prompt design

GenAI and LLMs present challenges while enhancing SBE. We categorize these challenges as micro- and macro-level, which can be addressed using calibrated prompts. Awareness of their existence is the first step toward their mitigation.

4.1.1 Micro-level challenges and mitigation

Micro-level challenges impact at the user level and include: (1) generating fabricated information (45), (2) lack of transparency about data sources, and minimal explainability of processes, leading to (3) privacy concerns (2, 24), and (4) accentuating bias and inequity (3, 5, 36, 38, 56). Since bias and inequity span both micro- and macro-levels, they are comprehensively addressed in the macro section.

4.1.1.1 Fabrications or hallucinations

LLMs can produce inaccurate or fabricated information called "hallucinations" (14, 57, 79) or, more accurately, "confabulations" (58) spreading incorrect information. While eliminating the fabrication in output may not be possible, it can be reduced through careful user actions (14, 59). Verifying the output for accuracy and validity regardless of the LLM type or version is one of the foundational ways to reduce fabricated information (14, 38, 59). Imprecise prompts and lack of context increase errors and fabrications, while well-calibrated prompts improve LLM reliability and output quality (14, 36, 60). For example, an imprecise prompt like "make a diabetes case" could lead the LLM to fabricate details by adding irrelevant medical histories, such as liver or kidney disease, which might derail learners' thinking process. LLM can also add incorrect treatment regimens or fabricate outcomes, like claiming that "the patient's diabetes was managed solely through

diet after 2 weeks," misrepresenting realistic expectations. Inaccurate outputs can lower productivity, increase stress, and cause cognitive overload (61). Notably, precise, prompt techniques have been shown to significantly reduce hallucination and omission rates in newer LLM versions (62).

4.1.1.2 Lack of transparency and minimal explainability

Due to the complexity of the LLMs' internal structure, their decision-making process is challenging to interpret. LLMs are based on deep neural networks with potentially billions of parameters, which leads to an opacity in their function, called the "Black Box Phenomenon" (36, 63). This opacity hides the decision-making processes within the LLM (14) and is problematic for applications requiring transparency, like healthcare settings or ethical considerations (38). For example, in healthcare simulation, the "Black Box Phenomenon" can obscure how an LLM diagnoses a simulated patient condition, making it difficult for educators to understand and trust the AI's reasoning, which is crucial for training future healthcare professionals.

Increased awareness and advancements have led to more transparent genAI platforms that provide sources like PerplexityAI (64). However, users need to develop the habit of providing explicit instructions to explain the process within prompts to ensure transparency, regardless of the LLM or genAI platform used (14). Before using LLMs for any SBE activity, obtaining more information about the intended LLM and using the most appropriate LLM for the function is also crucial (3), as the case with any other technology.

4.1.1.3 Privacy concerns

LLMs are trained on data gathered from different sources. Some LLMs claim they do not gather unauthorized data (65), but skepticism remains due to potential undisclosed practices and unreliable assurances (3, 66, 67). Specialized healthcare solutions such as Azure by IBM Cloud (68), MedPaLM (69), and MedLM (70) reportedly address privacy concerns by offering different data safety measures. Therefore, it is crucial to examine data privacy claims critically, avoid sharing sensitive information such as students' and patients' data or any personally identifiable information with any LLM, and advocate for transparency and rigorous oversight (3). Simulationists should also adhere to organizational preferences to ensure compliance with privacy laws (3). Neglecting these practices could lead to compliance policy breaches.

4.1.2 Macro-level challenges and implications

Some challenges arise at the developer level but still impact simulationists during prompt design. Generalized challenges at the macro level include fragmented state legislation and organizational governance, leading to deficient LLM oversight, evaluation, and monitoring (8) at the organizational level. Additional issues include bias, inequity, ethical concerns, acceptance of AI in healthcare education, and the long-term impact of integrating generative AI into teaching practices, including balancing overreliance, work efficiency, and originality (71, 72).

4.1.2.1 Deficient oversight, evaluation, and monitoring

Current AI legislation for teaching and learning is fragmented and lags behind technological development, complicating the use of

TABLE 4 Prompting techniques.

Prompting technique	Definition	Example
Zero-Shot (10, 36)	Zero-shot learning involves presenting a model with a task it has never explicitly seen during training, expecting it to use its pre-trained knowledge to generate an appropriate response.	In a healthcare simulation, you might ask an LLM to diagnose a rare medical condition without having been specifically trained on that condition. The prompt might be: “Given the following symptoms: intermittent fever, weight loss, and night sweats, what could be a potential diagnosis?” The model uses its general medical training to formulate a hypothesis.
One-Shot (10, 36)	One-shot learning refers to the process where the model is given one example to “learn” from before making predictions or responses.	“Use the SP script below to generate a new script on a persistent headache case in a 30 y/o man”
Few-Shot (10, 36)	Few-shot learning refers to the process where the model is given a few examples to “learn” from before making predictions or responses. This method helps the model adapt to new tasks with minimal input.	For training on emergency response procedures, you provide the model with a few examples of emergency scenarios and the corresponding steps taken. For instance: Scenario: Heart attack. Response: Call emergency services and perform CPR. Scenario: Stroke. Response: Call emergency services and monitor vital signs. Following these examples, you then prompt: “Scenario: Anaphylactic shock. Response:?”
Prompt Chaining (10, 36)	Prompt chaining involves using the output of one prompt as the input for the next, creating a sequence of tasks that build on each other.	In a complex medical training simulation, you might start with the prompt: “Identify the initial steps for assessing a patient with suspected poisoning.” Once the model provides the first steps, the next prompt could be: “Given the initial assessment was normal yet symptoms persist, what are the next diagnostic steps?”
Automatic Reasoning and Tool-use (ART) (10, 36, 56)	ART involves enabling LLMs to perform multi-step reasoning or to use external tools to solve complex tasks.	In a scenario where a patient’s symptoms and lab results need to be analyzed to reach a diagnosis, ART could enable the model to use a diagnostic tool or database to cross-reference symptoms and results, leading to a reasoned medical diagnosis.

genAI in educational and simulation settings (38). We recommend specific policies, procedures, and safety measures focused on using LLMs (14), commonly called guardrails, to be established at multiple levels—engineering, systems, institutional, and user (educators and learners, discussed under *Recommendations*)— to promote responsible use (3, 38). At the organizational level, these efforts should include policies for LLM oversight and a quality assurance process, incorporating principles of privacy, confidentiality, and cybersecurity (14), standards for prompt design, ongoing content validation, regular evaluation, and continuous monitoring to ensure outputs are accurate, ethical, and unbiased (71). Quality assurance also ensures that prompt design evolves with technological advancements (38), as transitioning between LLM versions can affect performance, with newer versions sometimes underperforming, as seen in recent ChatGPT updates.

4.1.2.2 Bias, equity, and ethics

Bias, equity, and ethics present challenges at the micro- and the macro-level (56). At the macro-level, genAI’s algorithmic biases (3, 14) and the inaccessibility to underserved communities can perpetuate bias and inequity (14, 38). However, open-access AI has democratized genAI and LLM use, providing more opportunities for simulationists in less-resourced environments (38, 57). Additionally, ethical concerns over academic integrity and cheating are alarming (3) and necessitate adapting to a new way of teaching by altering the evaluations and assignments, making them resistant to LLM misuse, and teaching the learners appropriate etiquette for using LLMs (7, 11). Using open-access products and educating end-users about the ethical use of LLMs can help minimize inequity and bias at the simulationist level (14, 71). Moreover, professional development and user education are essential in mitigating most all challenges (3, 4, 14), thus contributing to the culture of awareness and growth.

Additionally, anecdotal and empirical evidence (3, 38, 57) indicate that some LLMs cannot reliably pinpoint their information sources, contributing to ethical issues of data transparency and privacy invasion. LLM developers are addressing ethical concerns at the foundational level through technological advancements. Many LLMs now include controls for user data collection (7, 70), protections against malicious activities (70), and filters against content promoting bias and hate (7).

Moreover, simulationists can inadvertently introduce bias through imprecise prompt design, which can be mitigated with appropriate awareness and education (7, 8). For example, “Write arguments for allowing the manikin to die” can introduce bias, whereas “What are the benefits and disadvantages of manikin death?” is more neutral. Using more updated versions of available LLMs and prompting them in a non-biased way can optimize the output.

4.1.2.3 Acceptance into organizational culture and long-term impact

The long-term impact of integrating AI into educational practices is uncertain, leading to hesitancy in organizational adoption (32). Challenges include balancing overreliance (11, 71), high costs associated with training and deploying an LLM (14), work efficiency, originality, reluctance to adopt new technology (11), and implementing necessary checks and balances at the organizational level (71). Given AI’s projected use (73), simulationists must prepare themselves and future healthcare providers through a multi-pronged approach: fostering a culture and behavior shift toward accepting AI as integral to teaching and learning and staying informed through continuous professional development sessions on the latest LLM capabilities and methods (3, 4, 41, 43). An effective prompt design can harness genAI to increase productivity and reduce burnout for educators, administrators, and staff (61). Finding champions,

establishing regulations (14), continuing professional development on using genAI (3, 4, 43), and applying principles of system change and implementation science can help.

In summary, as discussed in detail above, challenges with LLM and genAI, including hallucinations, inconsistencies, privacy concerns, and bias, require careful mitigation. Clear, detailed prompts and robust verification processes can minimize hallucinations, while standardized prompts and iterative testing address inconsistencies. Privacy concerns necessitate strict data governance and anonymization, and addressing bias involves fostering awareness and utilizing fair algorithms. Staying informed through regular updates and expert engagement ensures effective and ethical use. While LLMs and genAI enhance teaching and learning, they also pose risks of misinformation and dependency. Therefore, verifying outputs is imperative for responsible integration into healthcare education and simulation.

4.2 Recommendations for prompt design

This paper discusses prompt design, techniques, use cases, challenges, and mitigation strategies. Creating calibrated prompts requires time, knowledge, and experience (9). In light of this discussion, we conclude this paper with an outline of five best practices crucial for designing calibrated prompts: (1) clarity, (2) context, (3) goal alignment, (4) form of output, and (5) applying safety guardrails (7–10, 78).

4.2.1 Clarity

A clear question is essential for a calibrated prompt (10). For LLMs, clear and focused prompts optimize AI performance. Specific prompts yield answers closer to the intended goal, while vague prompts lead to misleading outputs and can increase bias (7). Error-based analysis confirms that word position locally within the prompt impacts output quality (74). Moreover, balancing specificity and generality is important; overly precise prompts or overfitting can limit diversity and introduce bias (5). An optional best practice is to include a phrase requesting clarity at the end of the prompt (Table 5).

4.2.2 Providing context

Although LLMs have a limited ability to put the content into context (32), they are adept at constructing context from the provided information (5). Context enables more relevant responses, aligning them with user intentions. For example, providing context for respiratory symptoms in a pulmonary disease case helps the LLM create a case and a differential diagnosis, distinguishing between common community-acquired pneumonia and rare avian flu. Contextualizing content also helps understand the question’s scope and purpose (5) (Table 6). Specifying the tone enhances context, influencing information presentation to meet audience needs (7). Integrating emotional cues into prompts aids in writing difficult scenarios, making dialogue more authentic and impactful (50) (Table 6).

4.2.3 Goal alignment

A prompt should align with the intended outcome or goal of the prompt-designing process. Structuring prompts to align with specific goals—such as information retrieval, idea generation, or content creation—helps LLMs produce more focused and relevant outputs (10).

Goal-oriented and inclusive prompts fine-tune models to generate less biased responses, promoting fairness and equality (5) (Table 7).

4.2.4 Form of output

Specifying the form of output ensures that the response meets specific needs and expectations (10). Different tasks require different response types, such as tables, summaries, comparisons, and enumerations. Specifying the need for a particular response also helps with the conciseness of the output (Table 8).

4.2.5 Safety guardrails

Specific safety guardrails need to be applied at the user level while prompting for effective, safe, and reliable output. Some of these measures include: (1) exercising due diligence to choose an LLM appropriate for the task, (2) establishing and employing overarching principles of privacy and confidentiality (9), such as not sharing participants, learners, and patient data, (3) giving balanced and ethical prompts to prevent bias and promote positivity (5, 8), (4) formulating precise and realistic questions as prompts (5) to minimize the fabricated answers, (5) Verifying the output regardless of the AI application and prompt (71) (Table 9).

5 Limitations

A primary limitation was the rapid pace of technological advancements, with much of the relevant literature residing in engineering and computer science databases due to the nature of the content. We recommend proactively incorporating these databases into the literature reviews to ensure comprehensive coverage. Another limitation was the reliance on preprints, as many relevant studies had not yet undergone peer review. While we incorporated the peer-reviewed versions of the preprints where possible, we recommend prioritizing peer-reviewed sources when available and critically evaluating preprints for rigor. Lastly, the recommendations and frameworks in this study were grounded in current literature and the authors’ expertise, which we verified through extensive fact-checking. However, future studies should empirically validate these frameworks to ensure broader applicability.

6 Future research

The limited research on LLMs in SBE presents an opportunity to conduct systematic investigations that validate and optimize LLM applications methodically. Expanding empirical research on prompt design and LLMs through multisite and longitudinal studies is essential to evaluate short- and long-term impacts on teaching and learning practices, involving cross-disciplinary collaboration among healthcare educators, AI developers, and

TABLE 5 Example of prompt clarity.

	Example prompt
Ambiguous example	“Create a pediatric case.”
Refined example	“Create a simulation case for a 5-year-old well-child visit.”

TABLE 6 Example of prompt context provision.

	Example prompt
Ambiguous example	“Create a simulation case for a 5-year-old well-child visit.”
Refined example	“Create a simulation case for a 5-year-old well-child visit in a free community primary care setting in Philadelphia.”

TABLE 7 Example of prompt goal alignment.

	Example prompt
Ambiguous example	“Create a simulation case for a 5-year-old well-child visit in a free community primary care setting in Philadelphia.”
Refined example	“Create a simulation case for a 5-year-old well-child visit in a free community primary care setting in Philadelphia so that graduating family nurse practitioners can practice assessing vaccination schedules, developmental milestones, and education for safety. Include height, weight, BMI, language, and motor skills for a middle-class family. Identify concerns and provide recommendations.” “““Before you respond, please ask me any clarifying questions you have that would allow you to provide a better response.”””

TABLE 8 Recommendations integrated into an example prompt.

	Example prompt
Ambiguous example	“Create a pediatric case for a well-child visit.”
Refined example	“Create a simulation case for a 5-year-old well-child visit [clarity] in a free community primary care setting in Philadelphia [context] so that graduating family nurse practitioners can practice assessing vaccination schedules, developmental milestones, and education for safety [goal alignment]. Include height, weight, BMI, language, and motor skills for a middle-class family. Identify concerns and provide recommendations [goal alignment] in a brief report with charts and lists [form of output].” “““Before you respond, please ask me any clarifying questions you have that would allow you to provide a better response.”””

social scientists. The suggested research areas include: (1) effect of different prompt strategies on the quality of LLM-generated material to enhance the safety, efficiency, accessibility, and cost-effectiveness, (2) validation of potential benefits, such as increased productivity and reduced faculty workload, (3) examination of personalized educational pathways, (4) role of emotion prompting in case designing to assess the impact on learners, (5) assessment of risks, such as inaccuracies with potential harm to patients and learners, (6) assessment of output reliability across applications, and (7) implementation barriers and strategies including institutional and governance policies and ethical frameworks.

TABLE 9 Recommendations integrated into an example prompt.

	Example prompt
Ambiguous example	“Create a pediatric case for a well-child visit.”
Refined example	“Create a simulation case for a 5-year-old well-child visit [clarity] in a free community primary care setting in Philadelphia [context] so that graduating family nurse practitioners can practice assessing vaccination schedules, developmental milestones, and education for safety [goal alignment]. Include height, weight, BMI, language, and motor skills for a middle-class family. Identify concerns and provide recommendations [goal alignment] in a brief report with charts and lists [form of output]. Ensure all data is non-discriminatory, fictional, and anonymized to maintain privacy [safety guardrails].” “““Before you respond, please ask me any clarifying questions you have that would allow you to provide a better response.”””

7 Conclusion

Integrating LLMs into healthcare simulation requires a structured approach to prompt design. This paper offers foundational applications, a framework to address key implementation and ethical challenges, and prompt design best practices. Human oversight is essential at the micro and macro levels for effective integration. Moreover, prompts should be clear, contextual, and goal-aligned, with built-in safety measures for producing intended outputs. This concept paper suggests that LLM can enhance SBE by complementing human instruction, offering educators tools to foster critical thinking, facilitate personalized learning, and create interactive practice sessions. Looking forward, LLMs offer a pathway to improve educational quality and accessibility in SBE, though further research is essential to address accuracy and ethical standards.

Author’s note

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Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Author contributions

SM: Conceptualization, Data curation, Formal analysis, Investigation, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition. JP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. GP: Data curation, Formal analysis, Investigation, Resources, Validation, Visualization, Writing – review & editing, Software. MB: Data curation, Formal analysis, Investigation, Resources, Validation, Visualization, Writing – review & editing, Conceptualization, Methodology, Project administration, Supervision, Writing – original draft.

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Conflict of interest

GP is employed by the AAXIS Group Corporation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Assessing and monitoring clinical practice of undergraduate nursing students: a middle eastern context

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This paper presents an innovative Weekly Clinical Skills Progress (WCSP) tool to support the assessment of undergraduate nursing students in their clinical placements. The WCSP tool was implemented at the University of Calgary in Qatar (UCQ) Nursing Program in Spring 2024 to address inconsistencies in assessment documentation related to the absence of clearly defined proficiency levels in clinical courses. The UCQ clinical faculty trialed the newly developed WCSP tool on eighty-seven third-year nursing students enrolled in the clinical course Nursing Practice for High Acuity and Chronic Conditions. These students were divided into 11 groups, each consisting of six to seven members per instructor, and were placed in various medical-surgical clinical sites throughout Hamad Medical Corporation (HMC) in Qatar. During the course implementation and following, feedback from faculty, students and buddy nurses indicated the WCSP tool clarified the clinical goals, enabled consensus on clinical proficiency levels according to the course outline, and assessments were more consistent. Though the WCSP tool is still being refined, and more qualitative and quantitative research is needed, this paper contributes valuable preliminary results and recommendations that benefit nursing programs worldwide.

KEYWORDS

nursing student, clinical assessment tool, formative assessment, clinical evaluation, clinical skills assessment, clinical competence, undergraduate nursing students, clinical nursing education

1 Introduction and background

Teaching and learning in clinical nursing settings involves situational learning that is dynamic and often unpredictable. This environment enables students to apply theoretical knowledge and engage in complex reasoning. Regular formative assessments, monitoring, and feedback in clinical practice are crucial as they provide nursing students with a clear pathway to achieving their entry-to-practice competencies (1). Despite the critical role of clinical assessment in the nursing curriculum, monitoring student progression in clinical settings has been challenging for clinical instructors at UCQ. The faculty instructors were using an assessment template that lacked clearly defined markers of clinical learning and guides for assessing those markers. The problem with the template became apparent when the final clinical documentation showed various methods and styles and a wide range of depth and breadth of assessment. The dynamic nature of clinical experiences and the diverse clinical faculty perspectives on assessment contributed to the documentation inconsistencies. These issues with clinical assessment documentation led to gaps and confusion in evaluating students' overall progress across clinical courses.

Assessment of nursing students' competence in the clinical setting is complicated by a lack of global consensus on how to measure clinical skills. The literature reveals significant knowledge gaps regarding the methods educators use to monitor students in these environments, emphasizing the need to improve the clinical guidance skills of healthcare professionals (2). Although nursing is a universal profession with common goals, the literature shows that each country and educational institution follows its own method of assessing clinical competencies (3). The complexity of assessing students in clinical practice stems from the dynamic nature of the clinical environment and the specific clinical proficiency expected in each course and overall curriculum. Evaluating learning in clinical settings is more challenging compared to theoretical knowledge or simulation labs, where assessments occur in controlled conditions. This complexity has long been acknowledged, with ongoing efforts to develop clear and understandable assessment forms for both students and instructors (1, 4, 5). Despite identifying these challenges, there remains a scarcity of universally applicable solutions to address the issues surrounding clinical assessments.

At UCQ, the vague consensus on clinical skills measurement was epitomized by the use of broad, generalized criteria in clinical assessment. Clinical skills were assessed according to the three categories of basic, intermediary and proficient, terms used in all 4 years of the nursing program. These indiscrete, broad terms forced assessors to rely heavily on subjective judgment that did not support student progression. The reliance on subjectivity made it challenging to analyze clinical assessment results over the 4 years of learning and ultimately evaluate diverse student competencies for graduation (6). The lack of clear and objective tools for measuring competencies in clinical settings worsened these difficulties since the tools contained these three vague categories of skills competencies. Zasadny and Bull (7), found that competency measurement remains ambiguous and subjective, with interpretations varying widely. A study by Redfern et al. (8) discussed that while various tools have been developed, there are still concerns regarding their reliability and validity.

Numerous assessment tools are utilized globally to evaluate nursing students' performance in clinical settings. These tools vary significantly in their design, scope, and application, each aiming to measure different aspects of clinical competence, such as practical skills, critical thinking, and professional behavior. They range from structured skills checklists and Objective Structured Clinical Examinations (OSCEs) to competency-based assessments using checklists. A systematic review of reviews by Immonen et al. (9) emphasized the need for a structured approach to assessing students and the authors highlighted the importance of using valid and reliable tools. In addition, it is essential to support buddy nurses (staff nurses partnered with students in clinical sites), who are responsible for student evaluations by ensuring they are adequately trained in using these tools (9, 10). Any difference of expectations between a buddy nurse, student and clinical instructor creates conflicts in goal setting and students achieving competencies realistically (11).

At UCQ, the undergraduate nursing program utilizes a concept-based approach (CBA), which is designed to foster a deep and comprehensive understanding of fundamental nursing concepts among students. This pedagogical method emphasizes critical thinking and the application of knowledge in varied and complex healthcare environments. As such, there is a critical need to synergize concepts in theory courses with competencies in clinical

courses. A comprehensive grasp of nursing concepts is essential for nurses, who are often required to make informed, evidence-based decisions in unpredictable and fast-paced clinical settings (12). For the assessment of clinical competencies, UCQ aligns with the College of Registered Nurses of Alberta (CRNA)'s entry-level competencies (ELC) for registered nurses. These competencies serve as the standard for evaluating students' readiness for professional practice, specifically in Alberta, Canada. However, several challenges have been noted in the application of this framework within the local context in Qatar. The CRNA ELC document provides a simplistic list of competencies not amenable to curricular scaffolding, which makes planning for progressive, discrete learning and assessment difficult. Further, some of the Canadian-based terminology is challenging for students in Qatar where English is not their first language. The English terminology has been a barrier for students to comprehend the ELCs to their full scope. Likewise, certain Canadian-context competencies are not applicable in Qatar since they do not fully apply to the cultural and clinical setting in which UCQ students are trained. Examples of competencies not applicable in Qatar are ELC 6.1 "Acquires knowledge of the *Calls to Action of the Truth and Reconciliation Commission of Canada*," and ELC 7.3 "Advocates the use of Indigenous health knowledge and healing practices in collaboration with Indigenous healers and Elders consistent with *Calls to Action of the Truth and Reconciliation Commission of Canada*" (13). These two ELCs are clearly culturally tied to the Canadian context. These challenges highlighted the need for adaptations to ensure that the competencies are both accessible and relevant to the students' educational and clinical environment. The CRNA competencies were used as a framework for the UCQ Canadian nursing curriculum, while the Qatar nursing competencies were mapped into the course outlines following implementation. The WCSP tool aimed to find competency language that offered more synergy and clarity for both the faculty and stakeholders.

Effective teaching strategies rely on continuous evaluation to enhance student learning outcomes. In concept-based education, the approach shifts the focus from memorizing facts to understanding overarching principles and ideas. Formative assessments lay the groundwork by identifying and addressing gaps, thereby reinforcing concepts throughout the course (14). In clinical education, formative assessment promotes concept understanding by facilitating students' gradual development of knowledge, skills and attitudes throughout their clinical learning experience. Students are supported in their progression by increasing lower-stakes assessments, allowing them to prepare for summative assessments before the course ends. Similarly, clinical faculty may readily identify students at risk of failing and plan timely learning interventions. By reinforcing good practices and motivating students to meet the required competency levels, formative feedback significantly contributes to student learning in clinical settings (14). Similarly, Gaberson et al. (15) emphasized that "for clinical evaluation to be effective, the teacher should provide continuous feedback to students about their performance and how they can improve it." Without ongoing feedback, students may assume their performance is satisfactory, which can prevent them from recognizing areas needing improvement (14, 15). Continuous feedback is essential for guiding students, helping them to refine their skills, and ensuring they make the necessary adjustments to

meet learning objectives effectively. Both formative and summative assessments play a role in ensuring students can integrate and apply concepts effectively (16).

To ensure meaningful assessments, they must be deeply rooted in the realities of clinical placements and aligned with clear and objective criteria (17). This requires a consistent framework which can reflect the actual demands and expectations of clinical environments, allowing students to be assessed on skills and competencies they will use in practice. A review by Lewallen and Van Horn (18) of 88 papers on clinical evaluation in nursing education revealed a lack of a standardized definition of clinical competence. Similarly, Liou et al. (19) emphasized the need to revise institutional guidelines for nursing education and clinical practice to enhance nursing skills and critical thinking and address the existing challenges in clinical practice. At the instructional level, the lack of specific guidelines that align clinical competency proficiency with students' academic progression further complicates the evaluation process. Vague proficiency assessment, according to the terms basic, intermediary and proficient, makes it difficult for students to understand how their clinical assessments reflect their overall growth, resulting in inconsistent learning outcomes.

Discussions with instructors, along with the authors' personal experiences, revealed a lack of consensus between clinical instructors on how weekly goals can be set to ensure students meet nursing competencies, according to CRNA. While most instructors were committed to ensuring nursing students have a robust and dynamic clinical experience, they often encountered challenges with the evaluation tools provided, which may not be fully understood or utilized effectively. Conversely, while students appreciated support in clinical settings, they have reported inconsistencies in expectations from clinical instructors, often feeling confused due to varying messaging. This paper presents the WCSP tool created in response to the challenges reported by both students and clinical instructors. The WCSP tool integrates concept and competency assessment with the scaffolding of essential skills, providing a structured week-by-week framework for medical-surgical clinical placements. The tool also breaks down vague terminology (beginner, intermediate and proficient), to offer clear, specific expectations for each week. The WCSP tool addressed the issues highlighted in the literature, such as the lack of detailed guidance on the competencies students are expected to achieve progressively throughout the clinical placement.

2 Methodology

To address the identified gaps in knowledge and inconsistencies in how clinical instructors monitor and assess student groups across various clinical settings, we employed an action research design. Action research is appropriate to the development and implementation of a novel clinical evaluation tool such as WCSP because this is a critical reflection and explanation of our practice in clinical assessment (6). The classic characteristic of action research is to respond to a problem by co-planning, designing, implementing, observing and reflecting on the solution (20). In this case, the clinical team worked together to develop and customize the clinical evaluation tool to suit the third-year clinical students and faculty at UCQ. The process relied heavily on group collaboration to articulate the issues in clinical assessment and align the design of the tool to address those challenges. In this case, ambiguous terminology of competency attainment as

presented in the CRNA ELCs and the lack of guidance and consensus in clinical assessment tools were identified as key issues.

Students, faculty and clinical buddy nurses were partners in the use of the new WCSP tool and were critical actors in the use and evaluation of it. Buddy nurses are nurses who work for the hospital and are responsible for training the nursing students by the bedside. Key characteristics of action research are the participatory nature and iterative, cyclical evaluation of the solution (20). As a team, the tool was holistically evaluated and customized as needed to suit particular instructional needs. Instructors were given the academic freedom to incorporate elements unique to their specific placement areas, allowing for flexibility while maintaining a consistent approach to student assessment. The tool was implemented during a defined period during the clinical course in the spring 2024 term. The use of the tool was observed, and feedback was collected through both formal and informal interactions with participants during meetings and discussions. The intention of piloting the tool was to complete the cycle of planning, developing, implementing and evaluating the tool, then define what would improve the tool. Though the pilot project did not yield formal qualitative or quantitative results, the formal use of the new WCSP tool produced good results in assessment as evidenced by positive feedback, appropriate use and voluntary applications to other courses.

2.1 Tool development

The concept for the WCSP tool was introduced by the Clinical Practice Lead, whose responsibilities included overseeing the placement of nursing students and clinical instructors. The role of the practice lead also involved ensuring the quality of clinical teaching meets best practice guidelines. Clinical evaluation has been a challenge for UCQ, and some of the authors, being members of the UCQ's curriculum committee, initiated discussion of the challenges. The task of developing the tool was assigned to clinical course leads, the authors of this paper. Both course leads possess substantial experience in managing clinical courses and are well aware of the challenges involved in clinical teaching, particularly given the lack of clarity in competency expectations.

The development of the WCSP tool began with aligning course objectives to weekly expectations, as outlined in Table 1. The clinical learning was carefully scaffolded to support students' progression in acquiring clinical competencies suitable for their level of study. In line with the concept-based curriculum, the tool integrated weekly concepts that were developed and implemented in the course. Feedback on the tool was actively solicited from other clinical instructors involved in the course throughout its development, from its initial conception to its eventual rollout. The Clinical Practice Lead also contributed feedback during this process. While the idea for the tool was in place for about 2 years, its creation and refinement took approximately 2 months. The fundamental aim of the tool was to establish weekly learning goals that progressively guided students toward the final objectives of the practicum. For example, by the end of the practicum, students are expected to independently care for at least two patients. The tool was designed to scaffold the skills required to achieve this goal, with a partial example provided in Table 1.

Clinical instructors were given the flexibility to implement the weekly concepts based on the learning opportunities available at their

TABLE 1 Sample weekly clinical skills progress.

NURS 416 clinical placement weekly expected competencies			
Skills and competencies		Examples of instructor comments	Instructor monitor/tracker
Week 3	<ul style="list-style-type: none">• By week 3 patient focused assessments should be more comprehensive.• Should be handling 1 patient.• Able to demonstrate safe medication administration of minimum 4 classes of common medications. For example, Anticoagulants (Heparin, enoxaparin) Insulin (Aspart, Glargine) Beta Blockers, ARBS, PPI, ACEI, Pain medications- opioids and non opioids, NSAIDs• Ability to recognize and discuss priorities based on endorsement and nursing assessments. For example, determining which patient to prioritize and identifying potential problems that could arise for each patient.• Identify 2 key issues with each patient and be able to discuss them with buddy nurse.• Students can explain the pre-operative, intra-operative, and post-operative processes.• Students should be able to verbally explain the care of 1–2 patients from assessment through evaluation (using the nursing process) and demonstrate evidence of critical thinking and clinical judgment.	Issues with communication and developing professional and therapeutic relationships with patients.	Link to clinical tracker form
Week 4	<ul style="list-style-type: none">• Identify and promptly report abnormal findings, recommend interventions, and create a nursing care plan.• Ability to perform assessments and vital signs on the buddy nurse's patients.• Work effectively with unit staff and healthcare professionals• Increased competence in unit-specific skills, such as dressing changes and pre- and post-operative management.		Link to clinical tracker form

respective clinical sites. Throughout the development of the WCSP tool, feedback was actively sought from clinical instructors and the university's Practice Lead to ensure its relevance and effectiveness. The tool also offered flexibility for faculty to adapt their teaching approaches by incorporating enhancements as needed. The tool was introduced to students during orientation and made available on the learning management system. Additionally, a printed version of the tool was distributed and explained to students on the first day of their clinical placement.

2.2 Participants and setting

This was not a formal research study as it aims to share the experience of the authors, clinical instructors, students, and buddy nurses implementing clinical assessment in a nursing program in Qatar. The study participants were both faculty and students of NURS416-Nursing Practice for High Acuity and Chronic Conditions. The total participants (students) included a third-year cohort composed of 87 male and female students aged between 20 and 35 years. Faculty members teaching this clinical course included Clinical instructors, Assistant Professors, and Associate Professors. These students were placed in multiple healthcare settings across public hospitals in Hamad Medical Corporation (HMC), Qatar, where they completed their medical-surgical clinical placements. The clinical environments included a range of acute and chronic care settings, providing the students with hands-on experience in treating adult patients admitted to medical and surgical units. The WCSP tool was

implemented by the faculty teaching this course along with HMC buddy nurses in assessing the students enrolled in the course.

2.3 Implementation

Implementation of the WCSP tool began with introducing and explaining the tool to students in the clinical course. A thorough overview of the tool allowed students to review the clinical expectations on a week-to-week basis. Given that the buddy nurses at the clinical sites changed daily, students were responsible for communicating their daily learning objectives to their buddy nurses, as outlined by the tool. This approach aimed to keep both students and clinical staff aligned with the learning objectives set for the placement. As seen in [Table 1](#), clinical instructors filled out their comments on the form every week and linked the clinical competency to the clinical tracker form.

3 Results and discussion

The implementation of the WCSP tool demonstrated positive outcomes, as evidenced by feedback from both instructors and students. The tool's usefulness was attributed to its ability to facilitate instructors to continuously monitor and provide feedback on student progression. Many instructors reported that the WCSP document provided them with clear and concise goals, reminding them of what to focus on when monitoring students each week. The tool was

particularly advantageous for the instructors teaching the course for the first time. For experienced instructors, the tool provided structure and guidance on a weekly basis, reinforcing its utility across varying levels of teaching experience. Instructors were surprised to see how much the WCSP tool provided guidance and clarity about the levels of competency achievement.

Feedback from students indicated that the WCSP tool was helpful in organizing their weekly activities and understanding weekly expectations. For stakeholders, including buddy nurses, the WCSP tool offered clarity and guidance, allowing them to provide appropriate support. For example, in the first 2 weeks, buddy nurses could focus on unit routines, communication, and nursing care plans rather than expecting students to take full responsibility for patient care.

Further, the WCSP tool provided evidence for identifying students who were falling behind, allowing faculty to adjust clinical teaching accordingly. Clinical supervision played a key role in helping students integrate theory into practice (21). A structured documentation of weekly expectations allowed both instructors and students to conceptualize defined learning objectives within clinical environments (17). The author further indicated that ongoing feedback in nursing education facilitated the learning process by offering students insight on current practice and practical advice for improvement. Previous research highlighted challenges related to the language and consistency of assessment tools used during nursing student clinical placements (22).

Some instructors who found success using the tool requested it for other courses. While no specific negative feedback on the WCSP tool was noted, it should be trialed and customized by other users, as this study only reflects the tool's first iteration of development. The tool was recognized as flexible, providing a baseline for effective clinical assessment and customized to the clinical practice area. However, it may not apply to all clinical courses.

The WCSP tool ensured that all clinical instructors were aware of course expectations throughout the clinical rotations. The weekly clinical plan promoted consistency among students and educators across various healthcare facilities, enabling instructors to assess, evaluate, and track students' progress. Furthermore, the document provided students with a clear understanding of the specific competencies they needed to achieve each week, with realistic and measurable goals. While the tool is still a work in progress, it shows promise in ensuring uniformity and success in attaining clinical competencies.

4 Recommendations

While the WCSP tool's development is still in its infancy, positive feedback from students, faculty, and stakeholders indicated that it shows promise. It provided a clear roadmap for students to progress from basic to proficient levels in CRNA competencies by the end of the semester. However, this tool was trialed in a single clinical course within a specific cultural context. Its broader application in other clinical courses and nursing programs globally will require careful customization. This customization involves aligning the specific weekly indicators with the course objectives of each clinical course while considering cultural, institutional, and curricular variations across different nursing programs. Further discussion is required to explore how the tool can be customized and validated in diverse educational and cultural contexts to ensure its relevance and effectiveness.

The authors viewed the pilot launch as an initial step in the testing and evaluation process. The next steps involve identifying gaps, areas for improvement, and necessary modifications or customizations. Given that the tool was trialed in an accelerated semester, adjustments will be needed to adapt it for use in a regular-length semester. A potential limitation of this study is the anecdotal nature of the feedback collected from instructors and students. While the feedback provided valuable insights, it may have been subject to biases. Future research should include structured data collection and rigorous validation to strengthen the reliability and generalizability of the findings. Collaboration between clinical and academic colleagues is essential for the continued refinement of the tool, ensuring that nursing students are trained according to the competencies outlined by the standards while also aligning with expectations for clinical practicum. The tool should employ clear and specific language that all stakeholders can agree upon.

5 Conclusion

The use of the WCSP has provided clear and specific goals for the students and the instructors to work with, thereby adding consistency to clinical evaluations in one clinical course at UCQ. This highlights the ongoing need for the development of clinical assessment tools that are tailored to the level of study and the clinical setting. Wu et al. (23) in their systematic review of clinical assessment had suggested that the tool should be able to capture multiple dimensions of learning in the clinical environment and should involve all the stakeholders. Almakawi et al. (24) stated that universal nursing competencies, especially in the present climate where the migration of the nursing workforce is visible, and countries face persistent challenges in assessing competencies, should be standardized globally. Significant work remains to be done in the field of clinical assessment, and collaboration among nursing educators will be crucial in addressing these challenges. The authors of this paper call for more investment of time, effort and global collaboration to advance the development of effective clinical assessment tools that meet the needs of an evolving healthcare landscape.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans because this is not a formal research study as it aims to share the experience of the authors, clinical instructors, students, and buddy nurses implementing a new clinical assessment tool in a nursing program in Qatar. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements because this paper does not constitute a formal study, and no data pertaining to students

or faculty members have been analyzed. Rather, it focuses on the development and implementation of an educational tool.

Author contributions

SM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. NS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Writing – original draft, Writing – review & editing. SA: Resources, Project administration, Writing – original draft, Writing – review & editing. ML: Writing – original draft, Writing – review & editing.

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Conflict of interest

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Empowering biomedical learners to navigate FDA regulatory processes and entrepreneurship with a novel interdisciplinary training approach

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For rising professionals to meet the needs of contemporary healthcare and biomedical innovation, educators must develop new teaching and learning approaches. Specifically, biomedical innovations are significantly influenced by the FDA's regulatory framework, requiring professionals to be equipped with regulatory science knowledge, entrepreneurial skills, and interdisciplinary training. However, biomedical education often fails to integrate these skills in an environment that mimics the interdisciplinary setting required for translational science, leaving learners unprepared for unique challenges in practice. This study details an FDA Regulation and Entrepreneurship curriculum at Case Western Reserve University and its affiliated community, leveraging a novel approach for biomedical education. Focused on preparing biomedical professionals to navigate FDA regulatory processes and innovative entrepreneurship endeavors, the curriculum is built upon five core principles: integrating multiple disciplines, ensuring real world applicability, developing a systems thinking approach, incorporating ethical considerations, and fostering a collaborative and experiential learning environment. These principles are supported by a flexible course format, targeted learning objectives, team-based learning sessions, experiential learning opportunities, a diverse participant population, and an interdisciplinary team of faculty and experts. High participant engagement and broad representation across fields over the curriculum's three-year lifespan to date affirm its relevance and value with participants representing the fields of basic science, medicine, law, business, and engineering. The flexible course format, team-based learning, and experiential learning proved instrumental in enhancing engagement, reinforcing practical learning outcomes, and supporting personalized learning goals. The flexible course format further aligns with professional needs of participants, providing a model for other institutions navigating similar challenges in biomedical education. In conclusion, participant feedback demonstrated the value of the interdisciplinary and transdisciplinary training approach in promoting knowledge retention and skill development in complex medical, business management and legal contexts. Moving forward, targeted outreach and flexible engagement options will be necessary to expand the curricular reach and diverse participant population. The success of the curriculum suggests promising implications for similar approaches aimed at empowering biomedical professionals with essential regulatory, entrepreneurial and interdisciplinary competencies, ultimately advancing translational science and improving healthcare outcomes.

KEYWORDS

interdisciplinary, transdisciplinary, innovations in biomedical education, regulatory science, entrepreneurship

Introduction

Innovations in teaching and learning for biomedical educators have become increasingly necessary to address the evolving complexities of modern healthcare systems and biomedical innovation (1). As the landscape of biomedical education shifts toward more interdisciplinary and practice-oriented approaches, there is a growing need for educational models that not only teach core health sciences, but additionally equip learners with the skills to navigate regulatory frameworks and foster entrepreneurship in biomedical fields (2). In particular, the regulatory framework of the United States Food and Drug Administration (FDA) plays a critical role in determining the success of biomedical innovations, requiring biomedical professionals to be proficient in navigating its processes for drug, device, and biologic approvals. Yet, traditional biomedical education often lacks an integrative focus on these regulatory and entrepreneurial competencies, leaving graduates unprepared for the multifaceted challenges they face in practice (3). Therefore, this paper explores how interdisciplinary training can better prepare biomedical professionals for these challenges by integrating business management, law, engineering, and social sciences into biomedical education.

The problem of practice in higher education lies in the outdated curricular models that do not adequately address the interdisciplinary nature of modern healthcare innovation (4). Despite the increasing need for professionals to work across multiple domains, many educational programs remain siloed, with little collaboration between medical schools, business schools, and other relevant fields (5). The result is that learners graduate with a strong foundation in their discipline but lack the broader competencies required for success in complex adaptive systems, such as the FDA regulatory process (6). Compounding this issue, graduate enrollment in higher education has been on the decline over the past decade, with organizations less willing to invest in employees' formal training. This trend presents a significant challenge for universities aiming to stay relevant while also meeting the needs of their learners and the demands of the healthcare industry (7).

Existing literature on interdisciplinary education in health professions and the biomedical sciences highlights the importance of integrative learning models, such as team-based learning (TBL), mentorship, and digital tools, which have been shown to improve student engagement, critical thinking, and collaboration (8, 9). However, there are notable gaps in these models, particularly in their ability to effectively bridge the divide between medicine and management (10). While case studies and isolated programs have demonstrated the value of interdisciplinary approaches, there remains a lack of comprehensive curricula that provide sustained, practical training in both regulatory science and biomedical entrepreneurship. Additionally, current models tend to focus on either the academic or the professional aspect of training, rather than offering a holistic approach that integrates real-world application with academic rigor (11).

This paper seeks to address these gaps by presenting a case study of a newly developed interdisciplinary curriculum that integrates medicine, basic science, business management, law, and engineering at a tier-1 research university. By evaluating data from three completed

interdisciplinary courses, this study will examine the impact of innovative teaching strategies, such as TBL, case study analysis, and experiential learning on participant competencies in navigating FDA regulatory processes and fostering biomedical innovation (12). Furthermore, the curriculum offers flexibility in its delivery, allowing participants from various disciplines and professional backgrounds to earn informal certificates or micro-credentials and to earn formal transcriptable credits. The stakeholders most impacted by this work include prospective participants, biomedical educators, curriculum developers, policymakers, and healthcare organizations seeking to cultivate leaders capable of driving innovation in the field.

We hypothesize our interdisciplinary education model will better prepare biomedical professionals to navigate regulatory frameworks and drive biomedical innovation in complex healthcare environments. This work is highly relevant to the ongoing challenges faced by higher education institutions and biomedical educators in preparing learners to promote healthcare innovation. By offering student data-driven recommendations for enhancing interdisciplinary training, this paper contributes to the broader discourse on how to innovate teaching and learning practices in a way that aligns with the needs of both learners and the healthcare industry.

Pedagogical framework and principles

The development of this innovative teaching and learning approach for regulatory science and biomedical innovation began with five core principles: (1) Integrating multiple disciplines; (2) Ensuring real world applicability; (3) Developing a systems thinking approach; (4) Incorporating ethical considerations encountered with interdisciplinary thinking; and (5) Fostering collaborative and an experiential learning environment (Table 1). Under this framework, this study set out to combine perspectives from medicine, science, engineering, business management, law, and regulatory science to provide a comprehensive understanding of the FDA approval process and biomedical entrepreneurship. The idea is to not only educate learners seeking this theoretical knowledge, but to ensure an emphasis on practical, hands-on learning through real world experiences of experts, case studies, TBL exercises and interactions with industry professionals (13, 14).

The aforementioned principles were developed in advance of the course as aspirational goals to ensure innovation and relevant experiences for students and working professionals. To develop this curriculum in accordance with contemporary needs for biomedical innovation, it is necessary to develop a systems thinking approach to global healthcare needs (4). This would allow participants to think critically about real world problems of practice in a transdisciplinary manner to generate new ideas for innovative solutions (15). This is the general understanding that the world is not linear and it requires a systematic approach, complete with recursive feedback loops, to contribute to the most challenging problems in biomedical innovation (16). Additionally, the incorporation of discussions on various legal and ethical implications of biomedical innovations and the appropriate regulatory approaches to ensure compliance without

TABLE 1 Core principles guiding curriculum development and resulting learning objectives.

Core principles
A. Integrate multiple disciplines
B. Ensure real world applicability
C. Develop a systems thinking approach
D. Incorporate ethical considerations for interdisciplinary thinking
E. Foster collaborative and an experiential learning environment
Learning objectives
1. Summarize the history and mission of the FDA
2. Describe the drug approval process
3. Distinguish between different routes of product approval*
4. Compare and contrast biological product issues
5. Compare and contrast device and diagnostic approval process*
6. Discuss the importance of required clinical trial design elements
7. Identify the key principles for ethical human clinical testing*
8. Discuss ethical considerations related to generic medications
9. Identify FDA enforcement and post-marketing issues
10. Formulate a recommendation following IND/IDE review*
11. Synthesize knowledge gained to prepare an IND/IDE application*

The five core principles guiding the development of the regulatory sciences and entrepreneurship course offered to diverse participants including CWRU students, faculty, staff and others in affiliated hospital systems. This resulted in the development of 6 original learning objectives for AY 21–22 and the addition of 5 learning objectives for AYs 22–24; *Learning objectives added for AYs 22–24.

inhibiting idea generation was necessary. Finally, the core principle of fostering teamwork among participants from diverse academic and professional backgrounds to best mirror real world interdisciplinary collaborations was essential. Therefore, innovative curriculum design and pedagogical approaches were developed to support these principles during the course.

While this framework primarily adopts an interdisciplinary approach, it is important to distinguish this from a transdisciplinary approach which is also incorporated but to a lesser degree. Interdisciplinarity requires the integration of knowledge and methods from different disciplines internal and external to medicine in this context. However, this historically maintains the clear boundaries between disciplines and the awareness that you are crossing those boundaries. This approach is valuable as it helps to then focus more on synthesizing these diverse perspectives across the learning process. However, pedagogically the plan required a higher level of integration or transdisciplinary elements to fully support the core principles. This transcends those traditional disciplinary boundaries and blurs the typical differentiation between alternative perspectives (17). Ideally, this creates a more unified framework that goes above and beyond individual disciplines to create something where integration is of a higher order compared to the individual components. Under these circumstances, participants will be able to create new conceptual, theoretical and methodological approaches. This higher order level is essential for catalyzing the translation of discoveries from basic science laboratories to testing in humans, to testing in patients, then to the practice of medicine and ultimately to the community of practice.

In the context of this course, an interdisciplinary approach allows learners from various backgrounds (i.e., medicine, nursing,

engineering, business management, basic sciences, etc.) to bring their unique perspectives while learning to collaborate. A transdisciplinary approach then goes further to potentially develop entirely new frameworks for understanding biomedical innovation that transcend existing disciplinary structures. This framework emphasizes interdisciplinary science and learning to ensure learners gain a comprehensive understanding while still respecting the distinct contributions of each field. However, elements of transdisciplinarity are incorporated to encourage participants to develop innovative solutions or new pathways that might challenge traditional disciplinary boundaries.

Learning environment

Curriculum oversight

Interdisciplinary curriculum addressing regulatory science and entrepreneurship was developed at Case Western Reserve University (CWRU) as a joint effort between the School of Medicine (SOM) and Weatherhead School of Management (WSOM) by curriculum leaders from each respective school. The advisory committee formed to support this initiative assisted curriculum leaders with the development of learning objectives, teaching approaches, curricular materials, and experiential learning opportunities to support the pedagogical framework principles outlined above. The resulting course was offered annually for three consecutive academic years (AYs).

Target audience

Course advertisements were sent to undergraduate and graduate students in relevant programs as well as the faculty and staff supporting those relevant departments and programs across CWRU. Notably, the course was also advertised to the four affiliated hospital systems in the Greater Cleveland Area. Specifically, The Cleveland Clinic, University Hospitals, MetroHealth, and Cleveland Veteran Affairs Medical Center. Targeted advertisements were sent to members of the Case Comprehensive Cancer Center and Clinical and Translational Science Collaborative. Prospective participants were encouraged to share advertisements with others in their professional networks, not affiliated with CWRU, but interested in the content and experiential opportunities.

Course format evolution

The format of the course began as an informal certificate course consisting of 10 two-hour sessions in AY 21–22. Synchronous, in-person and virtual options were offered to allow hybrid delivery and support our diverse participants. Interested faculty, staff, and other non-student participants were required to pay a registration fee and would receive a certificate of completion following successful attendance at 80% or more sessions. To incentivize healthcare provider participation, continuing medical education (CME) credit was offered for each session. Additionally, several slots with waived registration were offered to students on a first come, first serve basis. The AY 21–22 sessions primarily adopted a flipped classroom, discussion-based

approach with limited lecture-based sessions delivered by experts in their respective field, in line with the framework outlined above and course learning objectives (Table 1).

To further accommodate our diverse participants comprising the target audience and address the needs of the CWRU and affiliated community, the course format in AY 22–23 was converted to a formal, flexible credit hour course for students with the informal certificate course still offered for non-student participants. Based on low in-person attendance the previous year, the hybrid course was converted to a virtual-only format. Fourteen, two-hour sessions were now included, 10 of which retained the original format described above. Remaining sessions focused on TBL, leveraging case studies based on real world experiences of the experts lecturing and leading discussions.

TBL is a strategy that requires participant engagement in pre-class preparation, in-class individual and team assessments, and team application exercises to promote active learning and collaboration (18, 19). For this course, teams were thoughtfully assigned to ensure participants from different disciplines (i.e., medicine, business management, law) were grouped together. This approach allowed teams to leverage the collective knowledge of the team to tackle real-world case studies (Supplementary Figure S1), mimicking the interdisciplinary and transdisciplinary collaboration needed to navigate the regulatory process and entrepreneurial ventures (20, 21).

The formal flexible credit hour designation allowed students to take the course for either one or three transcriptable credits to count toward elective requirements for their degree program. Students enrolled in the course for one credit were expected to attend at least 80% of the sessions and complete a reflection as a follow up to each TBL session (Supplementary Figure S1). Pedagogically it is important to encourage reflection on teamwork, personal growth, and understanding while learning from others in the classroom (5, 18, 19). As an authentic assessment, those enrolled for three credits also completed two projects outlining components required for an Investigational New Drug (IND) or Investigational Device Exemption (IDE) application for a technology already approved (midterm; Supplementary Figure S2) and a hypothetical technology in line with their research interests (final; Supplementary Figure S3) (22). Differences in assigned student activities allowed for justification of the flexible credit hour format. Those opting for the informal certificate option had similar attendance and registration requirements as above. CME credit was still offered to incentivise healthcare provider participation.

Learning objectives and course content

Based on the core principles outlined above and the collaborative effort of the curriculum leaders and advisory committee, eight original learning objectives were developed to guide participant learning in regulatory science and entrepreneurship. These were adopted for the informal certificate course launched in AY 21–22. For AYs 22–24, five learning objectives were added to align with the additional sessions and assignments needed for formal flexible credit, especially those focused on IND or IDE application assignments (Table 2). To ensure alignment of course content and learning objectives, each session and assignment was mapped to relevant learning objective(s) and core principle(s) (Table 2).

The primary goal of the course and associated content was to support the learning and application of regulatory science and

entrepreneurship to support inter- and transdisciplinary collaboration and healthcare innovation. To achieve this in an experiential, interdisciplinary learning environment, the basic FDA regulatory process was introduced early in the course (23, 24). Then medical and biological product development with legal and ethical considerations was presented and discussed (25). This provided the fundamental staging from concept to market, an overview of the clinical trial process, the institutional review board process, and steps to data submission review and approval. Finally, entrepreneurial fundamentals including disclosure, protection of intellectual property and licensing was introduced from a business management perspective that included market analyses and funding strategies (26). These ideas were developed against the backdrop of regulatory principles and strategic approaches to regulatory management. This helps learners craft effective regulatory submissions and communication plans (26). The latter has to be understood to develop skills needed to bridge knowledge gaps between disciplines while practicing techniques for ideation, prototyping and iterative human centered design principles in healthcare.

Faculty and guest speakers from diverse fields, including but not limited to physician scientists, business and legal experts, and regulatory and commercialization experts, were recruited to deliver course content that aligned with their expertise and to share real-world problems and perspectives from their field (Table 2). To further strengthen the team of experts delivering course content, biotechnology industry experts and successful entrepreneurs were recruited to deliver relevant sessions and further provide opportunities to explore entrepreneurial skills critical for biomedical professionals. Additionally, the involvement of industry experts provided an unique mentorship opportunity for course participants to grow their professional network of support.

Course evaluation

Course evaluation and a continuous quality improvement plan is needed to ensure the diverse groups of course participants achieve the learning objectives and competencies needed to navigate the regulatory process and entrepreneurship. Additionally, an evaluation plan will ensure our course adapts to the ever evolving biomedical innovation landscape and needs of the CWRU and Greater Cleveland community. A requirement for all courses or sessions offered as CME credits is an anonymous survey completed by participants after course completion. Leveraging this requirement, course participants were asked to complete an anonymous post-course survey each AY. Survey questions focused on participant demographics, achievement of course objectives, satisfaction with TBL activities, and an open text box to collect qualitative feedback. Retrospective analysis of survey data collected as part of the CME accreditation process was deemed exempt from IRB review by the CWRU IRB (STUDY20240761).

Results

Participant diversity mimics interdisciplinary environment of biomedical innovation

One of the core principles guiding the development of this course was integrating multiple disciplines in order to support inter- and

TABLE 2 Course sessions and assignments supporting core principles and learning objectives.

Session	Session topic and relevant assignment or project	Speaker or grader field of expertise	Mapped core principle	Mapped learning objective
1	History of FDA and FDA Mission	Medicine, Law, Science, FDA	A-B, E	1
2	Inside the FDA: Reflections of a Former Division Director	Medicine, FDA	A-C, E	1–2
3	The Drug Approval Process	Medicine, Law, Science, FDA	B-C, E	1, 3
4	Regulatory Considerations for Biologics	Management, Science, FDA	B-C, E	1–4
5	Team-based Learning Session 1	All Fields	A-E	1–4
	Assignment: Written Reflection 1	All Fields	A-E	1–4
6	Human Clinical Testing	Management, FDA	A-E	1–3, 6, 7
7	Clinical Trial Design Issues	Medicine, FDA	B-D	1–3, 6, 7
8	Generic Drugs and Ethics	Science, FDA, Engineering	B, D	1–3, 8
9	Team-based Learning Session 2	All Fields	A-E	1–8
	Assignment: Written Reflection 2	All Fields	A-E	1–8
10	FDA Review Process	Medicine, Science, FDA	A-C, E	1, 10, 11
11	FDA Enforcement	Medicine, Law, Science, FDA	A-D	1, 9, 10
	Project: IND/IDE Outline Approved Product	All Fields	A-E	1–11
12	Post-marketing Issues	Medicine, Science, FDA	B-D	1, 9
13	Medical Devices and Diagnostics	Science, FDA, Engineering	A-C, E	1–3, 5
14	Team-based Learning Session 3	All Fields	A-E	1–11
	Assignment: Written Reflection 3	All Fields	A-E	1–11
	Project: IND/IDE Outline Hypothetical Product	All Fields	A-E	1–11

Course outline indicating session number, session topic with relevant assignment or project, and session speaker or assignment grader field of expertise. Additionally, core principles and learning objectives from Table 1 were mapped to each session.

transdisciplinary experiential learning mimicking the diverse environment promoting healthcare innovation. While the curriculum design primarily supported interdisciplinary learning, it was important to establish a diverse group of course participants from varied training backgrounds and disciplines. Specifically, participants from medicine, law, business management, engineering and other disciplines would support the interdisciplinary interactions in TBL and discussion-based sessions necessary to support the remaining core principles of the course. To recruit diverse participants, recruitment strategies outlined above were used and demographic data collected from surveys and course registration forms was compiled and analyzed each year to confirm successful recruitment. In AY 21–22, 22–23, and 23–24, the number of participants who registered for the course was 40, 33 and 45, respectively. Importantly, nearly 100% of participants each year attended at least 80% of the sessions resulting in the awarding of a certificate of completion. Similarly, all students enrolled for formal credit received passing grades.

Participants were categorized as students, faculty, or staff at CWRU or affiliated hospital systems (Figure 1). Participants that did not fall in these categories included primarily postdoctoral fellows or individuals in leadership positions and were included in the other category. Interestingly, the participant distribution shifted from being relatively balanced across student, faculty and staff groups in AY 21–22 to demonstrating higher student representation in following years (Figure 1A). This effect coincided with creating a formal flexible credit option and more widespread student advertisement.

Further analysis of the student participants revealed that students from various training levels and fields were interested in the course

across AYs offered (Figure 1B). The greatest number of participants identified as either PhD or master students, which included students pursuing an MS or MBA. The remaining participants were either undergraduate students with a biomedical-related major, graduate students pursuing a JD, or graduate students pursuing a dual degree of an MD and PhD (Figure 1B). Moving forward, advertisement and recruitment strategies will support the continued diversity in student participants interested in our course with targeted opportunities to reach others from the minimally represented degrees (i.e., MD-PhD, JD, undergraduate).

Participants were also categorized by associated units, such as CWRU school or college. Those who were part of the CWRU community but were not associated with a specific unit were categorized as other and those who were a part of one of the affiliated hospital systems were grouped together as affiliates (Figure 1C). While the majority of participants were associated with the School of Medicine (SOM) and the Case School of Engineering (CSE) via the Biomedical Engineering Program, it was encouraging to see representation from other units across campus and affiliated hospital systems (Figure 1C). Specifically, Weatherhead School of Management (WSOM), School of Law (SOL), and the College of Arts and Sciences (CAS) had associated participants enroll during at least 1 year the course was offered. In the future, efforts will be made to ensure continued, yet expanded participation from units and affiliates already represented and those not yet participating.

With regard to the anonymous course evaluation survey distributed at the end of the course, the response rates were ~ 58%, ~52% and ~ 49% for AYs 21–22, 22–23, and 23–24, respectively. As

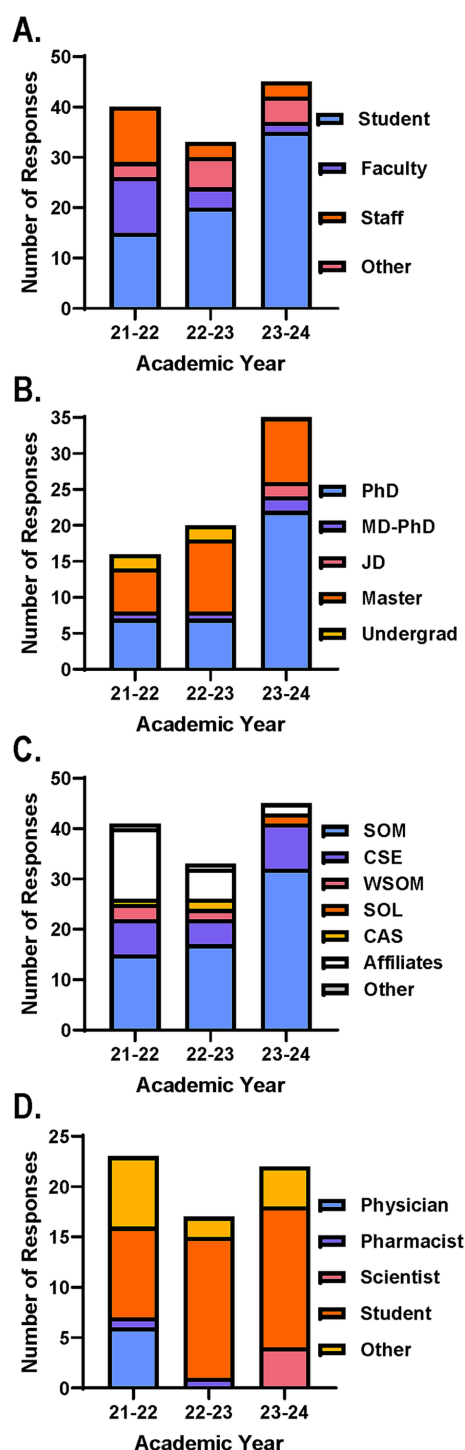


FIGURE 1

Course and survey participant distribution across years ensures interdisciplinary experiential learning environment. Course participant distribution based on number of registration form responses across AYs. Participants were categorized by (A) position, (B) student degree type, (C) associated school, college, unit, or affiliated hospital system. SOM, School of Medicine; CSE, Case School of Engineering; WSOM, Weatherhead School of Management; SOL, School of Law; CAS, College of Arts and Sciences. (D) Survey participant distribution based on number of responses on end of course surveys across AYs. Participants were categorized by position defined by CME requirements.

per CME requirements, participants completing the survey indicated if they were a physician (i.e., MD, DO, MD-PhD), pharmacist (i.e., PharmD), scientist (i.e., PhD, MS), student, or other (Figure 1D). Just as before the other group primarily consisted of postdoctoral fellows. Notably, the number of physicians completing the survey dwindled over the AYs the course was offered which likely corresponds to the reduced number of course participants hailing from the affiliated hospital systems over the same years (Figure 1D). This is important to note to allow for additional support and strategies to recapture prospective participants from these affiliates for future course installments.

Achievement of personal goals and competencies by diverse participants

Following the successful recruitment and participation of a diverse participant cohort each year, it was important to identify course components that were most successful in supporting the course goals and core principles, specifically from the participant perspective. Additionally, trends across years in participant perceptions and feedback will provide additional clarity. Participants were first asked to rate their level of agreement with the course's ability to support the achievement of their own personal learning objectives (Figure 2A). Encouragingly the majority of participants agreed that their personal objectives were met through the course. Only a few participants felt as if they either disagreed or were neutral toward this statement in AY 21–22 but this diminished with each passing year, possibly due to the incorporation of new learning opportunities in AY 22–23 and the refinement of those in AY 23–24 (Figure 2A).

With regard to specific course learning objectives, participants were similarly asked to rate their level of agreement with the course's ability to support the achievement of each objective (Figures 2B–E). Collectively, survey data across AYs 21–24 suggest that the majority of participants agree that the course supports the learning objectives with only a few participants disagreeing or feeling neutral toward the statement (Figure 2B). This pattern was consistent across survey data from each year when analyzed independently (Figures 2C–E). It is important to note that learning objectives 3, 5, 7, 10, and 11 (Table 1) were added for AY 22–23 to further support the core principles. Based on survey data, refinement of the sessions and activities supporting these objectives was needed (Figure 2D) and the number of those in agreement increased as a result for AY 23–24 (Figure 2E). This refinement included adjustment of topic schedule, TBL case study edits, team-teaching of specific topics and additional guidance for projects.

Enhanced interdisciplinary experiential learning through team-based learning

As mentioned above, three TBL sessions were incorporated into the schedule for AY 22–23 and AY 23–24 as part of the course changes that justified the formal flexible credit option. Specifically, TBL sessions for this course included pre-reading assignments before the session, readiness assurance discussions to begin the session, and two to three case studies designed by experts and based on real world

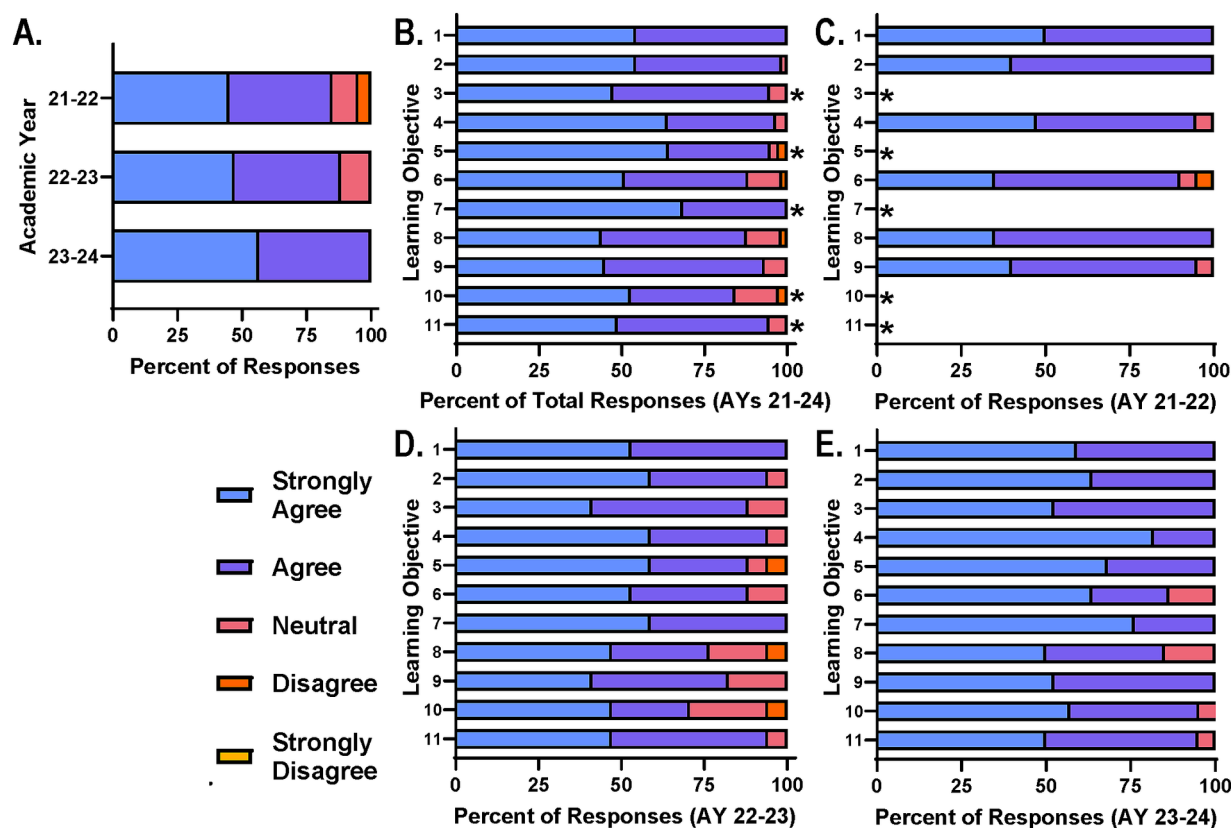


FIGURE 2

Participants agree course design and delivery supports achievement of learning objectives. (A) Course participants were asked on end of course surveys to rate their level of agreement with: "My personal learning objectives were met" on a scale of strongly agree to strongly disagree. Participants were also asked to provide their level of agreement with: "The course learning objectives were met" on a scale of strongly agree to strongly disagree. (B) Total responses for each learning objective across AYs, (C) AY 21–22, (D) AY 22–23, and (E) AY 23–24 are reported for comparison; *Learning objective added after AY 21–22.

situations. Each case study was accompanied by several probing questions to guide and encourage discussion among the interdisciplinary groups assigned (Supplementary Figure S1). Each group would read the case study and discuss the questions in a breakout room via Zoom and come to a consensus statement or stance which they would then report out to the larger group in the main Zoom meeting room. These sessions were designed in a way to support all core principles and the achievement of most learning objectives for the courses. As part of the survey distributed at the end of the course in AYs 22–24, participants were asked to rate their level of agreement with the TBL's ability to support the practical applicability of course content and effective delivery of content and organization (Figures 3A–C). Again, the majority of participants agreed with these statements with the number of limited participants disagreeing or responding as neutral dwindling from AY 22–23 (Figure 3B) to AY 23–24, coinciding with session refinement efforts (Figure 3C).

Innovative curricular design achieves course goals and objectives

Overall these data support that our recruitment and advertising strategies are able to successfully recruit diverse participants to support the inter- and transdisciplinary goals of the course. While

there will always be room for improvement in representation from diverse disciplines, participants' diversity was sufficient to support the core principles, promote achievement of personal and course learning objectives, and ensure the success of TBL sessions. Moreover, the format, content and delivery by diverse speakers supports the achievement of personal and course learning objectives. Finally, survey data support the use of TBL sessions to reinforce the core principles and provide an opportunity for the effective delivery and applicability of course content in an interdisciplinary and collaborative group setting.

Discussion

These findings highlight the effectiveness of an interdisciplinary and transdisciplinary approach to teaching and learning for biomedical education, specifically in preparing participants for the complexities of FDA regulatory processes and biomedical entrepreneurship. The high participant engagement and diversity over three AYs indicate sustained importance of content and skills taught as well as the relevance to a broad audience of current or future basic science, healthcare, law, business management, and engineering professionals. The inclusion of students, faculty, and staff across schools at CWRU, but also from affiliated hospital systems

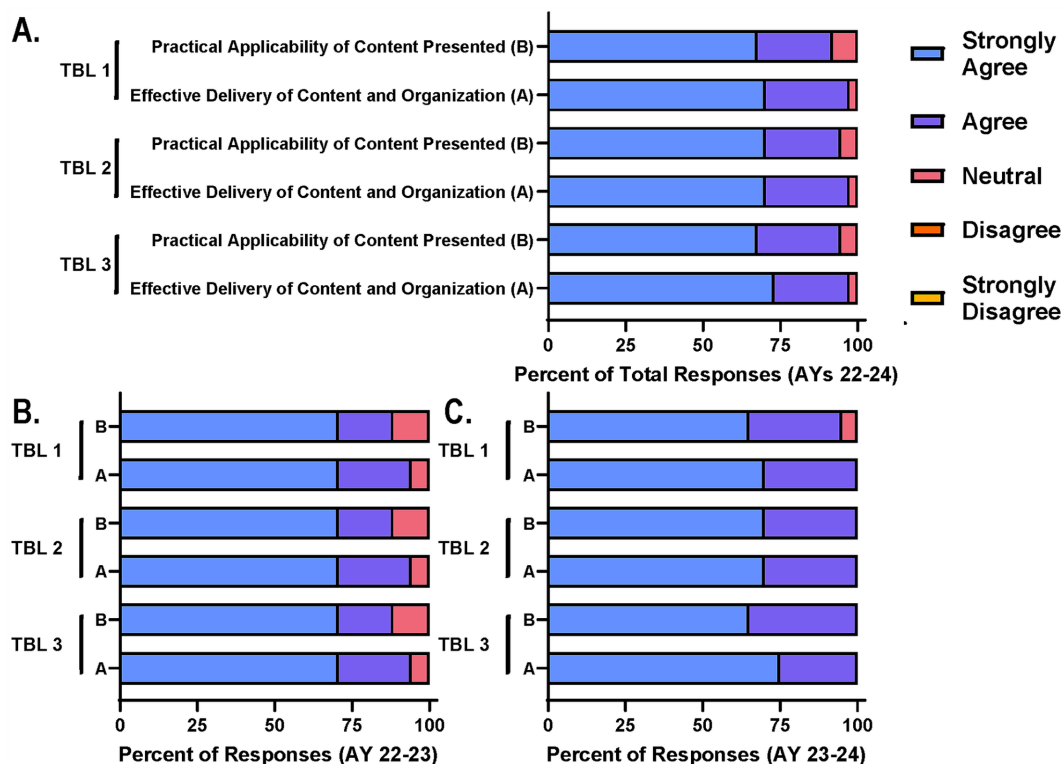


FIGURE 3

Participants agree TBL sessions support achievement of course goals and interdisciplinary collaboration. Course participants were asked on end of course survey to rate their level of agreement with two statements related to the practical applicability and effective delivery of content through TBL sessions. (A) Total responses for each TBL session across AYs, (B) AY 22–23, and (C) AY 23–24 are reported for comparison.

demonstrates similar interdisciplinary educational models are capable of mimicking the environment of and cultivating the skills necessary to foster biomedical innovation. Furthermore, these findings suggest that the recruitment strategies employed were successful in attracting diverse participants that align with and support the course goal of collaborative learning across disciplines. Leveraging this approach and core principles, two additional courses in this space entitled *Patent Law and the Biomedical Sciences* and *Regulatory Strategy and FDA Communication* were created. Moving forward, this educational approach will facilitate the creation of additional curricula designed to solve complex interdisciplinary challenges.

The recruitment of diverse faculty, FDA regulatory experts, and biomedical entrepreneurs to deliver the course content further supported the course goals of collaboration across disciplines. From the content experts conducting the class came diverse real-world experiences that were converted into TBL sessions in AY 22–23. These sessions required experiential and collaborative learning in interdisciplinary groups which further enhanced participant engagement and reinforced the practical applicability of content and skills. As a result, the majority of participants reported the course successfully supported their personal learning objectives, with feedback improving each year as course elements were added and refined. The progressive alignment of course learning objectives with content, especially with the addition of new objectives, sessions, and authentic assessments in subsequent academic years, reflects responsiveness of course developers to participant feedback and commitment to continuous quality improvement. This trend and

participant feedback indicates that experiential learning paired with interdisciplinary collaboration can significantly improve engagement as well as knowledge retention and application in complex regulatory and entrepreneurial contexts.

Despite course popularity among the CWRU community and affiliates, a decrease in participation from healthcare affiliates was observed over time, particularly among physicians. Though this decline coincides with increased student-targeted advertising and enrollment in AYs 22–24, this trend highlights the need for targeted recruitment efforts to re-engage this important population. The current and future physician and physician-scientist population is crucial given the importance of regulatory knowledge in research and clinical practice. To address this, future plans include asynchronous learning options, expanded CME credit opportunities, and collaborations with affiliated hospital systems to encourage greater participation. Recruitment and advertising plans also include improved outreach to students in the MD program at CWRU who historically enrolled in this course significantly less than students from other degree programs. The course described herein has already demonstrated significant flexibility to aid participant engagement from AY 21–22 to AY 23–24 and will be able to continually adjust to meet the needs of the course, participants, and the biomedical industry. For example, successful implementation of flexible credit options and micro-credentialing allowed participants from various fields and levels of training to engage in the way that best fit their current professional needs and future career aspirations. These future efforts will maintain strong representation from all relevant fields and

ensure the interdisciplinary benefits are maximized, which is essential for understanding the multifaceted nature of transdisciplinary biomedical innovation and regulatory frameworks.

Overall, the findings of this study contribute valuable insights into the design of biomedical education that effectively integrate regulatory, entrepreneurial, and interdisciplinary competencies. The TBL sessions and interdisciplinary group discussions accentuate the need for such to become the standard for biomedical education going forward. Future iterations of this curriculum could build on these insights, exploring additional strategies to enhance interdisciplinary representation and continuously adapt based on the evolving industry and participant feedback (27). This approach could serve as a model for other educational institutions aiming to remain strong and relevant in an era where traditional degree programs have not fully met industry needs, which is becoming more important with declining graduate program enrollment. The successes described herein underscores the need for related or similar curriculum to prepare healthcare, FDA regulatory, and scientific professionals for the complex, adaptive systems they will encounter as necessary stepping stones to advance innovation within healthcare. Ultimately, such advances in biomedical education will catalyze the translational science paradigm, thereby improving healthcare outcomes (28).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was exempted by Case Western Reserve University Institutional Review Board for the studies involving humans because the research was conducted in established or commonly accepted educational settings, involving normal educational practices. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board also waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because this was secondary research for which consent is not required: use of identifiable information or identifiable biospecimens that have been or will be collected for some other primary or initial activity.

Author contributions

PC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. TM: Conceptualization, Data curation, Formal analysis, Investigation,

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be considered a potential conflict of interest.

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Supplementary material

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The data-intensive research paradigm: challenges and responses in clinical professional graduate education

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With the widespread application of big data, artificial intelligence, and machine learning technologies in the medical field, a new paradigm of data-intensive clinical research is emerging as a key force driving medical advancement. This new paradigm presents unprecedented challenges for graduate education in clinical professions, encompassing multidisciplinary integration needs, high-quality faculty shortages, learning method transformations, assessment system updates, and ethical concerns. Future healthcare professionals will need not only to possess traditional medical knowledge and clinical skills, but also to master interdisciplinary skills such as data analysis, programming, and statistics. In response, this paper proposes a series of countermeasures, including curriculum reconstruction, faculty development, developing and sharing resources, updating the evaluation and assessment system, and strengthening ethics education. These initiatives aim to help clinical graduate education better adapt to this new paradigm, ultimately cultivating interdisciplinary talents in medical-computer integration.

KEYWORDS

data-intensive research, clinical medicine, graduate education, challenges, responses

1 Introduction

The rapid progress of information technology, particularly in big data, machine learning (ML), artificial intelligence (AI), and large language models, is causing a significant transformation in the paradigm of scientific research. This transformation is especially visible in the field of clinical research, ushering in a new, data-intensive research paradigm (1). At the core of this paradigm lies in systematic management and thorough leveraging of real-world data for comprehensive analysis, thus uncovering the complex connections between health and disease. This, in turn, drives the advancement of medical knowledge and the evolution of clinical practice.

In this shifting paradigm, traditional research methods that rely on small-scale sampling and hypothesis-driven approaches are giving way to exploratory research that leverages big data and data-driven methodologies (2). This shift in approach empowers medical researchers to grasp the occurrence, evolution, and therapeutic results of diseases in a more thorough and organized way, providing solid support for precision medicine and tailored treatment.

2 Key features of the data-intensive research paradigm

In the field of medical science research, there is an increasing focus on a data-intensive research paradigm, which is revolutionizing traditional methods and processes. This shift is creating new opportunities and directions for the field, highlighting the importance of analyzing and defining its characteristics to predict its future impact.

2.1 Deep application of big data

Big data applications have infiltrated numerous facets of the healthcare sector, especially in gathering, analyzing, and clinically applying electronic medical records (3), ergonomic data (4), and information from wearable devices, showcasing considerable real-world value and limitless potential. With the expansion and increasing use of electronic medical record systems, healthcare services have been able to gather, store, and manage the data created by patients during the diagnostic and treatment process more efficiently. The quick gathering of data has supplied an abundance of resources for clinical research, allowing for a more thorough examination of the genetic and molecular underpinnings of human health and diseases. The analysis of multisource, multimodal data presents practical strategies for precision medicine and personalized treatment alternatives.

2.2 Rapid progress in artificial intelligence and machine learning

Artificial intelligence and machine learning are revolutionizing the healthcare sector, particularly in disease diagnosis, treatment planning, and supporting clinical decisions (5). By analyzing and learning from extensive real-world patient data, AI and ML can identify early signs of diseases that are difficult to detect. They can also make accurate predictions and early diagnoses when traditional methods fall short. This capability not only significantly improves diagnostic accuracy but also enhances the efficiency of disease diagnosis, enabling patients to receive treatment earlier. When developing treatment plans, AI and ML can swiftly recommend personalized medical advice for patients by analyzing historical patient treatment data and the current patient's clinical phenotype characteristics (6). This enhances treatment outcomes and minimizes the unnecessary use of medical resources and time. Additionally, the application of AI and ML in clinical decision support aids doctors in making more accurate and efficient decisions in complex clinical situations by offering insights and recommendations based on big data analysis (7). In summary, the integration of AI and ML is gradually transforming the healthcare industry. By improving diagnostic accuracy, optimizing treatment plans, and enhancing the quality of clinical decisions, they provide safer, more effective, and more personalized medical services to patients.

The application of large language models in clinical data management underscores the profound integration of AI technology in healthcare. As an advanced AI technology, large language models can aid medical professionals in achieving more accurate data classification, integration, and analysis by deeply learning and

understanding vast amounts of medical text data (8). This not only helps medical institutions effectively manage medical records, research reports, and clinical trial data but also provides robust data and technical support for disease diagnosis, treatment recommendations, and patient care. Additionally, the ability of large language models to process natural language has significantly enhanced the efficiency and accuracy of understanding, analyzing, and structuring unstructured text in medical records. This offers a more solid foundation for further uncovering the value behind the data.

2.3 Unprecedented multidisciplinary collaboration

Multidisciplinary integration is an innovative and forward-thinking trend in contemporary research and social practice, especially in the deep integration of fields such as clinical medicine, computer science, and statistics (9, 10). This not only broadens the scope of medical science research but also significantly enhances the efficiency of medical research and the application of its results. The high-quality development of clinical medical practice drives researchers to continuously explore the nature and progression of diseases. Meanwhile, advancements in computing power and algorithms provide robust technical support for processing large-scale health data. Machine learning and statistical methodologies ensure the scientific validity and accuracy of clinical research outcomes. This deep interdisciplinary integration not only advances precision medicine by making disease prevention, diagnosis, and treatment more personalized and accurate but also fosters the widespread application of technologies like artificial intelligence and big data in healthcare, significantly enhancing the quality and efficiency of medical services. Thus, the integration of multiple disciplines has emerged as the primary driving force for advancing medical technology and achieving sustainable, high-quality development in healthcare.

3 The transformative impact of data-intensive research paradigm on clinical studies

The influence of data-intensive research paradigm on clinical research is growing more significant by the day. In comparison to conventional methods, data-intensive research paradigm provide more comprehensive and detailed data support, broadening the range, depth, and pace of clinical research. With their distinct advantages, data-intensive research paradigm is revolutionizing clinical research methodology and is emerging as a primary catalyst in propelling medical science forward and improving human health.

3.1 Accelerating the evolution of precision medicine

Precision medicine aims to personalize treatment plans for patients by considering their individual characteristics such as genetics, lifestyle, and environment. This approach seeks to improve treatment outcomes and reduce side effects. Transitioning to a

precision medicine model involves three key considerations: (1) collecting comprehensive data on patients, including genetic and real-world information, (2) developing advanced analytical tools for patient stratification and prediction, and (3) integrating these tools into clinical practice through medical information systems. This data-intensive research paradigm utilizes big data technologies, high-performance computing, artificial intelligence, and other advanced tools to analyze healthcare data and support precision medicine research effectively.

3.2 Prediction and management of risks and benefits in disease treatment

The new paradigm of data-intensive research involves combining multivariate analysis and machine learning to utilize data from various fields like genomics, clinical phenomics, and imaging for creating predictive models. This advancement improves the quality and scope of research on disease treatment risk assessment and interventions, reducing uncertainty in patient prognosis and treatment outcomes. By analyzing individual health data, including genetic information, lifestyle habits, medical history, and environmental factors, machine learning algorithms can develop complex predictive models to accurately predict an individual's future disease risks (11). These predictions help individuals anticipate potential health risks and treatment responses, while also providing healthcare professionals with scientific evidence to customize more personalized interventions based on the predictive results. This allows for early detection and intervention to improve treatment effectiveness and reduce side effects.

3.3 Accelerating new drug discovery and drug repurposing

Data-intensive research is becoming a powerful driving force in the medical field, particularly in the discovery of new drugs (12). By analyzing large amounts of data on drug-target interactions, scientists can quickly and accurately identify new therapeutic targets. This approach also allows for the discovery of potential new uses for existing drugs, which can then be validated through experiments to determine their effectiveness and safety. By utilizing this method, the drug development process can be accelerated, costs can be reduced, and the success rate of research and development can be improved.

Moreover, by extensively exploring current drug databases, not only can new therapeutic uses be uncovered, but robust scientific evidence for drug repurposing can also be obtained (13). This significantly enhances medical resources and expands treatment options for patients. Thus, utilizing data-intensive research in the realm of new drug discovery undoubtedly paves the way for efficient, cost-effective, and innovative research and development, thereby playing a pivotal role in the advancement of pharmaceutical science.

3.4 Developing personalized treatment plans

As personalized medicine becomes increasingly important in healthcare, data-intensive research are playing a crucial role in

developing individualized treatment plans for patients. This research approach utilizes advanced bioinformatics technologies, big data analysis, and artificial intelligence algorithms to analyze patients' genetic backgrounds and disease characteristics. By delving into patients' genetic information, biomarkers, and disease progression, researchers can uncover the underlying mechanisms of diseases and predict how patients will respond to specific treatments. This personalized approach not only allows medical experts to tailor treatment plans to each patient's unique needs, but also improves treatment outcomes, reduces unnecessary side effects (14), and ultimately achieves true personalized medicine. Additionally, this data-intensive personalized treatment strategy can provide valuable data support for future medical research, driving innovation and advancements in the field of precision medicine.

4 Challenges in clinical professional graduate education

The importance of data science and programming skills is on the rise in the healthcare sector. However, traditional medical courses do not focus on developing these abilities. Most medical schools still adhere to traditional curriculum models that emphasize biomedical knowledge and clinical skills, providing limited education on modern medical technologies such as data science and programming.

4.1 Interdisciplinary integration of data-associated knowledge and skills

In today's clinical practice, the integration of knowledge and skills from various disciplines is essential for improving healthcare quality and supporting patient recovery (15). The rapid advancement of data science is blurring the lines between medicine and other fields, leading healthcare teams to adopt a multidisciplinary approach to address complex clinical challenges. Fields such as computer science and data analysis are increasingly becoming indispensable in healthcare, allowing providers to create personalized treatment plans and facilitate knowledge sharing among team members.

The integration of artificial intelligence and big data in healthcare is fostering cross-disciplinary teamwork, providing novel approaches and tools for medical practice, and fueling advancements in healthcare services. Nevertheless, existing educational frameworks are failing to equip medical students with the necessary data processing and analytical capabilities, hindering their capacity to utilize cutting-edge technology in diagnosing illnesses, devising treatment strategies, and enhancing healthcare delivery in their professional journeys.

4.2 Urgently needed educational resources and teaching staff

Educators in the medical data science field need a strong foundation in medical practice, as well as expertise in mathematics and statistics. However, there is a lack of high-quality resources for teaching medical data science. There is a shortage of textbooks and course content, as well as a lack of teachers who can effectively teach this material (16). Building a qualified team of medical data science

educators is a major challenge, as it requires teachers to have in-depth knowledge of data science, integrate medical expertise, and effectively teach educational concepts and methods.

Furthermore, teachers must continuously update their knowledge base to keep pace with the rapidly evolving field of data science. Thus, forming a diverse and highly qualified team of medical data science educators requires not only systematic training and professional development pathways but also collaborative efforts from educational administrative departments, medical higher education institutions, and the industry.

4.3 Outdated teaching techniques

Data-intensive research involves actively uncovering in-depth information within data and exploring unfamiliar subjects. This process goes beyond learning within a single discipline, emphasizing the integration of multiple disciplines. By combining knowledge from various fields, a comprehensive and multi-perspective research approach is developed. This interdisciplinary integration not only fosters innovation and breakthroughs in knowledge but also enhances understanding of complex issues and facilitates finding effective solutions. Therefore, transitioning from passive knowledge acquisition to active exploration and from learning within a single discipline to integrating multiple disciplines is essential for advancing clinical scientific progress and technological innovation in data-intensive research. To succeed in the constantly evolving clinical practice environment and surmount challenges, clinical researchers must possess a diverse knowledge background, a broad perspective, sharp insight, and innovative thinking skills (17). This is because the data-intensive research paradigm requires a focus on developing critical thinking, communication, collaboration, and creativity skills.

4.4 The evaluation and assessment system deviates from the genuine requirements

Data-intensive research is becoming more and more important, particularly in real-world studies. Nevertheless, existing assessment system frequently fall short in thoroughly assessing students' skills in this field. Traditional assessment methods, like standardized tests and course grades in medical statistics, primarily emphasize students' ability to memorize and comprehend knowledge. However, they do not adequately evaluate students' skills in identifying which clinical issues can be addressed with existing data and analysis methods or determining the necessary data and methodological support for specific clinical problems. The field of data-intensive research demands students to not only master a vast amount of theoretical knowledge but also possess high levels of logical thinking, critical thinking, and innovation. Evaluating these abilities often requires more in-depth, flexible, and diverse approaches.

As technologies such as big data and artificial intelligence continue to advance rapidly, the demands for knowledge and skills in data-intensive research areas are always changing. This means that assessment system need to be able to adjust to new requirements quickly by updating their content and methods. Therefore, to effectively evaluate students' abilities in these fields, it is crucial to revamp and modernize the current assessment system,

creating more comprehensive, adaptable, and forward-thinking methods that accurately showcase students' capabilities and potential.

5 Response and outlook

In order to meet the needs of clinical professional graduate students training in the era of data-intensive research, it is essential to establish a set of thorough strategies. This includes restructuring the curriculum and enhancing faculty development, sharing and developing resources, and updating evaluation and assessment system. Furthermore, it is crucial to improve the ethical awareness and data protection consciousness of clinical professional graduate students, ensuring they comply with applicable laws, regulations, and ethical standards when managing patient data.

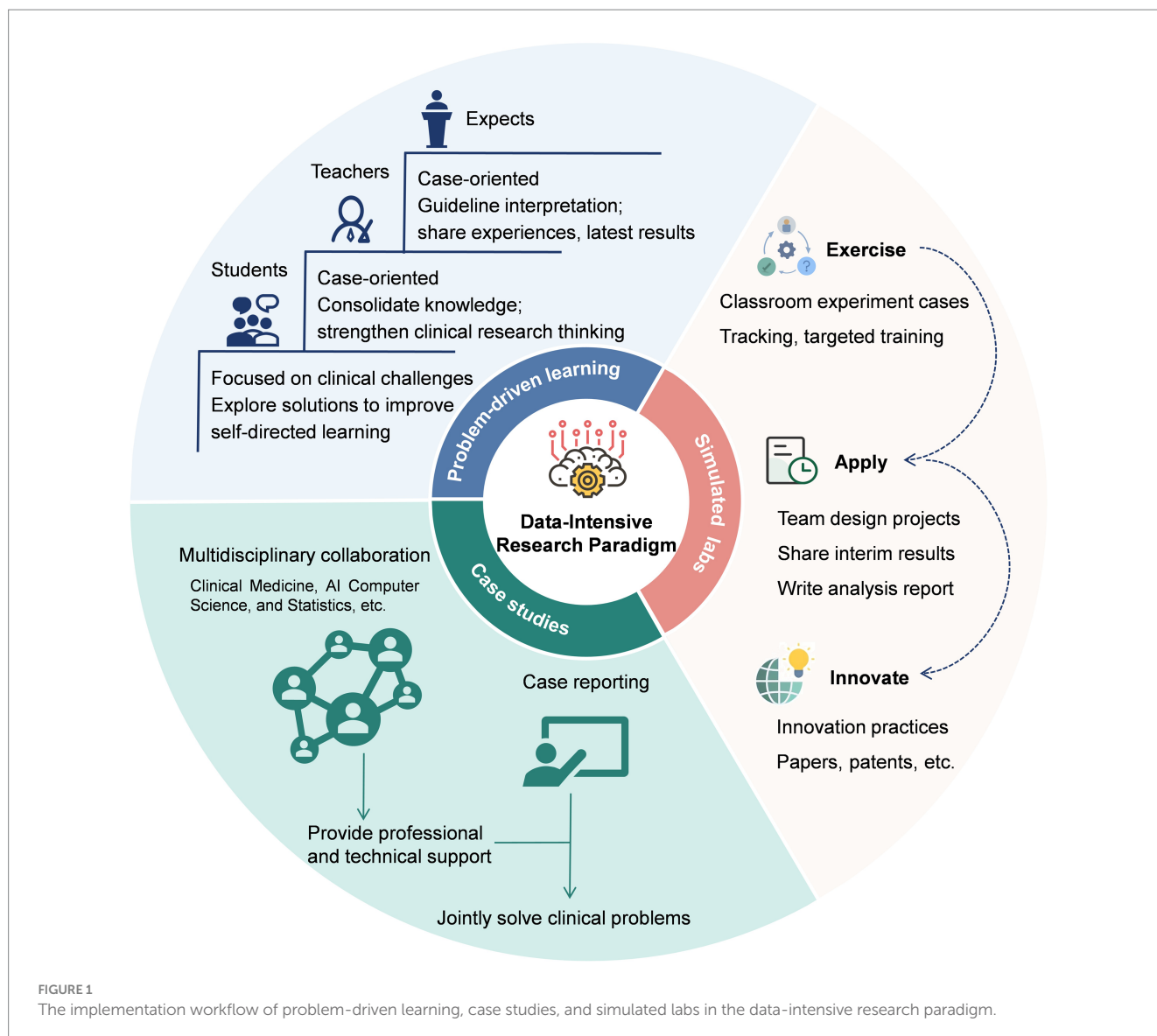
5.1 Advancements in medical data science courses and teaching methods

Creating a medical data science course that combines data science, statistics, and programming fundamentals offers students a well-rounded education in data analysis and application. This approach also encourages students to think creatively and identify clinical problem-solving skills. To improve learning outcomes, incorporating case studies and problem-driven learning is essential. Case studies provide real-world examples that help students connect theoretical concepts to clinical practical situations, leading to better retention of memory and increased motivation to learn (18).

Problem-driven learning is a teaching approach that emphasizes tackling real-world clinical issues throughout the course (19, 20). This method encourages active participation and helps students develop teamwork, communication, and problem-solving skills. Moreover, the stimulated labs provide students with a comprehensive training platform for pre-course preparation, in-class learning, and post-course consolidation, allowing them to enhance practical skills and foster innovative thinking through the integrated three-dimensional teaching model of "exercise, apply, and innovate" (21). By incorporating various disciplines like data science, statistics, and programming basics, and using case studies, problem-solving activities and stimulated labs (Figure 1), students can improve their learning efficiency and practical abilities. This sets a strong groundwork for their future in the field of data-intensive clinical research.

5.2 Building a team of medical data science experts

Establishing and strengthening the teaching staff of Medical Data Science is essential for improving the quality of education and addressing various training requirements. To accomplish this objective, medical colleges and clinical training facilities must adopt a holistic approach. This includes providing thorough and structured training for existing medical data and statistics instructors, as well as actively seeking out new faculty members with varied interdisciplinary backgrounds and extensive real-world experience.



By offering sustainable opportunities for existing medical data and statistics instructors to improve their subject knowledge, they can not only update their thinking and teaching techniques, but also become proficient in the newest educational technology. This can ignite their passion for teaching and research, and boost their appeal, presentation, and impact on student learning.

Bringing in new teachers with varied interdisciplinary educational backgrounds can inject new perspectives and creative teaching approaches into medical schools. This can foster interdisciplinary collaboration and address the growing need for data science skills in clinical settings. Additionally, a diverse teaching team can better reflect the disciplinary diversity of clinical practice, providing students with a broader perspective on clinical medical data.

5.3 Sharing and collaborating on learning resources

Unprecedented changes are being witnessed in the field of medical data science education. With the continuous advancement and

popularization of Internet technology, online courses, open educational resources, and collaboration among universities have become crucial for driving educational innovation and enhancing quality for clinical professional graduate students. By providing a variety of resources and collaboration models, learners have access to a wide range of materials and practical opportunities. This opens more ways to acquire data knowledge and facilitates personalized and ongoing learning.

The availability of online courses has eliminated barriers related to location, time, and access to crucial clinical data resources, making education and training more convenient and accessible for clinical professional graduate students. By promoting open clinical data resources, these professionals can access high-quality educational materials in clinical data science at little to no cost, including e-books, tutorial videos, and curriculum guides. This not only reduces the financial burden of learning but also facilitates the sharing and dissemination of medical data science knowledge. Additionally, collaborating with non-medical and data engineering subjects provides clinical professional graduate students with opportunities for interdisciplinary and cross-cultural

learning. Through resource sharing, joint research projects, and academic exchange activities, this collaboration enhances the learning experience and promotes mutual growth among universities.

Create a customized learning platform that identifies behavioral fingerprints from the study habits of clinical professional graduate students, examining individual learning patterns, interests, and effectiveness. Through the analysis of this information, design personalized learning strategies for each clinical professional graduate students to assist them in mastering knowledge more efficiently and improving their academic skills comprehensively.

To sum up, by utilizing online clinical data science courses, open educational resources, collaborating with non-medical and data engineering disciplines, and creating personalized learning platforms, clinical professional graduate students can benefit from a more accessible, productive, and engaging learning environment. This approach helps in nurturing medical professionals with a strong focus on data-intensive research thinking and skills.

5.4 Upgrade the quality assessment system for training clinical professional graduate students

The rapid development in data-intensive research fields has raised higher demands on the overall capabilities of clinical professional graduate students. Therefore, there is an urgent need in the medical education sector to develop new assessment systems and standards that more comprehensively and accurately reflect the abilities of clinical professional graduate students in this field. This involves not only assessing skills such as data analysis, data management, and data interpretation, but also evaluating the innovative ability, critical thinking skills, and teamwork spirit of clinical professional graduate students in addressing real-world clinical challenges. Despite scholars' innovative efforts, such as integrating capability-driven AI teaching into medical curricula (22) and establishing a multi-platform collaborative "virtual AI laboratory" for dynamic evaluation of classroom experimental projects (which comprehensively cover routine assignments, group projects, and innovation outcomes) (21), resource constraints remain prevalent. Against this backdrop, the AI-driven evaluation platform can be streamlined with open-source frameworks, free cloud computing, and simulation-generated data to cut costs and ease resource strain through local collaboration.

The new assessment system and standards should cover all relevant aspects of capabilities in clinical research while also being flexible enough to adapt to changing needs. Fairness and inclusivity must be key considerations in the assessment process to ensure that all clinical professional students could practice and showcase their abilities. Developing such assessment systems and standards can help guide educational training programs, provide timely feedback to students on their progress, and ensure the equitable distribution of resources in clinical data science education. Collaboration between clinical medical educators, management experts, and data scientists is essential to create a scientifically sound and forward-thinking assessment system and standards through interdisciplinary cooperation, ultimately contributing to the sustainable development of medical education.

6 Ethical considerations for data-intensive research paradigm

The rapid development of data science and technology has brought about improvements in efficiency and precision to traditional healthcare. However, it has simultaneously triggered a series of profound and complex ethical issues (23, 24). In essence, these dilemmas are the core wellspring of ethical considerations in the data-intensive research paradigm, meriting our utmost attention. The foremost issue is the challenge of privacy protection. In the process of data acquisition and utilization, although countries are strengthening the regulation of medical data, the pace of technological iteration far outpaces the update of regulations, highlighting a significant contradiction (25, 26). Secondly, the transparency of AI decision-making warrants critical attention. The "black-box" nature of algorithms makes it difficult to clarify the attribution of responsibility in cases of decision-making deviations. The absence of transparency and an accountability mechanism not only endangers patients' health but also exposes medical institutions and doctors to legal and moral risks. Therefore, it is recommended to construct an interpretable AI framework and establish clear demarcations of responsibility (27).

Furthermore, due to potential data biases, algorithms may generate unfair assessment results (28). This requires educators to transform from traditional knowledge transmitters to learning facilitators and ethical guides. Various teaching strategies, such as case-based teaching (29), embedded AI ethics education frameworks (30), and AI scenario-based teaching in clinical practice (31), can be employed to equip healthcare professionals with both technical skills and moral insights. Meanwhile, the application of AI in clinical education may exacerbate the digital divide. Strengthening ethical regulations and allocating resources rationally are necessary to alleviate this problem (32). Lastly, the issue of doctor-role conflict has also drawn much attention. Defining the boundaries between technology and humans requires joint exploration among medical practitioners, technology developers, and the ethics community. Multi-stakeholder collaboration ensures a healthy, sustainable data-intensive research paradigm for medical progress and human health.

7 Discussion

In the current epoch of rapid data science and technology progression, data-intensive clinical research has emerged as a novel research paradigm. Bolstered by a robust technical underpinning, abundant educational resources, and a personalized teaching model, it demonstrates substantial feasibility (33, 34). This paradigm can effectively enhance learning efficiency, optimize teaching outcomes, and improve students' practical capabilities through personalized learning paths and virtual simulation technologies (35, 36). Nevertheless, this advancement is fraught with challenges. These include data privacy protection, ethical compliance, and the potential erosion of students' critical thinking abilities. The key focus lies in efficiently managing and analyzing voluminous clinical data, as well as transforming it into valuable insights and guidelines for clinical practice. Achieving this goal requires collaborative efforts from technology developers, governments, educational institutions, educators, and students alike.

To tackle these challenges, it is essential to introduce innovative teaching methods in clinical data science. This includes utilizing problem-driven learning, studying disease case examples, and providing simulated labs to enhance students' skills in clinical data practice and encourage creative thinking with data. Building a diverse faculty team is crucial, requiring the recruitment of educators with expertise in data science and training existing medical statistics instructors to effectively utilize data science methods and tools. Furthermore, offering high-quality resources for learning clinical data science, such as access to international disease databases and data analysis software, is essential for fostering the education of clinical professional graduate students. Enhancing the assessment system by including criteria related to clinical data governance and analytical abilities can further engage students and encourage innovative thinking. Meanwhile, ethical education should be seamlessly integrated into the curriculum system to strengthen the ethical awareness and data protection consciousness of clinical postgraduate students.

The data-intensive research paradigm undoubtedly places higher competency demands on clinical graduates, necessitating the development of a multidimensional capability structure. To begin with, it is essential to solidify foundational knowledge by thoroughly understanding and applying AI tools, while developing robust data analysis skills to accurately interpret data and evaluate results (37). Furthermore, participation in model optimization and external validation from a critical perspective is necessary. Secondly, proficiency in digital healthcare systems and the integration of Internet of Medical devices is required to enhance service efficiency (38). It is equally important to strictly adhere to medical data security regulations and be equipped to handle information security incidents (39). In addition, cultivating resilience in managing stress is vital for effectively addressing academic and career development pressures, enabling better adaptation to industry changes. Of course, integrating these competencies is by no means an easy task. Implementing AI training in a step-by-step manner may prove beneficial.

Remarkably, given the urgency of patient care, it should focus on specific target groups and promote the implementation of the data-intensive research paradigm in a phased approach. In the initial stage, identify the key groups most likely to benefit from data-intensive clinical research, covering basic disciplines like anatomy, physiology, and clinical specialties such as radiology, ophthalmology, and neurosurgery (40). Leveraging AI-assisted diagnosis and automating administrative tasks can optimize workflows and enhance healthcare professionals' efficiency. However, the concomitant need for innovative thinking brings new challenges and stress. In response, providing technical training and psychological support (41), and establishing effective feedback and improvement mechanisms are essential steps (42, 43). This promotes a balance between adopting data-intensive clinical research practices and alleviation of stress and

burnout among healthcare professionals. By implementing these strategies comprehensively, we can enhance the overall application skills of clinical professional graduate students when faced with data-intensive research challenges. We are confident in our ability to cultivate clinical professional graduate students who not only possess a strong foundation in clinical medical knowledge but also excel in addressing clinical data challenges and making significant contributions to medical innovation research.

Author contributions

CY: Conceptualization, Writing – original draft, Writing – review & editing. YC: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. CQ: Writing – review & editing. FS: Writing – review & editing. YG: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A transdisciplinary dual degree curriculum yields novel and successful learning outcomes: early lessons from training physicianeers

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The evolving needs in healthcare education and delivery have led to diverse MD-based dual degree programs offering trainees broader experiences and credential-based credibility after graduation. Medical schools typically implement multidisciplinary or interdisciplinary dual degree training with designs that separate the contributing disciplines chronologically and experientially. As a result, these designs fail to maximize the cohesive learning environment and outcomes possible with a transdisciplinary dual degree design, which integrates the contributing disciplines chronologically, experientially, and conceptually. Though rare, transdisciplinary dual degrees promise transformative educational outcomes and discipline convergence by dissolving traditional discipline boundaries and fostering a new learning environment and professional identity. Therefore, we hypothesize that a transdisciplinary dual degree curriculum yields novel—and potentially better—learning outcomes. ENMED, a transdisciplinary dual degree program collaboratively developed, sponsored, and implemented by Texas A&M University and Houston Methodist Hospital, is testing this hypothesis by training “physicianeers.” This new type of healthcare professional trains simultaneously for the MD and Master of Engineering degrees, thereby integrating medical and engineering expertise to advance health system innovations. Supporting the hypothesis, ENMED’s early experiences suggest its transdisciplinary dual-degree model leads physicianeer trainees to novel perspectives with the potential to transform healthcare systemically.

KEYWORDS

multidisciplinary, interdisciplinary, transdisciplinary, innovation, engineering medicine, convergence

1 Introduction

The US healthcare system is one of the largest in the world with a workforce of highly trained specialists and a robust research sector that historically is associated with improvements in outcomes for significant portions of society. However, the system is challenged with providing access across diverse populations and high costs associated with the delivery of care and treatment, especially as advances in research and innovation have often outpaced funding resources and coverage. The complexity of the system provides the context for both its strengths and weaknesses. It encompasses multiple components that operate independently and, at times, collaboratively, such as federal and state-supported or regulated programs, private sector stakeholders, and ambulatory and hospital-based facilities (1). Additionally, the pipeline of education and training is challenged with producing future healthcare professionals who can solve this system's complex problems.

A common approach for solving complex problems in healthcare is a multidisciplinary approach, where people from multiple disciplines work in parallel (2–4). Originating in the academic environment, disciplines “are kinds of collectivities that include a large proportion of persons holding degrees with the same differentiating specialization name, which are organized in part into degree-granting units that in part give degree-granting positions and powers to persons holding these degrees” (5). Examples of contributing disciplines are health professions (e.g., medicine, nursing, pharmacy), basic sciences, engineering, social work, architecture, economics, and business. Although people from different disciplines want to develop solutions to the same problem, their solutions are often uncoordinated and unintegrated because they bring different technical languages, solution methods, incentives, and goals and think within single discipline boundaries and conceptual silos (6).

A second approach to complex problem-solving in healthcare is interdisciplinarity with its cooperative analysis and synthesis of problem-solving approaches among disciplines. Experts, each representing a different discipline, reach a consensus across disciplines on a coordinated and harmonious solution. For example, a tumor board decides on a patient's therapy (7, 8), reflecting diverse expertise and perspectives across discipline boundaries (6). Interdisciplinary problem-solving brings together extensively trained individuals who contribute their diverse discipline-based problem-solving methods (9).

A third and more upstream approach to solving complex healthcare problems is MD-based joint degree or combined dual degree training (10, 11). In principle, a person trained multidisciplinarily or interdisciplinarily in two disciplines will think innovatively across the disciplines' boundaries with the disciplines' competencies and knowledge when encountering healthcare problems after training. Another potential benefit is an additional degree-based credential after graduation supporting residency matching (12) or leadership aspirations (13, 14). Dual degree examples combining MD degrees are MD/PhD (15, 16), MD/JD (17), MD/MBA (14), MD/

MPH (18, 19), and MD/MS degrees. About 7% of MD graduates in 2024 also earned a graduate (master's or doctorate) degree (20).

However, the extent of the trainee's integrated and coordinated learning between the disciplines depends on the dual degree curriculum design and the trainee's initiative. If integrated and coordinated learning is negligible, the trainee must independently develop thinking skills that merge disciplines and cross discipline boundaries. In contrast, integrated learning can be substantial within a dual degree curriculum when the learning experiences of the disciplines are closely coordinated, instructors cross discipline boundaries, and the learning environment fosters integration. If integrated learning across disciplines is extensive, the dual degree training can be described as transdisciplinary (21), a term describing the dissolving of discipline-based boundaries that generates “fundamentally new conceptual frameworks, hypotheses, theories, models, and methodological applications that transcend their disciplinary origins, with the aim of accelerating innovation and advances in scientific knowledge” (22). Transdisciplinary dual degree training seems ideal for solving complex healthcare problems through convergence (23–27). Two questions accompany this optimism: Under what conditions does such training succeed, and what can it achieve?

2 Hypothesis

ENMED (a portmanteau of “engineering” and “medicine”) (28), was founded in 2016 as a collaboration between Texas A&M University and its clinical partner Houston Methodist Hospital in the Texas Medical Center. It was envisioned and developed as a transdisciplinary dual MD/Master of Engineering (MEng) degree program for all its students, with its inaugural class matriculating in 2019. It originated as a parallel track for the MD degree in the Texas A&M University College of Medicine and as the MEng degree, focusing on engineering innovation in medicine (29), in the College of Engineering. ENMED is based on the hypothesis that its chronologically, experientially, and conceptually integrated dual degree curriculum yields novel and successful learning outcomes that positively impact health care. The transdisciplinary combination of engineering and medicine leads to innovative graduates who identify and solve simple to complex healthcare problems. ENMED gives these graduates the name “physicianeers.”

This hypothesis mixes what appear to be two opposing concepts—“transdisciplinary” and “dual degree.” Transdisciplinary training merges and dissolves discipline boundaries. By extension, no existing discipline labels should suitably describe a transdisciplinary degree. On the other hand, training leading to MD and MEng degrees seems to need discipline-identified learning experiences that maintain discipline boundaries and qualify a graduate for both degrees. Despite the model's name, we find that a transdisciplinary dual degree model fits ENMED's mission, vision, and discipline-merging realities. This article describes ENMED's early experiences developing, delivering, and refining a transdisciplinary dual degree curriculum for physicianeering. These experiences might equip other nascent engineering medicine programs that include the MD degree to choose among the options for integrating engineering and medicine.

Abbreviations: ENMED, an engineering medicine dual degree MD/MEng program of Texas A&M University and Houston Methodist Hospital; MEng, Master of Engineering.

3 Transdisciplinary dual degree curriculum design—chronological and experiential integration culminating in a conceptual merger of disciplines

To explore the hypothesis more deeply, we first describe multidisciplinary and interdisciplinary dual degree options in terms of chronological, experiential, and conceptual integration and then compare them to a transdisciplinary dual degree model. As the origin for our integration reference frame, an education-focused description of disciplinary is, “Concepts and skills are approached separately, allowing students to engage and be assessed on a singular discipline, with minimal integration” (30).

3.1 How multidisciplinary and interdisciplinary dual degrees integrate disciplines chronologically, experientially, and conceptually

As a definition, “Multidisciplinary draws on knowledge from different disciplines but stays within their boundaries” (6). Additionally, an education-focused description of multidisciplinary is, “A common theme or approach is used to allow students to connect concepts and skills learned separately in each discipline. Multiple disciplines are incorporated but they are not *integrated*” (30).

A practical, integration-focused description is that a multidisciplinary dual degree program separates discipline-based training chronologically and experientially. For example, the MD student takes a leave of absence from MD training that occurs with a large cohort of MD-only students—often immediately before or immediately after clerkships—while exclusively pursuing the second degree [called an intercalated second degree (31) outside the United States]. MD/PhD or MD/MBA training usually has this design. Although the need for clinical training continuity during the PhD training years is a recognized need and challenge (32), such clinical training continuity is often implemented with little experiential or conceptual integration with research training. As an advantage, this design is easier for an institution to administer and for instructors to implement because cross-disciplinary interactions are minimized. A trainee independently experiences two discipline-focused learning environments, a design that favors learning and skill acquisition in each discipline. This leave of absence design, however, has implications for dual degree trainees. The dual degree trainee starts MD training with the learning environment and relationships of a matriculating cohort of MD-only trainees. After a leave of absence for the second degree, the dual degree trainee completes and graduates from MD training with the learning environment and relationships of a different cohort of MD-only trainees. For example, serially completing an MD degree and Master of Science degree in an engineering discipline (e.g., biomedical engineering) often requires 5 years in contrast to the usual 4 years for only MD-degree training (33). Moreover, the dual degree trainee typically is not training for either degree with an entire class of like-minded, dual degree trainees, potentially diluting synergies that could arise among like-minded trainees. Additionally, if mentors are not experienced in dual degree thinking, a trainee might acquire less experience with applying dual degree training to complex problems benefitting from interdisciplinary or transdisciplinary solutions

compared to the experience acquired from training with mentors who emphasize dual degree thinking. To partially improve discipline integration, a multidisciplinary dual degree design can concurrently deliver discipline-based courses to chronologically merge the disciplines in a student’s schedule. For example, courses leading to an MS degree in an engineering discipline could be scheduled as electives during the pre-clerkship or post-clerkship phases of MD training. Nevertheless, this chronologically merged design neglects to experientially and conceptually integrate the two disciplines.

As a definition, “Interdisciplinarity analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole” (6). Additionally, an education-focused description of interdisciplinary is, “Students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills. Educators and learners collaborate to identify a concept involving multiple disciplines in an integrated way that makes the concept authentic and real-world” (30).

A practical, integration-focused description is that an interdisciplinary dual degree program integrates the two disciplines chronologically and experientially in courses and practicums. Faculty members represent their disciplines and coordinate their teaching across disciplines while retaining their discipline-centric professional identities. For example, team-teaching and co-teaching are approaches to chronologically and experientially integrating interdisciplinary education (34–36). Successful implementation necessitates interdisciplinary planning and faculty development to cultivate interdisciplinary mindsets among faculty members.

A variation on an interdisciplinary dual degree is an interdisciplinary approach to an MD-only degree. For example, the Carle Illinois College of Medicine includes an engineering and transformative innovation focus in its MD degree curriculum (37, 38). Its courses are designed and co-directed by teams including a basic scientist, a clinician, and an engineer (39). The University of Texas at Austin Dell Medical School includes leadership and transformative healthcare problem-solving in its MD-degree curriculum, which includes opportunities to earn a master’s degree inside the four-year MD-degree curriculum (40–42). The Vanderbilt University School of Medicine’s Medical Innovators Development Program includes emphases in engineering, translational development, and innovation in its MD-degree curriculum (43). The University of Massachusetts T.H. Chan School of Medicine has implemented an MD curriculum with an Entrepreneurship, Biomedical Innovation, and Design pathway (44).

3.2 How transdisciplinary dual degrees integrate chronologically, experientially, and conceptually

As a definition, “Transdisciplinarity integrates the natural, social and health sciences in a humanities context, and transcends their traditional boundaries” (6).

An education-focused and distinguishing description of transdisciplinary is:

“Learners identify complex problems and work together to create a shared conceptual framework and draw together theories, concepts, and practices that transcend individual disciplinary boundaries.

Focus is on broad, real-world constructs drawn from an increasingly interconnected world, societal relevance, and student interest. Transdisciplinary (including applied interdisciplinary approaches) is distinct from multi-or inter-disciplinary in that subjects are blended in a transformative manner that provides important gateways for student-centric, student-defined problems or topics that lead to authentic and meaningful learning experiences and student-driven innovations" (30).

A practical, integration-focused description is that the two degree-awarding disciplines of a transdisciplinary dual degree program provide essential foundations for the increasingly integrated continuum of multidisciplinary, interdisciplinary, and transdisciplinary education (30). Transdisciplinary dual degree training builds on these foundations but is not limited by them. Instead of a leave of absence bridging two disciplines, this program tightly integrates the two disciplines chronologically, experientially, and conceptually. In transdisciplinary learning's purest form, teaching and learning dissolve discipline boundaries and focus on solving real-world problems with skills and approaches drawn from both disciplines and novel skills and approaches that transcend the limits of both disciplines (45).

Another manifestation of transdisciplinary learning is nearly instantaneous transitions in thinking between and beyond the two disciplines. For example, learners and instructors seamlessly move between and beyond disciplines during learning, innovation, and problem-solving. Transdisciplinary learning places unique demands on faculty members and faculty development. They must learn to think and teach transdisciplinarily, even if they start with only single-discipline expertise. Unique demands also are placed on the learners. They must become equipped with the two discipline-based foundations while also learning in the multidisciplinary, interdisciplinary, and transdisciplinary continuum.

Determining measures of a program's success can be challenging because of the pioneering nature of a transdisciplinary dual degree program. The measures, in part, come from the disciplines' traditional measures. However, they must also go beyond the disciplines and into the convergence that addresses healthcare problems.

4 ENMED's transdisciplinary dual degree: training physicianeers

Among the dual degree design options, ENMED is following a transdisciplinary dual degree design for all its students because of its mission and vision to train physicianeers, a new type of healthcare professional, through the merging of engineering and medicine (46). Its mission is "to develop a new healthcare professional, trained to be an exceptional physician who is also equipped to invent practical solutions to healthcare problems through the convergence of engineering and medicine. Such innovators will be Physicianeers." Its vision is that, "ENMED graduates will uniquely help to transform healthcare as Physicianeers. This will be achieved through convergence born innovations that improve the understanding and treatment of disease." To facilitate students' completion of this dual degree training within 4 years, ENMED requires its students to have earned a baccalaureate degree in engineering or computer science or have completed mathematics and engineering leveling courses (47).

Thus, students enter ENMED with a foundation in engineering-oriented thinking. They build on that discipline-centric foundation to earn the MD and MEng degrees through increasingly transdisciplinary experiences across the curriculum timeline (48). In addition to program objectives for MD and MEng degrees, ENMED also has these four physicianeering objectives:

- Integrate basic medical and clinical sciences with engineering concepts.
- Critically analyze current practices in order to identify opportunities to develop innovative solutions to problems in medicine and health care.
- Demonstrate an understanding of key concepts needed for the implementation of medical technologies in health care.
- Demonstrate the ability to form teams with relevant transdisciplinary expertise and work collaboratively to develop and implement solutions to real-world medical problems.

Faculty, students, staff, and the learning environment implement ENMED's curriculum and achieve ENMED's physicianeering objectives. Courses, including clinical training, have discipline-specific aspects that contribute expertise and course credits to either degree, but engineers, basic scientists, and clinicians collaborate with course planning and execution throughout the four-year curriculum [see (48) for more information about ENMED's curriculum model]. The curriculum initially employs multidisciplinary and interdisciplinary approaches, including the Stanford Biodesign process (49), to introduce students to engineering medicine. As students encounter increasingly complex healthcare problems, faculty members encourage students to think increasingly across disciplines through curricular activities designed for applying integrated knowledge across basic and clinical science and engineering (e.g., team-based learning and self-directed learning).

Students' shared experiences from engineering backgrounds contribute to a learning environment committed to learning physicianeering and forming a professional identity as a physicianeer. The faculty members' mindset also is essential to this learning environment. Although they come from basic medical science, engineering, and clinical disciplines, they acquire an increasing transdisciplinary mindset through their interactions across disciplines and with students. Faculty members' transdisciplinary development trajectory shares features with, but continues beyond, interdisciplinarity as faculty members become increasingly adept at thinking across discipline boundaries and like physicianeer instructors. Staff members' transdisciplinary thinking and practices support ENMED's dual degree and transdisciplinary goals. Overall, the learning environment committed to physicianeering distinguishes ENMED from most other dual degree settings in which relatively few students share dual degree goals in an overall learning environment dedicated to only one degree (48).

Two activities principally are intended to put transdisciplinary learning into practice. Three 4-week-long Innovation Immersion Experiences (IIE) and the five semesters of Engineering Analysis of Clinical Processes (EACP) during clerkships and the transition to residency phase provide environments for students to devise engineering solutions to clinical problems. The projects are overseen by engineering faculty and clinicians to ensure relevance and fulfill Stanford Biodesign's need statement (49–51).

Students enrich their learning by interacting with biomedical inventors, entrepreneurs, and biodesigners (49, 52). They explore and realize their creative ideas in the Engineering Innovation Center (EIC; an engineering makerspace) and the Biological Engineering Maker Space, a cellular-and molecular-based counterpart to the EIC, while learning basic science, clinical, and innovation-engineering curricular content. Their transformational mindset is expected to help students develop skills for addressing real-world healthcare problems.

5 ENMED's early outcomes—successes and challenges

5.1 Successes

As tracked by Texas A&M University and Houston Methodist Hospital, currently available measures of success for the ENMED program include several established outcome measures used by medical education and biodesign engineering programs. ENMED's outcomes, with its almost 200 matriculated students and its two graduated classes of 2023 (22 members) and 2024 (33 members), thus far support the hypothesis. The mean USMLE Step 2 scores of the two graduated classes exceeded the national average. Some students are highly clinically oriented, while others are highly oriented to translational innovation and commercialization. All graduating students were matched for post-graduate residency training.

ENMED faculty and students published more than 60 articles and presented at more than 60 conferences during 2023 and early 2024. ENMED students produced six intellectual property disclosures in 2022 and 16 in 2023. They have filed seven provisional patents and five Patent Cooperation Treaty patents. A student-led company was formed to commercialize an invention.

5.2 Challenges

Many of ENMED's challenges arise from its unprecedented goal of training physicianers in 4 years. Students must have an engineering or computer science baccalaureate degree or equivalent. This prerequisite helps reduce cognitive overload and facilitates earning the MEng and MD degrees concurrently but constrains the pool of eligible applicants. Faculty must embrace a transdisciplinary mindset, which is demanding given the acquired traditional expertise in a distinct basic science, engineering, or clinical discipline. Faculty members must learn how to teach physicianering without an established template. No existing curriculum, faculty development, and career paradigms exactly fit this goal, and blazing this new path with its dual MD/MEng degrees completed in 4 years requires innovative thinking and experimentation. For comparison, physician-scientists have recognized training and independent career paths, often in academic medicine (53). In contrast, training for physicianers continues to unfold at ENMED. Moreover, career paths of ENMED graduates have yet to be fully realized because physicianers are a new category of healthcare professionals. An emerging alternative to ENMED's dual degree is an MD-degree-only approach to training for healthcare innovation as a "physician-innovator." Many US medical schools are developing this approach (37, 40, 44,

54–59). Accumulating experience will help identify contexts and career goals that favor dual degree "physicianer" versus single-degree "physician-innovator" training.

6 Limitations of ENMED's hypothesis testing

Support for the hypothesis from our ENMED experience has limitations. First, ENMED is only one implementation of an MD-based transdisciplinary dual degree program specializing in MD and MEng degrees. Transdisciplinary dual degree experiences from other institutions and discipline combinations with an MD degree would more broadly explore the hypothesis and its scalability. Second, qualitative and quantitative research data from students, faculty, and graduates will more deeply explore the hypothesis and provide a better understanding of how ENMED works and career paths of ENMED's graduates. Third, ENMED's experience is relatively short term. Long-term outcomes from ENMED's relationships with healthcare ecosystem partners will provide important tests for the hypothesis. These partners include patients and their families, graduate and subspecialty medical education, academic medical centers, biomedical innovation centers (60, 61), and biotechnology.

7 Conclusions, questions, and future work

Our ENMED experiences highlight three important elements of transdisciplinary dual degree programs. First, students need tailored preparation for transdisciplinary dual degree training beyond medical school prerequisites. ENMED students have a baccalaureate degree in engineering or computer science, equipping them for master's degree-level training in engineering when they start ENMED. Students must be eager for the three professional identities they will acquire—physician, engineering professional, and physicianer. Second, faculty must be eager to transcend their discipline's familiar boundaries, be willing to create and deliver educational materials transdisciplinarily, and be able to develop a transdisciplinary professional identity. Third, the learning environment must be transdisciplinary and encourage students and faculty to be, think, and work unconstrained by discipline foundations and silos.

ENMED's early experiences have raised further questions about transdisciplinary dual degree programs. First, what paradigms can guide transdisciplinary dual degree programs' creation and evolution? Interdisciplinarity is an initial concept but can only be a starting paradigm for a practical design. Second, on what timeline might a transdisciplinary dual degree evolve into an academic and professional discipline distinct from the two foundational disciplines? Third, is a transdisciplinary dual degree program realizable in the context of discipline-based dual degrees? ENMED's early experiences answer this question in the affirmative. More experience is needed before judging whether an interdisciplinary or transdisciplinary single-degree design is preferred to a dual degree transdisciplinary design. Judgment will probably depend on a specific program's goals, resources, and context.

Transdisciplinarity intends to solve a range of complex problems, which are abundant in healthcare. Supporting the hypothesis, ENMED's experiences and outcomes show its transdisciplinary dual

degree design has a promising beginning for contributing effective solutions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

GW: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. DB: Conceptualization, Writing – review & editing. LD: Conceptualization, Writing – review & editing. TB: Writing – review & editing. MM: Writing – review & editing. JG: Writing – review & editing. TP: Writing – review & editing. MM-M: Writing – review & editing. EG: Writing – review & editing. NS: Writing – review & editing. MP: Writing – review & editing. RP: Conceptualization, Writing – review & editing.

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Beyond carrots and sticks. Exploring faculty motivation to join a digital health professions educator program

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Introduction: Faculty development programs in the health professions are essential in addressing the evolving and expanding roles of educators. These programs have become a cornerstone of organizational development and contribute significantly to improving student learning. However, the motivation of faculty to engage in such programs is often challenged by the significant demands of their clinical responsibilities and already busy schedules. This study aims to explore the motivation of teaching health professionals to voluntarily participate in the Digital Health Professions Education (d-HPE) program, a 200-h certification program at the Charité - Universitätsmedizin Berlin to train digital teaching skills and competencies.

Methods: In this qualitative study, we analyzed the motivation letters from faculty members who volunteered to participate in the d-HPE program. We used coding based on Self-Determination Theory (SDT) as a framework for analysis with three main themes: autonomy, competence and relatedness. Within autonomy, the sub-themes were intrinsic motivation and self-directed choices. Competence included the sub-themes of mastery of teaching practices and digital skill development. Relatedness included the sub-themes of interprofessional collaboration and mentorship.

Results: A total of 21 motivational letters were analyzed from two d-HPE cohorts, representing diverse health professional backgrounds and career stages. Analysis of the autonomy theme revealed an intrinsic motivation shaped by early teaching experiences and a self-directed decision to pursue advanced qualifications. The competence theme reflected the need to master evidence-based teaching practices and to develop advanced digital skills, with the COVID-19 pandemic as a driving factor. The relatedness theme demonstrated the importance of inter-professional collaboration and mentorship in promoting educational innovation across disciplines and institutions.

Discussion: The motivation of health professions educators to participate in faculty development programs goes beyond the traditional 'carrots and sticks' of external rewards or punishments constellation; it is rooted in their intrinsic motivation to improve teaching qualifications and fulfill their role in digital education. Despite the demands of a busy clinical and professional work schedule, active engagement in intensive faculty development programs is aligned with the need for interprofessional networking and the evolving demands of digital education.

KEYWORDS

faculty development, qualitative study, digital health professions education, self-determination theory, intrinsic motivation

1 Introduction

The rapidly changing landscape of health professions education creates significant challenges for both students and educators, particularly with the increasing integration of digital technologies into education, research, and patient care (1–3). As these changes usually bring both opportunities and challenges, digital education has emerged as a key strategy to equip health professionals with the skills needed to navigate this transformation. Its growing adoption spans all levels of health professions education, from pre- and post-graduate university programs, as well as faculty development, lifelong learning and continuous professional development (2). Faculty participation in development programs to improve digital competencies often depends on intrinsic and extrinsic motivational factors, including the perceived relevance of training to their teaching practice, the opportunity for personal and professional growth, and institutional support (4). However, traditional management approaches commonly rely on the “carrots and sticks” model of rewards and punishment that may fail to address the deeper motivational needs, potentially limiting faculty engagement and the long-term impact of such programs. Understanding these motivational factors may be essential for designing effective faculty development programs that promote long-term engagement and successful and sustainable implementation of digital teaching competencies. Therefore, this study seeks to move beyond the “carrots and sticks” framework by exploring intrinsic motivational factors, as outlined by self-determination theory, to better understand what motivates faculty to join and remain engaged in a digital health professions educator program.

Digital education is broad and evolving in nature and is used as an umbrella term for different educational approaches, methods and technologies and is defined as “teaching and learning using digital technologies, ranging from the simple conversion of content into a digital format (e.g., a book into a PDF or HTML format) to the complex use of digital technologies (e.g., mobile education, serious games, virtual patients and virtual reality)” (2). The benefits of digital education generally include flexible and widespread access to content, personalized learning experiences, increased engagement with content and deeper information processing. However, it is also likely to present challenges such as the digital divide (requiring IT infrastructure and digital literacy), higher development and deployment costs, and potential negative emotional effects such as anxiety and feelings of isolation among students and teachers (2).

Following the COVID-19 pandemic, which led to a rapid transition to digital teaching and learning in many educational institutions, there has been an increasing need for faculty development specifically aiming at preparing and supporting health professions educators to deliver effective digital instruction and assessment, maintain student engagement, and foster interprofessional collaboration in a virtual environment (5). Digitally competent faculty are generally better equipped to design and implement educational strategies that meet diverse needs of learners and to navigate the complexities of digital health education (6). As a result, faculty development programs that focus specifically on digital education have received increasing attention for their ability to address the specific learning needs of educators and equip them with skills to teach in a rapidly digitizing

environment (4). However, given time pressures associated with clinical practice and service, understanding factors which motivate faculty to voluntarily engage in such faculty development programs is crucial for effective design and implementation in the future (3).

Teaching competencies in health professions education are evolving and expanding to encompass various roles, including the teacher as facilitator and mentor, curriculum developer and implementer, assessor and diagnostician, role model, manager and leader, scholar and researcher, and professional (7, 8). In addition, with recent advances in digital technology, there has been a growing emphasis on digital competence, defined as “the set of knowledge, skills, attitudes, abilities, strategies, and awareness required to use information and communication technology (ICT) and digital media” (9, 10). It includes self-rated competencies (e.g., digital literacy and eHealth literacy), psychological and emotional aspects of using digital technologies (e.g., attitudes and beliefs, confidence and awareness), use of digital technologies (e.g., for general and specific functions) and knowledge of digital technologies (11).

Digital competence is often interchangeably referred to as pedagogical digital competence (PDC), which refers to the ability to consistently apply knowledge, skills, attitudes, approaches to technology and learning theory to plan, deliver, evaluate and continually revise digital education (4). Several digital competency frameworks have been developed for health professions educators to inform the development of faculty training programs in this area (12). However, the digital competencies and support needed by educators vary widely, depending on factors such as pre-existing skills, local conditions and individual needs, which differ from region to region (13).

Despite a widespread need to support these teaching and digital competencies, specialized training programs remain scarce, highlighting a necessity to integrate these skills into faculty development programs to reach health professionals, especially those with heavy workloads and leadership roles (3, 6, 14). Evidence from the literature shows that digital education faculty development interventions have been designed and delivered to a diverse range of healthcare professionals, in a variety of settings, and with a range of different outcome measures (2, 4). The most common approaches used were formal workshops, group work, case studies, discussions and practical exercises or simulations, but relatively little attention was paid to informal and individualized approaches (e.g., peer coaching and collegial support) (8, 15). Evidence from the literature recommends the integration of multi-method strategies in authentic contexts such as experiential learning, role modeling, reflection, and applying evidence to teaching practice to improve digital competencies of teaching health professionals (8, 16, 17). It is also recommended to provide extended longitudinal programs, which could have the advantage of fostering a community of practice, aligning with institutional priorities, promoting educational leadership, and increasing scholarly productivity (8, 18, 19).

To further enhance the effectiveness of faculty development programs, it is essential to consider how learning processes align with key dimensions: cognitive (what to learn), affective or motivational (why to learn), and metacognitive regulation (how to learn) (20). Among these dimensions, motivation plays a critical role in faculty engagement hence focusing on stimulating faculty motivation can have a significant impact on the outcomes of faculty

development (FD) programs. Several motivational theories have evolved over time, such as Murray's Need to Achieve Theory (1938), which suggests that motivation is a dynamic construct shaped by time and context rather than a fixed trait (21), Hull's Drive Theory (1943), which suggests that human behavior is driven by needs that must be met to maintain a steady state (22), and Maslow's Hierarchy of Needs (1943), which proposes that human motivation is organized in a hierarchy (23). Other motivational theories include Atkinson's Expectancy-Value Theory (1966), which argues that motivation is influenced by an individual's desire to succeed or avoid failure (24), and Bandura's Social Cognitive Theory (1977), which emphasizes the role of self-efficacy in motivation (25). The Self-Determination Theory (SDT), developed by Edward Deci and Richard Ryan, is one of the current major motivational theories in many fields, including education and health care, and its applications in medical education are gaining increasing interest (26). It was selected for this study because it is particularly well suited to exploring faculty motivation to voluntarily engage in development programs, such as the program that is subject of this study where participation is not externally mandated but driven by personal and professional factors. Given the voluntary nature of the program and the challenges posed by faculty's clinical responsibilities, SDT would allow for a nuanced understanding of internal drivers that influence their decision to participate in an intensive and time-consuming program. This theoretical framework enables the exploration of how intrinsic motivation, rather than external rewards or obligations, plays a key role in faculty engagement, making SDT an appropriate choice for examining the factors influencing participation in faculty development (27, 28).

In Germany, the digitalisation of healthcare has been established by law with the "Digital Healthcare Act" from 2020, and there is a growing need for further training in digital education (13). However, only a few German medical schools have integrated digital health skills into their curricula, often as an elective course that reaches a small number of students (29). There is a growing need to train faculty in digital skills in order to make future courses more accessible to a wider range of students (29). Existing research has predominantly focused on either assessing the digital competencies of health professions educators (11, 30–33) or evaluating the outcomes of faculty development programs designed to enhance digital competencies (15, 34, 35). These evaluations typically assess program effectiveness in terms of teaching effectiveness and successful integration of digital tools into teaching practice. However, there is a gap in the literature regarding the motivations that drive faculty to participate in these programs (36). Addressing this gap seems important for several reasons. First, as motivation directly influences the level of commitment of healthcare educators to their professional development, it is important to design and implement programmes that not only meet institutional goals but also resonate with the personal and professional aspirations of educators. This approach ensures greater commitment and sustained success by investing time and effort in learning new skills, experimenting with innovative teaching methods and overcoming technological challenges (37). A second reason is that faculty development programs require significant institutional investment in terms of resources, time and funding, so it is important for institutions to understand

what motivates faculty to participate and remain engaged in these programs (38). Third, motivation research has shown that adult learners, such as educators, have distinct needs to see clear value and relevance to their practice, to have autonomy in their learning, and to feel competent in new skills (39, 40). Finally, sustaining behavioral change in teaching practices, particularly in the context of digital health education, requires more than initial skill development; it requires ongoing motivation to implement and refine new approaches (41, 42). Thus, understanding motivational factors is critical for designing faculty development programs that support the long-term integration of digital competencies into teaching practices.

1.1 Aim of the study

The purpose of this study is to explore the motivations of teaching health professional at Charité - Universitätsmedizin Berlin (Charité) to voluntarily enroll in the Digital Health Professions Educator (d-HPE) program, a 200-h interprofessional faculty development program. This research focuses on understanding why educators choose to voluntarily participate in such an intensive program, despite their demanding professional responsibilities.

2 Materials and methods

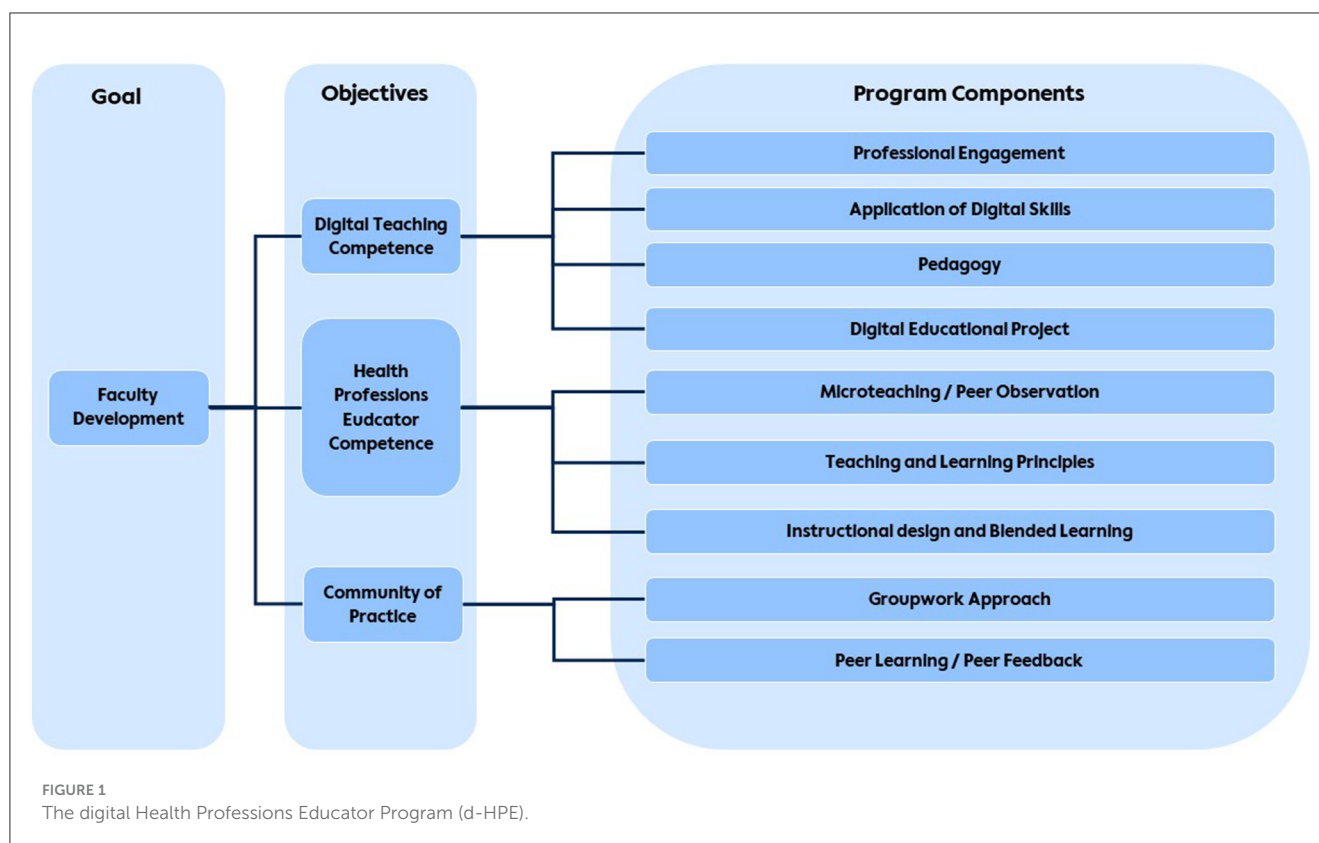
2.1 Philosophical assumptions and study design

This study is underpinned by a constructivist epistemology which assumes that knowledge is created through social interaction and that motivation is a complex, contextual phenomenon shaped by personal beliefs, prior experiences and social interactions (43). In line with this paradigm, we adopted an exploratory qualitative research approach to understand the perspectives and motivations of health professions educators applying for the d-HPE program, designed for faculty interested in obtaining a formal qualification in digital education. A qualitative approach also allows for in-depth exploration of nuanced and multifaceted motivational aspects and is increasingly used in the context of motivational theories (44).

2.2 Study setting and participants

The study was conducted from May 2023 to July 2024 at the Charité Germany. The sampling frame consisted of educators in the health professions applying for the d-HPE program, a blended learning interprofessional faculty development program delivered over 1 year.

The d-HPE program was developed and implemented as a comprehensive faculty development initiative aimed at equipping healthcare educators from diverse professional backgrounds and career stages at the Charité with digital competencies needed to teach, assess, and mentor in digital education contexts. The program is structured into three progressive modules, comprising a total of 200 teaching units (45 min each), designed to build



participants' basic knowledge and skills in addition to advanced application (Figure 1).

Module I (60 teaching units) focuses on the fundamental principles of digital health education, including topics such as constructive alignment, teaching and learning methods, instructional design, and the use of blended learning and online teaching tools. Participants are also introduced to media production techniques where they learn to create digital teaching materials such as screencasts and videos. This module emphasizes reflective practice and peer feedback as essential components of professional development. Module II (60 teaching units) provides more advanced training, enabling participants to engage in the practical application of tools and educational strategies specific to online environments, e.g., the development of virtual patient cases, online seminars and exams, with a particular focus on humanizing online learning environments. Module III (80 teaching units) requires participants to undertake a major digital teaching project, synthesizing and applying their knowledge to the design and implementation of a large-scale digital learning initiative. Throughout this module, participants receive individual mentoring and participate in workshops and journal clubs focused on digital health professions education.

The 12-month program offers a flexible, blended learning approach that includes both online self-study and face-to-face workshops. The final module culminates in the presentation and peer review of participants' digital teaching projects. The program has been co-designed by an interprofessional team of experts in medical education, faculty development, e-learning and interprofessional education at the Charité. A collaborative design

process ensured that the program is tailored to the needs of a broader interprofessional range of participants from various areas and health professions. Based on adult learning principles, the program emphasizes collaborative inquiry, where participants learn through shared experiences, and reflective practice, which encourages critical self-assessment and continuous professional development (3).

2.3 Data collection

For data collection we used letters of motivation of applicants to the d-HPE program in the two consecutive cohorts of 2023/2024 and 2024/2025. The motivational letters, with an average length of one page, were anonymized and translated into English by the author MS.

2.4 Qualitative data analysis

A deductive approach to qualitative data analysis was adopted for this study, which begins with an organizing framework derived from existing literature to provide a structured starting point for analysis, making it both structured and flexible and ensuring that the coding process was grounded in the existing literature (45, 46).

In contrast to conventional qualitative content analysis, used for example in grounded theory, where coding categories are derived directly and inductively from raw data, the current study adopted a directed content analysis approach with the aim of

TABLE 1 Coding framework adapted from Ryan and Deci (49).

Theme	Subthemes	The theme explores
Autonomy	Intrinsic drive	The motivation that arises from personal interest, curiosity, or internal satisfaction in the context of teaching or learning practices.
	Self-directed choices	The motivation derived from autonomy to determine the most appropriate teaching strategies or methods.
Competence	Mastery of teaching practices	The motivation to attain a high level of expertise in the field of teaching.
	Digital Skill development	The motivation to develop or enhance specific teaching skills, with a particular focus on digital and innovative methods.
Relatedness	Interprofessional collaboration	The motivation to collaborate with peers and engage in interprofessional projects.
	Mentorship	The necessity of establishing connections with and helping the forthcoming generation of learners and professionals.

extending the conceptual framework or theory, in our case the Self-Determination Theory (46, 47). Analysis was conducted using Atlas.ti qualitative data analysis (QDA) software (a computerized indexing system, Berlin, Germany) (48). The coding framework was constructed around the three main themes of autonomy, competence, and relatedness (49). The main themes, subthemes, and their definitions are summarized in Table 1.

In a collaborative, iterative analysis process, author (MS) carried out the initial analysis based on the first cohort of motivation letters. The analysis was revised by authors (ML) and (HP) and a consensus-building process followed: disagreements in the collaborative analysis process were addressed through a structured and iterative approach. Any differences in analysis were resolved through in-depth discussion to ensure agreement on the coding process. Finally, the analysis of the remaining motivation letters was continued in an iterative process by MS, ML, and HP.

2.5 Ethics approval

This study was conducted in compliance with the data protection regulations at the Charité and was approved by the Ethics Committee of the Charité. Anonymity was ensured; a consent form was signed by the participants, who were informed about the study purpose, the use of data collected, and their right to withdraw at any time without consequences for their success in the program.

2.6 Reflexivity

The reflexivity was achieved through the maintenance of a research diary, which included notes and comments on the motivation letters as well as interaction between the researchers and the course participants (50). In this case, researchers act as insiders, taking on the role of course development, implementation, and evaluation, as well as being responsible for teaching all participants and providing ongoing support throughout the program. While this role facilitated a deeper understanding of contextual complexities, potential drawbacks emerged, primarily in terms of power dynamics between researchers and participants. Measures were taken to mitigate this, including anonymizing the motivational letters and ensuring that participants' performance was not influenced by their involvement in the study. We also

recognize that the researchers' intense involvement in the program may have potentially influenced the data analysis process (51). To address this, we engaged in an iterative process of careful review of the analysis in which initial disagreements were discussed and resolved through collaborative discussions. This approach ensured that consensus was reached and the integrity of the research findings was maintained.

3 Results

3.1 Participants

A total of 21 motivation letters were analyzed from two d-HPE program cohorts in academic years 2023/2024 and 2024/2025 including anaesthesiology ($n = 3$), pediatrics ($n = 2$), geriatrics ($n = 2$), internal medicine ($n = 2$), emergency medicine ($n = 2$), clinical nursing ($n = 1$), pediatric Surgery ($n = 1$), orthodontics ($n = 1$), radiation oncology ($n = 1$), nephrology ($n = 1$), pharmacology ($n = 1$), IT/scientific computing ($n = 1$), pathology ($n = 1$), medical physics ($n = 1$) and social medicine ($n = 1$).

3.2 Autonomy

Regarding the intrinsic drive, the analysis revealed a strong passion for teaching and an enthusiasm for creative and effective teaching methods, e.g., the inherent interest in digital tools combined with a personal passion for drawing and illustrating to enhance medical presentations for research and teaching (Table 2, quote 1). Intrinsic drive is also associated with an early commitment to teaching, either early in the medical career (Table 2, quote 2) or even during the participants' undergraduate years (Table 2, quotes 3 and 4). These examples illustrate how intrinsic motivation, often rooted in personal interests and early experiences, served as a foundational driver for engagement in an intensive faculty development program.

In addition to intrinsic motivation, participants made self-directed choices to improve their digital teaching skills and to pursue career advancement and leadership in education. A key motivation was the decision to acquire substantial additional qualifications, reflecting a commitment to continuous improvement in teaching methods (Table 2, quote 5). In addition, the program was seen as an essential investment in personal

TABLE 2 Autonomy.

	Quote	Participant
1	"But the digital aspect also appeals to me personally Since the beginning: I already use my passion for drawing and illustrating to prepare medical content for my presentations in research and teaching"	Male participant, location 7
2	"Since the beginning of my medical career, I have been involved in teaching students with commitment and enthusiasm."	Female participant, location 10
3	I myself have been involved in teaching since I was a student, including as a tutor. Very early in my medical career, I trained as a medical educator.	Male participant, location 5
4	My passion for teaching began during my studies. I was able to gain my first experience as a lecturer as a member of the anonymous (a student working group).	Female participant, location 1
5	"I would like to optimize my teaching by obtaining a substantial additional qualification".	Female participant, location 3
6	"I am also convinced that expanding my digital skills will not only enrich my teaching methods, but also advance my personal academic career. The qualification from your program represents an essential investment in my future, enabling me to be a leader in the development and application of innovative teaching strategies".	Female participant, location 11

TABLE 3 Competence.

	Quote	Participant
1	"In 2016, after seven years of studying medicine, I went from being a learner to a teacher in one fell swoop. This change of perspective made me realize that I really enjoy teaching, but also that I know relatively little about my new role. And although my growing experience in the many courses that followed gave me a lot of confidence, I was always keen to immerse myself in didactics in a structured way."	Male participant, location 7
2	"By strengthening and expanding my own didactic and methodological skills, I can further develop my 'own' teaching and lecturing activities."	Female participant, location 9
3	"I want to base my teaching on sound evidence and to learn and try new approaches."	Male participant, location 14
4	"My main goal is to use the program to refine my teaching methods so that they not only meet current academic standards, but also increase the interactivity and accessibility of my teaching."	Female participant, location 11
5	"The restrictions imposed by the Corona pandemic over the last 3 years have impressively demonstrated the importance of innovative and digital approaches to teaching in (higher) education institutions. Acquiring the skills to create digital learning content, such as videos or live online surveys, would be a great asset, as this will certainly play an increasingly important role in knowledge transfer at universities in the future."	Female participant, location 6
6	"I hope that my participation in the Digital Health program will give me the opportunity to develop and implement my own media-based teaching concepts."	Male participant, location 13
7	"The goal of the participation is to develop an interactive online course on <i>anonymized</i> topics for <i>anonymous</i> , which will provide basic knowledge through examples and illustrations and provide feedback to the students."	Male participant, location 15

academic growth, with participants recognizing its potential to enrich their teaching while positioning them to lead the development and implementation of innovative teaching strategies (Table 2, quote 6). This highlights a deliberate and forward-thinking approach, with participants choosing the program to align with their long-term goals of becoming leaders in the evolving field of medical education.

In summary, the analysis of the autonomy theme reveals that faculty members' motivation to engage in the d-HPE program stems from both an intrinsic drive, rooted in a passion for teaching and early teaching experiences, and a self-directed decision to strategically pursue advanced qualifications to improve teaching practice and position themselves as leaders in educational innovation.

3.3 Competence

In terms of mastering teaching practice, participants expressed a need to expand expertise and refine evidence-based teaching methods. For some, this need stemmed from an early transition from learner to teacher, which highlighted a need to better

understand teaching practices and pursue structured educational training in didactics in order to gain confidence and competence (Table 3, quote 1). Participants also emphasized the importance of continuously improving their pedagogical and instructional skills in order to increase their teaching effectiveness and adaptability (Table 3, quote 2). In addition, grounding teaching on sound evidence while remaining open to experimenting with innovative approaches was highlighted as a key strategy, reflecting a commitment to combining proven pedagogical methods with flexibility and creativity in practice (Table 3, quotes 3 and 4).

Regarding the development of digital skills, participants highlighted the challenges and opportunities presented by the COVID-19 pandemic, emphasizing the need to adopt innovative digital approaches to enhance knowledge transfer, such as creating digital learning content like videos and live online surveys, as essential tools for future educational success (Table 3, quote 5). In addition, there was a motivation to use the dHPE program to help develop and implement personalized media-based teaching concepts or interactive online courses tailored to specialized topics to support student engagement and provide real-time feedback (Table 3, quotes 6 and 7).

TABLE 4 Relatedness.

	Quote	Participant
1	" <i>Anonymous</i> is a particularly interprofessional field; we communicate, treat and research with other areas of human medicine, medical technology and materials development. This makes an interprofessional program and joint learning particularly interesting for us in order to establish further cooperation in therapy, research and teaching."	Male participant, location 4
2	Another key objective is to develop and implement digital teaching and learning tools specifically tailored to the needs of interprofessional healthcare professionals.	Female participant, location 11
3	"My goal is to further develop innovative, future-oriented learning and teaching methods in the <i>anonymous</i> at the Charité. I am convinced that the exchange and networking of faculty and teaching staff through programs such as this can significantly advance teaching, and I would like to be a part of it."	Female participant, location 1
4	"My goals for participating in the program are networking and exchanging experiences with other teachers at the Charité to initiate interprofessional teaching projects and to work together on the further development of digital teaching concepts."	Male participant, location 12
5	"I would like to provide the next generation of health professionals with adequate training and digital and online learning materials."	Female participant, location 3
6	"Of course, I would also like to pass on the knowledge I have gained to interested colleagues, not only in <i>anonymous</i> , and thus support the integration of the various possibilities of digitalization into university didactics."	Female participant, location 6
7	"In addition, I would like to pass on the knowledge gained in such a project not only to interested colleagues already working in the field of anonymous, but also to support other digital didactic projects at universities."	Male participant, location 6

In summary, the theme of competence underscores participants' motivation to master teaching practice in general and to develop advanced digital skills in particular, acknowledging the role of the COVID pandemic in accelerating an adoption of innovative teaching strategies and reflecting a dual focus on evidence-based methods and innovative approaches.

3.4 Relatedness

Regarding interprofessional collaboration, motivation to engage in collaborative learning and interdisciplinary programs was particularly evident, with some participants emphasizing the collaborative nature of their fields, making interprofessional faculty development programs and collaborative learning opportunities essential to advancing interprofessional collaboration in therapy, research, and teaching (Table 4, quote 1). Others expressed a commitment to developing teaching methods and tools tailored to the needs of interprofessional health care teams, e.g., creating and implementing digital teaching and learning tools for interprofessional contexts as a key goal for applying to the program (Table 4, quote 2). Similarly, participants recognized the role of interprofessional networking in improving educational practice and promoting innovative, future-oriented teaching methods in an interprofessional skills lab (Table 4, quote 3). Other participants highlighted the potential of such collaboration to initiate interprofessional teaching projects and drive development of digital teaching approaches, emphasizing the critical role of interprofessional exchange (Table 4, quote 4).

Mentorship was highlighted as a central component of motivation, with participants aiming not only to support the development of students, but also to actively contribute to professional growth of their professional peers, ensuring that advances in education and digital instructional methods are widely shared and implemented. Passing on knowledge and skills to future generations of health professionals reflects a commitment to supporting peers and junior colleagues with digital tools in a rapidly evolving educational landscape (Table 4, quote 5). Application

to the d-HPE program was also motivated by an intention to integrate digitization into university teaching by disseminating any knowledge gained to colleagues, further underscoring the cascading effect of mentorship in fostering innovation across disciplines (Table 4, quote 6). Other participants noted the value of sharing insights with colleagues in specialized fields while also contributing to broader digital teaching projects at universities (Table 4, quote 7).

In summary, the theme relatedness emphasizes the importance of interprofessional collaboration and mentorship to promote educational innovation, professional development and the dissemination of advanced teaching practices across disciplines and institutions.

4 Discussion

The motivation of teaching health professionals to deliberately participate in an extensive faculty development program, despite the significant demands of their clinical roles, is a critical factor to the success and sustainability of such initiatives. This study explored motivations of health professions faculty to engage in a voluntary faculty development program, the d-HPE at the Charité Berlin. The theoretical framework of self-determination theory, with its three dimensions of autonomy, competence and relatedness, provided a deeper understanding of the personal and professional factors that drive participation in such a faculty development program. In the following sections, we will discuss our findings in the context of the literature, highlighting the importance of intrinsic motivation and the need for teachers to feel supported in their professional development. In addition, we will derive implications on how to motivate faculty to engage in similar faculty development programs based on the findings identified in our sample of motivation letters.

Overall, the results indicate that intrinsic motivation plays an important role in attracting faculty to participate in faculty development initiatives, moving beyond the "carrots and sticks" of extrinsic motivations commonly highlighted in the

literature, such as scholarships, awards, promotions, incentives, or coercion by department heads (36). While intrinsically motivated faculty may be more likely to use best teaching practices, extrinsically motivated faculty may choose less effective strategies as their goal is the shortest path to outcome completion (28). Autonomy and self-direction were associated with increased motivation, so rather than focusing solely on institutional and functional needs, addressing faculty members' perceived needs for autonomy in planning their own professional development path led to higher levels of curiosity to learn and try new things, resulting in increased sustainability and success of faculty development initiatives (52–55). Conversely, the limited autonomy experienced by some educators appeared to inhibit the long-lasting impact of continuing professional development projects, despite the voluntary nature of attendance (56, 57). Autonomous motivation was also found to predict greater incorporation of effective teaching strategies and instructional clarity, as well as collaborative learning, by healthcare professions educators (28). It is therefore recommended that teachers' engagement in professional development activities should be driven by their own determination, alignment with their personal aspirations or values, confidence in their ability to acquire new skills, and autonomy in shaping their own professional development trajectories, rather than by extrinsic sources of motivation.

Early teaching experiences serve as important sources of motivation for engaging in faculty development, which is consistent with the literature suggesting that early teaching experiences can play a critical role in shaping educators' long term commitment to teaching (58, 59). This is particularly important in shaping the identity as a health professions educator, as prior to teaching, students do not make an explicit connection between teaching and being a physician (or maybe better) "health professional" (58). Thus, our findings underscore an importance of promoting early teaching experiences as it can significantly increase motivation to participate in faculty development programs and promote an identity as a teacher (54).

Regarding the competence theme, our results show that motivation to master evidence-based teaching practices and develop advanced digital skills encourages health professionals to engage in faculty development activities, which is consistent with previous research (36). In this context, digital competence, characterized by a desire to learn and develop professionally, is crucial for institutions to develop digital competence policies and initiatives, plan professional development and integrate technology into teaching practice (60, 61). However, research has shown that motivation to learn and teach digital competence is not always directly related to training received; it is also influenced by other factors such as "working climate" and institutional support (62). A key implication, therefore, is that faculty development and competence are mutually reinforcing. The participation in faculty development activities enhances teachers' digital competence, while the desire to improve one's own competence serves as a key motivator for engaging in such initiatives (61).

Regarding the relatedness theme, participants showed a strong appreciation of interprofessional collaboration, recognizing its value in networking, developing collaborative skills and fostering a

better understanding of different professional roles. These findings are consistent with recent literature advocating a growing need for interprofessional faculty development programs and describing relatedness as the "enjoyment" of working with and learning from others (63, 64). This reinforces the notion that faculty development should foster a sense of community and support, and that digital interprofessional education is needed across the continuum of undergraduate, postgraduate and faculty development (65, 66). In addition, the integration of digital tools into interprofessional teaching contexts addresses the frequent lack of advanced digital skills among health professional educators, particularly in collaborative and interdisciplinary settings (67). Participants in our study emphasized the importance of creating and implementing digital teaching tools tailored to interprofessional health care teams, reflecting a commitment to bridging this digital skills gap.

Mentorship emerged as another key theme, with participants in our study expressing a strong desire to support the professional development of colleagues and students through mentoring initiatives. This focus on mentorship reflects a commitment to long-term professional development, with teachers acting as catalysts for innovation by passing on knowledge and skills to both students and colleagues. Just as formal faculty development programs—such as workshops—provide structured opportunities for professional growth, mentoring serves as an important, often informal, approach to fostering long-term development (68). This highlights the critical role of mentorship in promoting sustainable professional development and reinforces the idea that faculty development is not only about individual growth and promotion, but also about creating communities of practice and cultivating a culture of continuous learning and excellence in healthcare education.

In summary, faculty are intrinsically motivated to engage in intensive programs in addition to their clinically demanding lifestyles and daily responsibilities when the faculty development initiatives combine formal and informal learning elements to provide a flexible, longitudinal learning experience in an interprofessional setting. The motivation for faculty to participate in such intensive programs goes beyond carrots and sticks, i.e., external rewards and punishments, and is driven by their personal commitment to professional development, the desire to acquire new skills, and the opportunity to collaborate with colleagues across disciplines, all of which contribute to their long-term satisfaction and development as educators. The carrots and sticks metaphor is consistent with the findings of the current study, where faculty participation is driven by internal factors (autonomy, competence and relatedness) rather than external rewards or punishments. It is also consistent with the theoretical framework of Self-Determination Theory (SDT) used in the study, which emphasizes intrinsic motivation over external rewards and punishments. The use of the metaphor also aims to effectively challenge traditional management approaches that rely heavily on rewards and punishments and reflects the modern understanding of professional motivation in education. The integration of structured workshops with peer coaching and collaborative networking to promote personal and professional growth helps to increase motivation. By fostering interprofessional

collaboration and sustained engagement, the faculty development program not only improves individual teaching practice, but also supports the development of a culture of continuous learning, ultimately bridging the digital skills gap and advancing healthcare education.

While this study provides valuable insights into motivations of health professions educators to engage in a digital health professions education program, some limitations need to be acknowledged. First, the study relies on a small sample size of 21 motivational letters from two d-HPE cohorts, which may limit the generalisability of the findings to a broader population of health professions educators. In addition, all participants were from a single institution, Charité Berlin, where the 21 teachers are known within the institution for their participation in the programme. To protect their confidentiality and adhere to ethical research standards, we anonymised detailed demographic data such as place of work and specialty. However, this limits the level of contextual detail in the findings and their wider applicability to different educational settings with different institutional cultures and resources. In addition, the analysis is based on self-reported data, which introduces the potential for social desirability bias. Participants may have framed their motivations in ways that they perceived to be more socially acceptable or in line with the goals of the programme. While collaborative discussions during the analysis helped to ensure rigor and consensus, the inclusion of additional methods, such as interviews or focus groups, in future research could provide richer and more triangulated data. The lack of a comparison group of faculty who did not participate in the d-HPE program is another limitation, as this would have allowed for a deeper exploration of the unique factors driving participation relative to broader faculty development needs. Future research should aim to address these limitations by including a larger and more diverse sample from multiple institutions, incorporating a mixed methods approach, and including a comparison group to provide a more comprehensive and generalizable understanding of faculty motivations in similar programs.

5 Conclusions

Motivation of teaching health profession faculty to participate voluntarily in an intensive faculty development program is primarily driven by intrinsic motivational factors, particularly the desire for professional development and mastery of digital teaching skills. Rather than being swayed by the traditional “carrots and sticks” of external rewards or pressures, faculty are motivated by the opportunity to improve their teaching practice and contribute to educational innovation in digital health, despite the challenges posed by their busy clinical workloads. The findings also highlight the importance of interprofessional collaboration and mentorship in fostering a sense of belonging and supporting continuous professional development. Effective faculty development programs should prioritize autonomy, competence and relatedness to enhance engagement and align with the evolving demands of digital education. In addition, there is a need for faculty development initiatives that not only respond to external pressures, but

also cultivate intrinsic motivations to ensure sustained faculty engagement and to facilitate professional growth.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Committee of the Charité University of Medicine. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MS: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. ML: Data curation, Formal analysis, Writing – review & editing. HP: Formal analysis, Resources, Supervision, Writing – review & editing.

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Unleashing potential: evaluating the effectiveness of the BOPPPS teaching strategy in Chinese urology education

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Introduction: The BOPPPS teaching strategy has gained popularity in medical education in China as a more effective and practical pedagogy. However, its impact on knowledge acquisition and clinical skills in urology education has not been comprehensively evaluated. This study seeks to assess the effectiveness of the BOPPPS strategy in comparison to traditional lecture-based learning (LBL) during clinical internships in Chinese urology education, utilizing meta-analysis for verification.

Methods: A cohort of 96 clinical medicine students from Xijing Hospital, engaged in clinical practice at the Department of Urology from September 2022 to June 2023, were stratified into two groups and exposed to identical teaching materials. The experimental group (n=48) was instructed using the BOPPPS model, while the control group (n=48) adhered to traditional instructional methods. Data on student satisfaction and self-assessment of the course were collected through a questionnaire, and end-of-course performance was evaluated through a post-study examination. We used meta-analysis aimed to evaluate the overall effectiveness of the BOPPPS teaching strategy compared to LBL teaching in surgery-related medical education.

Results: The experimental group, which received instruction using the BOPPPS teaching model, achieved significantly higher scores in theoretical knowledge assessments and clinical practical skills compared to the control group. Additionally, the experimental group demonstrated greater levels of interaction with both teachers and students, with instructors displaying a higher ability to foster independent thinking among students. Furthermore, the teaching process in the experimental group was found to utilize classroom time more efficiently in comparison to the control group. And we confirmed that the BOPPPS model demonstrated a greater capacity to stimulate student interest in urology and improve their overall proficiency by meta-analysis.

Discussion: The BOPPPS model exhibits superior efficacy in clinical teaching of urology, thus warranting consideration for wider adoption and dissemination.

KEYWORDS

BOPPPS, urology, education, meta analysis, visual reality (VR), traditional lecture-based learning (LBL)

Introduction

Urology is a crucial surgical specialty that places a strong emphasis on clinical reasoning and the resolution of complex clinical challenges (1). Hence, the stringent demands for doctors' fundamental theoretical understanding and practical skills are emphasized (2). Within the conventional urological educational framework in China, clinical instructors are heavily occupied with patient care, thereby relegating trainee doctors to primarily observational roles (3). The level of interaction between clinical educators and medical trainees is inadequate and ineffective (4). Furthermore, due to the sensitive nature of urological diseases and the importance of maintaining patient privacy, trainee doctors frequently encounter limitations when observing treatments or conducting urological examinations (5). Minimally invasive technology is integral to the advancement and modernization of urology, as well as in practical instruction (6). However, due to constraints in medical teaching resources and operating environments, interns are often unable to gain hands-on experience with advanced technologies like laparoscopy and the Da Vinci surgical robot, thus limiting their acquisition of relevant practical skills (7, 8). In summary, novice medical practitioners have limited chances to acquire practical experience, resulting in a tenuous connection between theoretical understanding and application in clinical settings.

Traditional lecture-based learning (LBL) instruction serves as the primary method for imparting fundamental knowledge to medical students during their clinical rotations, with an emphasis on the instructor and the delivery of syllabus content and concepts (9). The internship experience may be perceived as tedious by trainee doctors, leading to a lack of motivation for engaging in active learning (10). This lack of motivation hinders the development of essential clinical skills, critical thinking abilities, and effective doctor-patient communication. Therefore, it is imperative to reform the conventional teaching approach in China to foster trainee doctors' problem-solving skills and cultivate a new generation of highly skilled medical professionals.

In contemporary medical education, traditional teaching methods often adhere to the BOPPPS instructional framework, which stands for Bridge-in, Objectives and Outcomes of Learning, Pre-assessment, Participatory learning, Post-assessment, and Summary. It was first introduced by Douglas Kerr from the University of British Columbia (11), and has been developed recently in medical education in China. According to the constructivist learning theory, the BOPPPS teaching strategy provides a comprehensive framework and process for attaining instructional goals (12). The BOPPPS model prioritizes comprehensive engagement and reciprocal communication between educators and medical trainees, with a central emphasis on the trainees themselves.

Over the last decade, the BOPPPS teaching strategy has been implemented in the instruction of various medical subjects, across a wide range of medical disciplines, including but not limited to dental materials education (11), ophthalmology education (13), oral histopathology education (14), physiology education (15) and gynecology education (16). There is currently a lack of literature regarding the implementation of the BOPPPS model in urology education. While the BOPPPS model has demonstrated success and effectiveness in enhancing students' academic

knowledge, its applicability in urology education for clinical medical students in China remains uncertain. In this study, a cohort of 96 undergraduate students who have completed clinical probation in the urology department of Xijing Hospital were selected to investigate the varying impacts of integrating the BOPPPS model with Virtual Reality (VR) technology and conventional Lecture-Based Learning (LBL) approaches in urology education. And we also use meta-analysis aimed to evaluate the overall effectiveness of the BOPPPS teaching strategy compared to LBL teaching in surgery-related medical education.

Methods

Participants

This observational study was conducted among final-year undergraduate medical trainee doctors at the Department of Urology, Xijing Hospital, from September 2022 to June 2023. All participants provided informed consent for their involvement in the study. A control group of 48 interns utilized the traditional Lecture-Based Learning (LBL) teaching method, while an experimental group of 48 interns utilized the BOPPPS model combined with Virtual Reality (VR) technology. The control group comprised 7 females and 41 males, while the experimental group included 9 females and 39 males. Both cohorts of students utilized the urology related diseases from a common textbook as instructional material. The teaching procedures were conducted concurrently in both the experimental and control groups. Patients were chosen from the inpatient population of the urology department for use as a teaching case. Prior to the instructional session, the teacher engaged in communication with the patients and secured their consent. Subsequently, the teacher compiled the pertinent medical information of the patient into a case study. The specific pedagogical approaches employed are outlined.

Traditional LBL model

The control group was mainly taught by the traditional LBL teaching method. The teacher first explained the relevant theoretical knowledge of the selected disease according to the syllabus's specific requirements. Afterwards, students discussed and answered clinical questions based on the cases provided by the teacher. Finally, the teacher summarized the course content according to the requirements of the syllabus.

BOPPPS model

One week prior to the commencement of the internship, the instructor provided the students with an overview of the theoretical chapters and associated topics. The BOPPPS model was delineated into six distinct stages.

Bridge-in: Based on the instructional material, prior to the internship, an online teaching platform was established and teaching

resources were uploaded, encompassing three typical representative cases of urological diseases, pertinent theoretical knowledge, recent literature, as well as videos and images of clinical procedures, thereby enhancing the study's focus and practical significance from basic to advanced levels.

Learning objective: According to the syllabus, the teacher emphasized the specific requirements and key points of theoretical knowledge and clinical skills for urological diseases.

Pre-assessment: Following the establishment of learning objectives, medical trainees were allotted a day for independent study. Subsequently, they participated in an online theoretical examination and interactive interview designed to assess their proficiency in case analysis and theoretical knowledge prior to commencing their internship. The instructional administrator then evaluated the examination outcomes, pinpointing areas of high error frequency for clinical instructors to prioritize during the internship period.

Participatory learning: Initially, the trainee doctors were organized into groups and tasked with selecting classic cases that aligned with the instructional content of the discussion. Subsequently, a spokesperson from each group was designated to address the questions pertaining to the selected cases. Ultimately, the instructor provided feedback on the responses from each group and elucidated key and challenging aspects of the cases. Students were encouraged to refer to textbooks and scholarly literature, share gathered information, engage in group deliberations, analyze and synthesize the posed questions, and collaborate to enhance their understanding.

To enhance trainee doctors' theoretical understanding and practical skills, the instructor utilized the resources of a clinical

skills training center to develop a 3D model of urological anatomy using VR simulation and 3D body software. This model was employed to elucidate the physiological structure and pathological morphology of the urinary system in detail. In the context of practical implementation of minimally invasive surgery, novice medical practitioners can acquire proficiency in utilizing minimally invasive surgical instruments by engaging with virtual reality simulators and da Vinci surgical robot operating systems. Additionally, they can enhance their skills in instrument manipulation through exercises in instrument handling and suturing, thereby fostering proactive learning and improving overall efficiency.

Post-assessment: The post-assessment, conducted on the final day of the rotation, comprised an online theoretical examination and an offline clinical skills assessment. The instructors emphasized the complex theoretical concepts related to diseases of urology in formulating the post-assessment queries. By utilizing the post-assessment to gauge students' comprehension of the instructional material, educators can refine the difficulty level of the curriculum and enhance its efficacy.

Summary: The educators utilized a flow chart to assist students in synthesizing the lecture material, reinforcing key concepts, addressing challenging points, and expanding the scope of instruction. Additionally, clinical instructors responded to inquiries posed by medical trainees and elaborated on the lesson content by referencing the chapters on urological diseases within the course. The BOPPPS model flowchart is depicted in Figure 1.

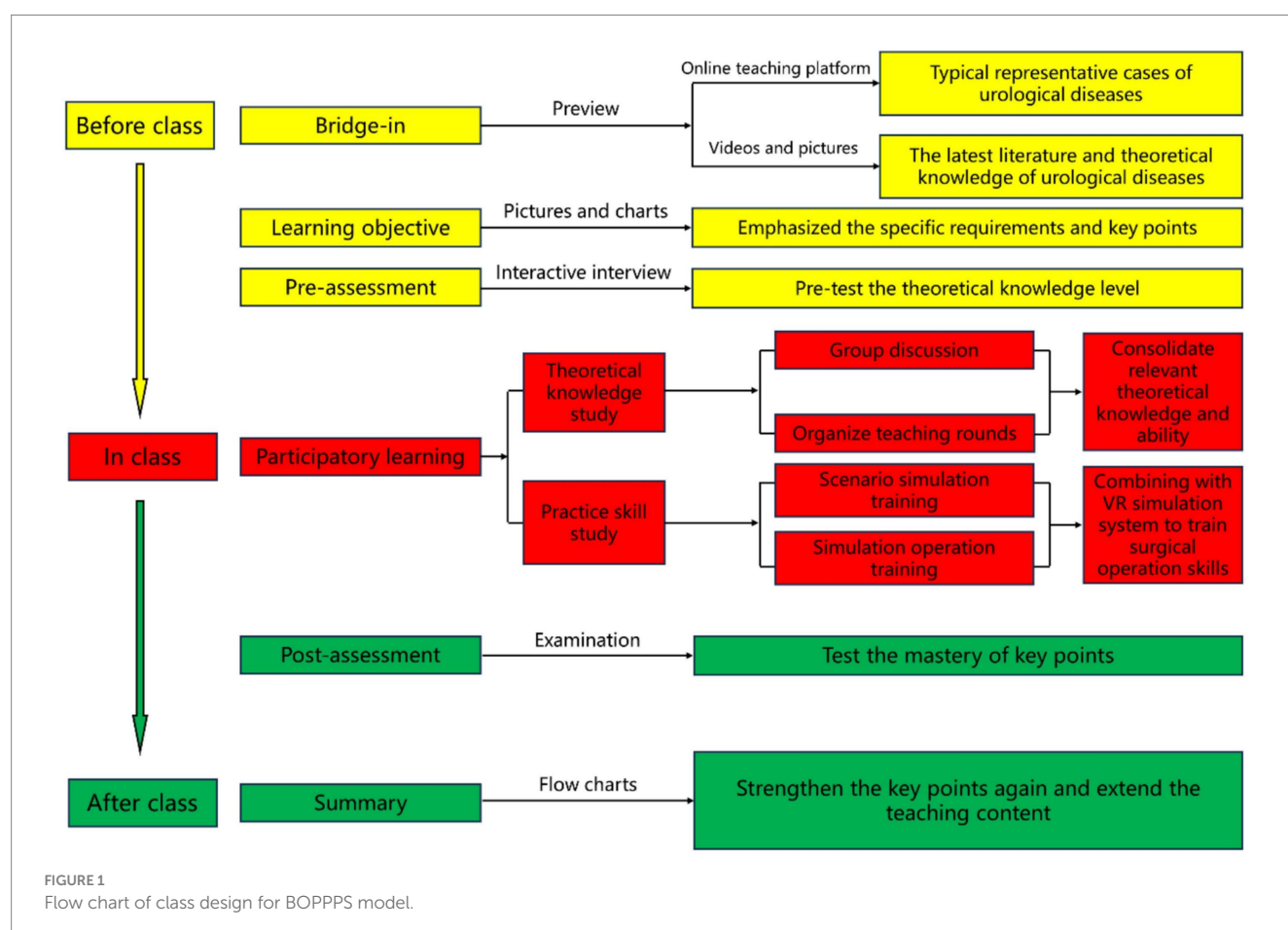


FIGURE 1
Flow chart of class design for BOPPPS model.

Effectiveness assessment

This study primarily assessed the effectiveness of integrating the BOPPPS teaching method with virtual reality technology in enhancing the mastery of professional theoretical knowledge, clinical thinking skills, practical abilities, and overall satisfaction among urology interns. All participants underwent standardized evaluations on theoretical knowledge and clinical skills, with the former being assessed through a closed-book examination comprising multiple-choice, definition, and case analysis questions. The clinical skills assessment comprises evaluations of clinical practice operations and clinical comprehensive abilities. Both student cohorts are administered identical test papers, with uniform marking criteria and scores assigned on a 100-point scale for each component.

Moreover, the effectiveness and satisfaction of the course were assessed through a questionnaire survey. A total of 96 questionnaires were distributed, all of which were successfully returned, resulting in a 100% recovery rate. According to the teaching evaluation guidelines outlined by the Cornell Center (11), the questionnaire primarily encompasses assessments of instructors' professional knowledge, clarity of instructional content, level of student-teacher interaction, responsiveness to student inquiries, enhancement of independent thinking skills, promotion of active student engagement in practical activities, cultivation of interest in the subject matter, and evaluation of the efficient utilization of class time. Each survey response was rated on a 5-point scale, with scores ranging from 1 to 5.

Meta-analysis

This meta-analysis and systematic review were designed according to the PRISMA (preferred reporting items for systematic reviews and meta-analyses, PRISMA) guidelines (17). The PICOS (population, intervention, comparison, outcome, and study design) framework was used to determine the inclusion criteria of studies. The following studies will be included: (a) the participants for the studies were medical students in Chinese medical schools; (b) the experimental group received the intervention of BOPPPS teaching strategy; (c) the groups of LBL were as control; (d) the core curriculums covered clinical medicine and/or biomedicine disciplines; (e) the studies were two-group controlled (randomized/nonrandomized); (f) the outcomes presented as data or descriptions of each controlled studies included at least one of the following measurements: PSS, KES, TS; (g) only studies fulltext published in English language and Chinese language were included. (h) All mentioned studies conducted before 22 Nov 2023. Any study which did not meet the inclusion criteria was

excluded. The key search terms included BOPPPS, medicine and student. PubMed and Chinese electronic databases of CNKI were searched before 22 Nov 2023. According to a predefined form, data were searched, collected, and extracted by two independent reviewers (R. Rong and K. Gan). The Cochrane risk of bias 2 (RoB2 v9) tool was used to evaluate the quality of individual included studies (18).

Statistical analysis

Statistical analyses were conducted utilizing SPSS version 27.0 software and Microsoft Office. Measurement data were presented as mean \pm standard deviation ($x \pm s$) and significance was determined through an independent sample t-test with a threshold of $p < 0.05$.

Results

Comparison of general information between the two groups

The study sample consisted of 96 five-year undergraduate interns specializing in clinical medicine at the First Affiliated Hospital of Air Force Medical University, comprising 80 males and 16 females. Utilizing the random number table method, the experimental group was stratified into two groups: the experimental group receiving instruction through a combination of VR technology and the BOPPPS teaching model, and the control group receiving instruction through the traditional LBL model. As indicated in Table 1, each group consisted of 48 students. Analysis revealed no statistically significant disparities in demographic variables such as gender, age, and prior academic performance between the two groups ($p > 0.05$), thus ensuring comparability in the study population.

Comparison of the theoretical knowledge assessment of the two groups

The results presented in Table 2 indicate that students in the VR technology combined with BOPPPS teaching group achieved a mean theoretical knowledge assessment score of (85.23 ± 4.673) points, while students in the traditional LBL model group scored (80.81 ± 7.151) points. The scores of the experimental group were found to be significantly higher than those of the control group, with a statistically significant difference ($p < 0.05$). Further analysis in Figure 2A reveals

TABLE 1 Comparison of general information between the two groups.

Variable		Experimental group ($n = 48$)	Control group ($n = 48$)	t/χ^2 value	p value
Gender (%)	Male	39 (81.25)	41 (85.42)	0.3000	0.5839
	Female	9 (18.75)	7 (14.58)		
Age(year)		21.94 ± 0.9087	21.85 ± 0.9223	0.4459	0.6567
Prior academic performance(score)		84.42 ± 3.4450	84.64 ± 4.0680	0.0542	0.9569

that the distribution of scores among students in the experimental and control groups. None of the students in the experimental group scored within the 60–70 points range. In the 71–80 points range, there were 6 students in the experimental group and 14 in the control group. For scores between 81 and 90 points, there were 35 students in the experimental group and 26 in the control group. In the 91–100 points range, there were 7 students in the experimental group and 5 in the control group. A score of 75 was used as the threshold between good grades and passing grades for further analysis of the theoretical assessment results of both groups. Figure 2B demonstrates a significantly higher number of students with good grades in the experimental group than that in the control group.

Comparison of the clinical practical skills assessment of the two groups

The clinical practical skills assessment encompasses both the evaluation of clinical practice operations and the assessment of clinical comprehensive abilities. The clinical practice operation assessment includes procedures such as catheterization, suprapubic bladder puncture ostomy, urethral dilation, cystoscopy, digital prostatic rectal examination, and laparoscopic basic operations, totaling six items. The clinical comprehensive ability assessment evaluates skills in bedside consultation, physical examination, medical record writing, doctor-patient communication and clinical

critical thinking abilities, totaling four items. During the assessment of clinical practice operations, the experimental group demonstrated statistically significant higher average scores in urinary catheterization, suprapubic bladder puncture ostomy, cystoscopy, and laparoscopic basic operations compared to the control group ($p < 0.05$). Conversely, there was no significant difference in the average scores between the two groups in urethral dilation and digital prostate-rectal examination, as illustrated in Figure 3 and Table 3. In the clinical comprehensive ability assessment, the average scores of the four assessment contents in the experimental group were significantly higher than those in the control group, as indicated by statistical analysis ($p < 0.05$) presented in Figure 4 and Table 4.

TABLE 2 Comparison of the theoretical knowledge assessment scores of the two groups.

Variable	Experimental group	Control group	<i>t</i> value	<i>p</i> value
Theoretical knowledge assessment (score)	85.23 ± 4.673	80.81 ± 7.151	3.582	< 0.05
Pass rate %	100	100	–	–

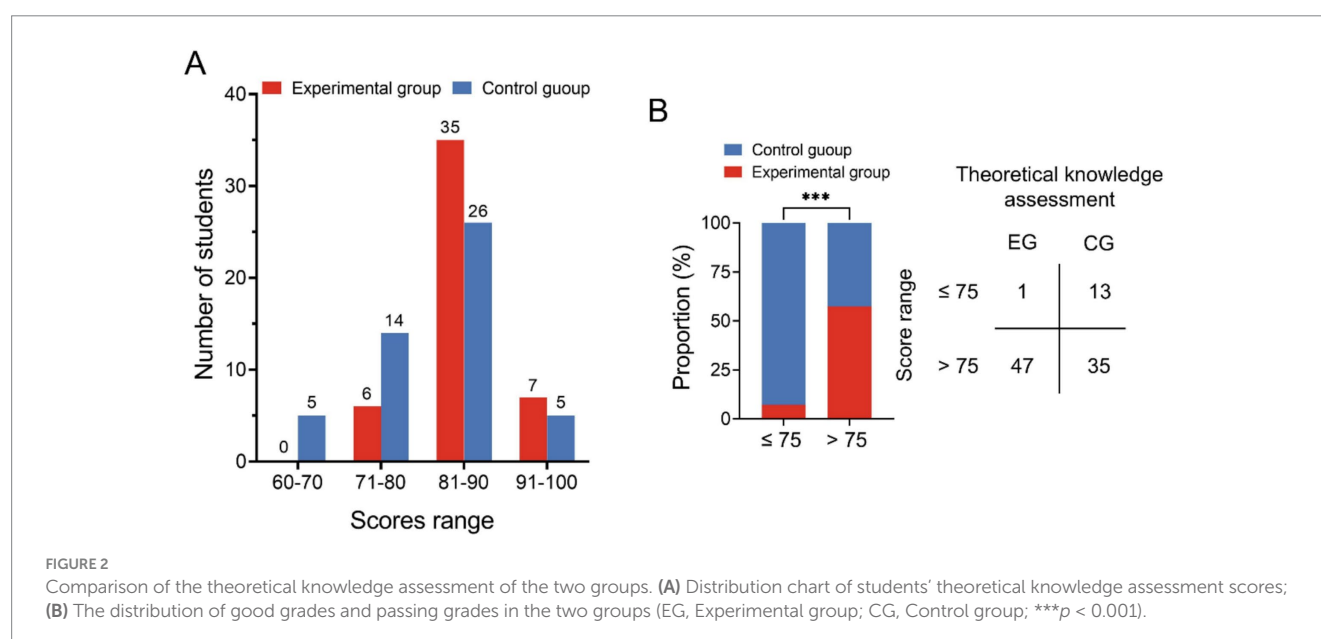
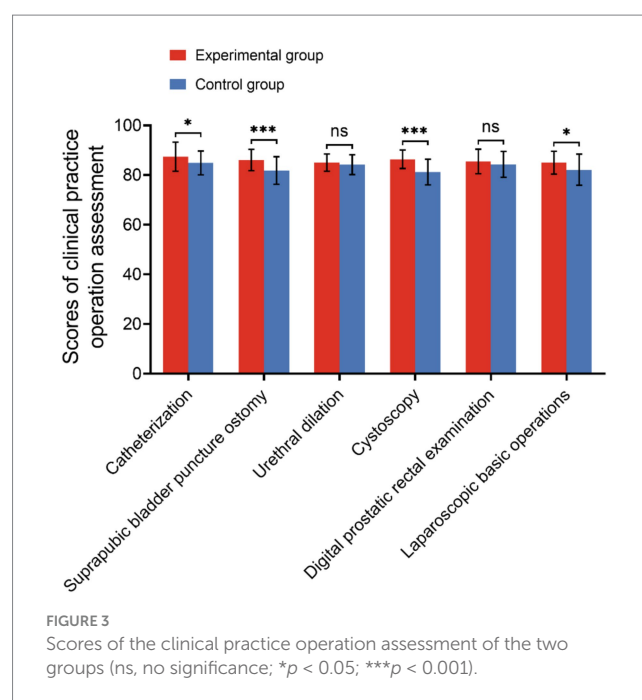
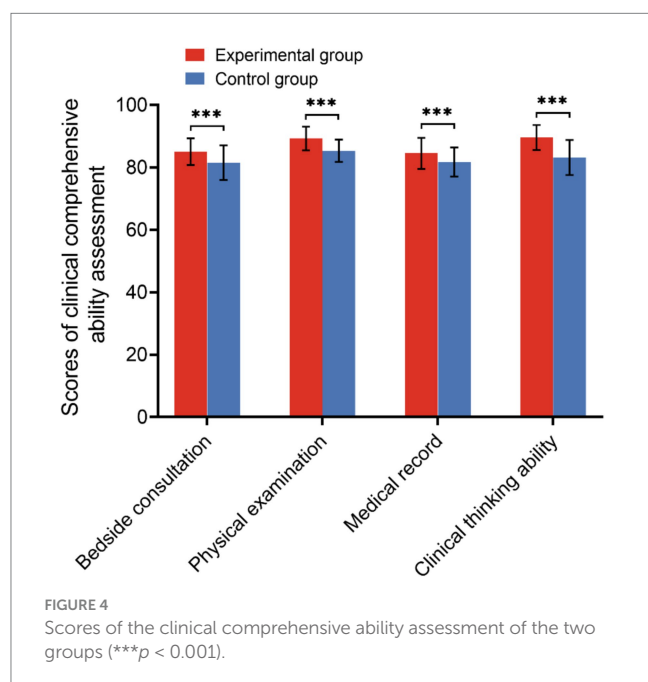


TABLE 3 Comparison of the clinical practice operation assessment of the two groups.

Variable	Catheterization	Suprapubic bladder puncture ostomy	Urethral dilation	Cystoscopy	Digital prostatic rectal examination	Laparoscopic basic operations
Experimental group	87.38 ± 5.859	86.06 ± 4.290	85.02 ± 3.492	86.35 ± 3.716	85.45 ± 4.959	84.98 ± 4.592
Control group	84.88 ± 4.832	81.83 ± 5.552	84.17 ± 4.028	81.21 ± 5.182	84.31 ± 5.219	82.15 ± 6.284
<i>t</i> value	2.282	4.176	1.110	5.591	1.103	2.522
<i>p</i> value	0.0247	< 0.01	0.2698	< 0.01	0.2730	0.0133



Comparison of course effectiveness and satisfaction between the two groups

The VR technology combined with the BOPPPS teaching model group exhibited a higher level of interaction with both teachers and students ($p < 0.01$), with instructors demonstrating a greater ability to promote independent thinking among students ($p < 0.01$). Furthermore, the teaching process in this group effectively utilized classroom time more efficiently ($p < 0.01$) compared to the control group. There was no statistically significant difference in the questionnaire results between the two groups regarding teachers' professional knowledge reserves, clarity of knowledge points, and clarity of question answers. The findings indicate that the BOPPPS combined with VR technology teaching mode has the potential to enhance students' critical thinking and active learning skills, as well as increase their satisfaction and recognition levels compared to traditional classroom teaching methods, as illustrated in Figure 5 and Table 5.

The findings presented above are derived from our single-center investigation. However, recognizing the inherent limitations of single-center studies, such as methodological constraints and the restricted sample size, we conducted a systematic review and meta-analysis to enhance the robustness and objectivity of our conclusions.

To achieve this, we aggregated data from multiple peer-reviewed studies, performed comprehensive statistical integration using validated analytical software, and synthesized the evidence to yield the following key results (Figures 4, 5).

Effectiveness of BOPPPS strategy in medical education of surgery-related clinical internships: a systematic review and meta-analysis

Database searching and selection

The methodological flowchart of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was presented in Figure 6. Initially, 332 potentially relevant records were retrieved from the electronic database, with 278 duplicate records being subsequently excluded. Following a review of the titles and abstracts, 87 publications were further excluded due to their lack of relevance to the subject of the meta-analysis, including those related to internal medicine, pharmacy, experience summaries, or questionnaire surveys without quantitative score measurements. After a thorough review of the complete text, an additional 32 articles were excluded due to insufficient data for extraction ($n = 24$) and/or lack of control trials ($n = 8$). Ultimately, 14 randomized controlled trials (RCTs) met the inclusion criteria and were included in the meta-analysis.

Study characteristics

The essential characteristics of the 14 selected studies are outlined in Table 6. The publication dates of these studies were prior to November 22, 2023. A total of 730 medical students participated in the BOPPPS teaching strategy, while 709 medical students were involved in the LBL approach across the 14 studies. All participants in the included studies were enrolled in medical school. Furthermore, all of the studies selected were randomized controlled trials (RCTs). Four trials focused solely on theoretical courses, one trial focused solely on practical courses, and nine trials examined both theoretical and practical courses.

Evaluation of the effectiveness of BOPPPS teaching model compared with LBL model

Measurements of final knowledge examination scores

Thirteen studies were included in the final KES evaluation, encompassing a total of 716 and 695 students in the BOPPPS and

TABLE 4 Comparison of the clinical comprehensive ability assessment of the two groups.

Variable	Bedside consultation	Physical examination	Medical record	Clinical thinking ability
Experimental group	85.06 ± 4.260	89.27 ± 3.780	84.52 ± 4.968	89.60 ± 4.020
Control group	81.56 ± 5.558	85.38 ± 3.606	81.73 ± 4.653	83.19 ± 5.633
<i>t</i> value	3.463	5.167	2.842	6.424
<i>p</i> value	< 0.01	< 0.01	< 0.01	< 0.01

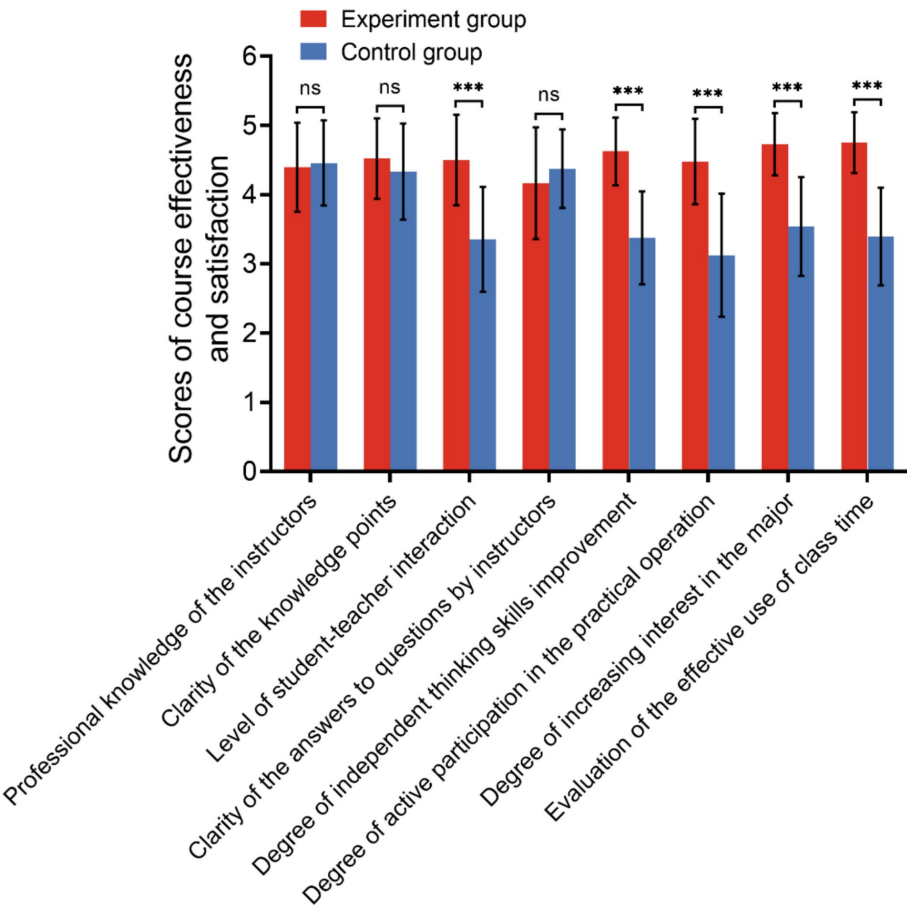


FIGURE 5 Scores of course effectiveness and satisfaction between the two groups (ns, no significance; **p* < 0.05; ****p* < 0.001).

LBL groups, respectively. The pooled effect size of these studies (SMD 0.48, 95% CI: 0.37–0.59, $Z = 8.83$, $p < 0.00001$) indicated a significant improvement in theoretical knowledge scores with a large effect size in the BOPPPS teaching strategy compared to LBL teaching. A fixed-effects model was employed for the meta-analysis due to the moderate heterogeneity ($p = 0.08$, $I^2 = 38\% < 50\%$) observed in the data (Figure 7).

Measurements of practice skill scores

The analysis included data from 10 studies involving a total of 616 and 605 students in the BOPPPS and LBL groups, respectively, in relation to SS evaluation. In comparison to LBL teaching, the pooled effect of the 10 studies (SMD 1.29, 95% CI: 0.80–1.78, $Z = 5.18$, $p < 0.00001$) demonstrated a significant enhancement in SS within the

BOPPPS group. The utilization of a random-effects model for the meta-analysis was warranted due to the notable statistical heterogeneity ($p < 0.00001$, $I^2 = 93\%$) observed among studies (Figure 8).

Quality assessment

Following the guidelines outlined in the Cochrane Collaboration Handbook, the assessment for each outcome included evaluation based on five domains: Selection of the reported result, Measurement of the outcome, Missing outcome data, Deviations from intended interventions, and Randomization process. Based on these domain ratings, the overall bias of each included study was determined to be at a “low risk of bias.” Subsequently, the funnel plot depicting the relationship between knowledge examination scores and practice

TABLE 5 Comparison of course effectiveness and satisfaction between the two groups.

Questionnaire items	Experimental group	Control group	t value	p value
Professional knowledge of the instructors	4.396 ± 0.6438	4.458 ± 0.6174	0.4854	0.6285
Clarity of the knowledge points	4.251 ± 0.5831	4.333 ± 0.6945	1.433	0.1553
Level of student-teacher interaction	4.500 ± 0.6523	3.354 ± 0.7576	7.940	< 0.01
Clarity of the answers to questions by instructors	4.167 ± 0.8078	4.375 ± 0.5696	1.460	0.1475
Degree of independent thinking skills improvement	4.625 ± 0.4892	3.375 ± 0.6724	10.41	< 0.01
Degree of active participation in the practical operation	4.479 ± 0.6185	3.125 ± 0.8903	8.655	< 0.01
Degree of increasing interest in the major	4.729 ± 0.4491	3.542 ± 0.7133	9.760	< 0.01
Evaluation of the effective use of class time	4.750 ± 0.4376	3.396 ± 0.7068	11.29	<0.01

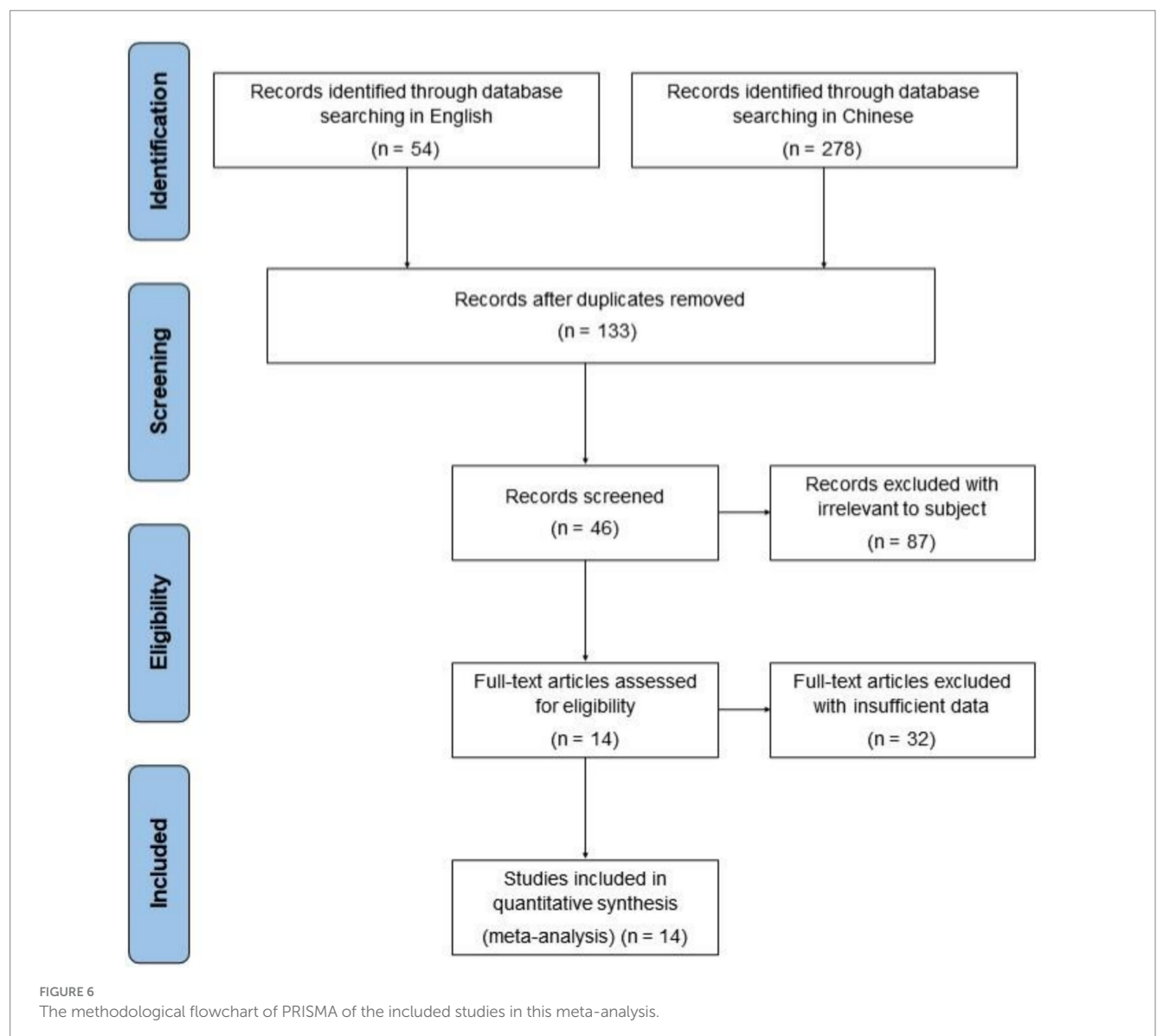


TABLE 6 Main characteristics of the included studies in the current meta-analysis.

References	Study design	Sample size (BOPPPS)	Sample size (LBL)	Population	Course name	Course type	Outcome measures	RoB2
Bai et al. (36)	RCT	57	58	Undergraduates	Pediatric surgery	Theory and Practice	KES, PSS, TS	L
Chen et al. (13)	RCT	44	43	Undergraduates	Ophthalmology	Theory	KES, TS	L
Duan et al. (37)	RCT	55	52	Undergraduates	Orthopedics	Theory and Practice	KES, SS	L
Gu et al. (38)	RCT	30	30	Undergraduates	Neurosurgery	Theory and Practice	KES, PSS, TS	L
Hu et al. (39)	RCT	40	40	Undergraduates	Thoracic surgery	Theory	KES, TS	L
Hu et al. (29)	RCT	44	44	Undergraduates	Thoracic surgery	Theory	KES, TS	L
Jia et al. (40)	RCT	64	64	Undergraduates	Thoracic surgery	Practice	PSS, TS	L
Li et al. (41)	RCT	108	109	Undergraduates	Gynecology and obstetrics	Theory and Practice	KES, TS	L
Li et al. (30)	RCT	36	27	Undergraduates	Surgical nursing	Theory	KES, TS	L
Tao et al. (42)	RCT	52	52	Undergraduates	Surgery	Theory and Practice	KES, PSS, TS	L
Wang et al. (43)	RCT	25	25	Undergraduates	General surgery	Theory and Practice	KES, PSS, TS	L
Xu et al. (16)	RCT	121	114	Undergraduates	Gynecology	Theory and Practice	KES, PSS, TS	L
Yang et al. (11)	RCT	54	51	Undergraduates	Dental Materials	Theory and Practice	KES, PSS, TS	L
Zhang et al. (44)	RCT	50	50	Undergraduates	Neurosurgical nursing	Theory and Practice	KES, PSS, TS	L

RCT, randomized controlled trial; Undergraduates, medical students from freshmen to five-grade in the school; KES, knowledge examination score; PSS, practice skill score; TS, teaching satisfaction. RoB2, The Cochrane risk of bias 2; L, overall bias of low.

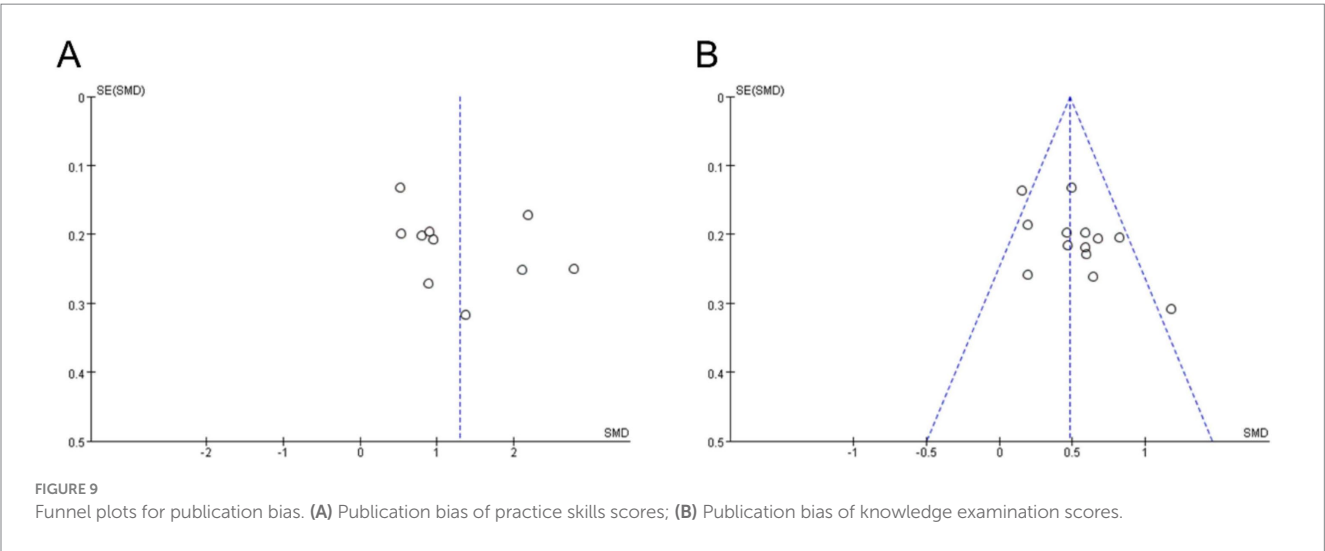
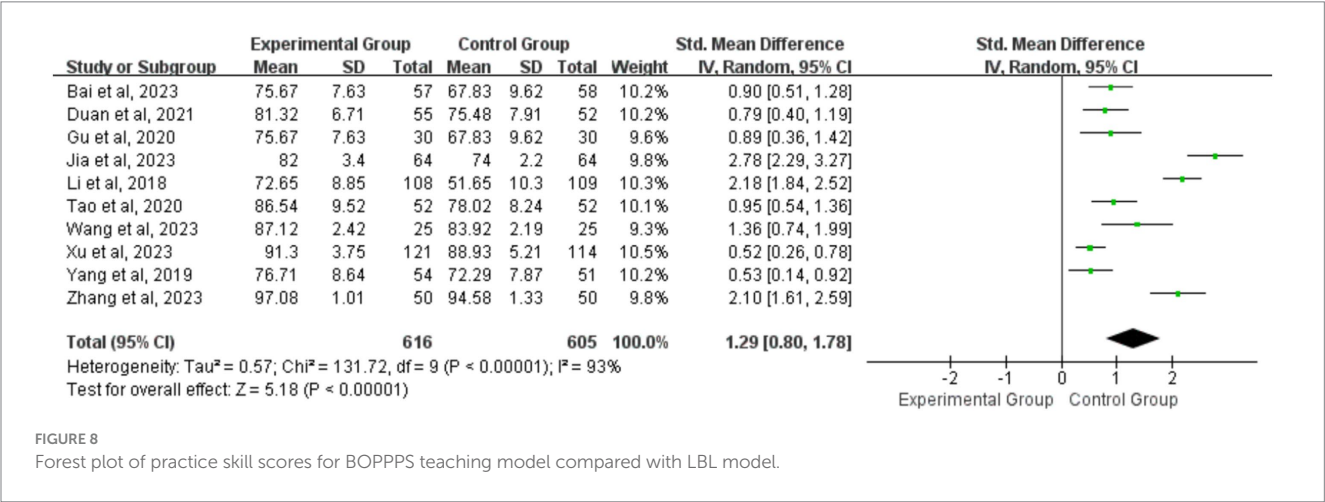
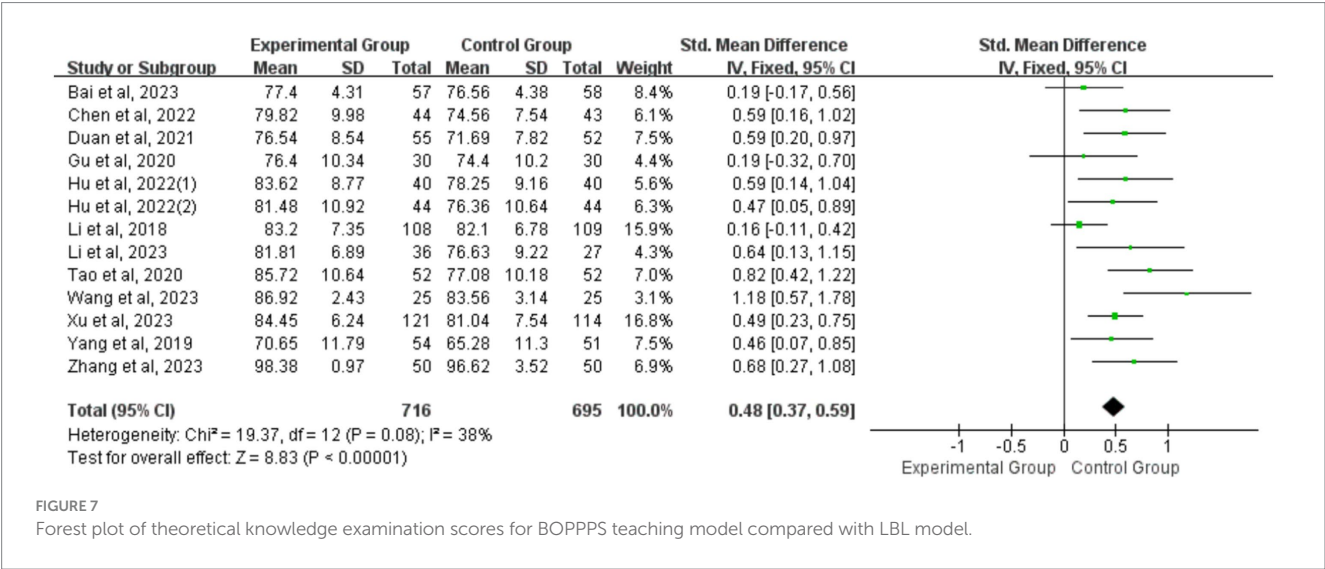
skills scores exhibited near symmetry, suggesting minimal indication of substantial publication bias (Figure 9).

Discussion

The projected rise in urological disease cases among an aging population will likely lead to an increased demand for medical providers in this field (19, 20). However, the current trend in medical school curricula shows a decreasing emphasis on urology education (1, 21). The primary obstacle facing medical schools in China is the training of competent clinicians who can effectively navigate the evolving hospital setting and address the healthcare needs of the Chinese population (22, 23). As educators in urology, it is incumbent upon us to optimize the learning outcomes for medical students during our limited yet influential interactions. In the conventional urological education framework in China, clinical instructors are frequently overburdened and often ill-equipped for internships, relying predominantly on didactic teaching methods (24). Consequently, medical trainees primarily serve as passive observers with limited hands-on experience, resulting in inadequate and inefficient interactions between instructors and trainees. Students often experience disengagement, lack of motivation, and suboptimal learning outcomes (24, 25). Hence, there is a pressing need for enhancing the quality of teaching, leading to the implementation of a

teaching position filled by senior urologist attending physicians who dedicate 1 year to serving as a full-time teaching administrator. However, addressing the challenges of stimulating student interest in urology, enhancing clinical teaching effectiveness, and optimizing teaching methodologies are critical issues that require resolution in the current educational process.

The BOPPPS teaching strategy was first proposed by Douglas Kerrin from the University of British Columbia in 1978 (26). In contrast to LBL, the BOPPPS teaching strategy is not commonly utilized in medical education in numerous countries (27). This strategy offers a structured six-phase framework for developing learning activities, making it a valuable tool for educators seeking to deconstruct and evaluate their teaching methods in order to enhance student learning outcomes in medical education (28). The implementation of the BOPPPS teaching strategy in Chinese universities was first explored in 2011 with the aim of enhancing teaching efficacy and comprehensive skills in non-medical disciplines such as botany and English instruction (26). The BOPPPS model has recently been implemented and rigorously tested within China's higher medical education sector with the aim of enhancing educational and learning efficacy through a structured teaching approach and fostering active student engagement (12). The main courses included are thoracic surgery (29), gynecology (16), surgical nursing (30), dental Materials education (11), physiology (15) and ophthalmology (13). This student-centered teaching method and observation system offers distinct advantages over conventional teaching methodologies by effectively



stimulating student interest and enthusiasm for learning, thereby enhancing teaching efficiency. Moreover, the intricate nature of the urinary system presents a significant challenge in surgical education, with trainee physicians often struggling to comprehend its three-dimensional structure accurately (31–33). When compared to the conventional LBL model, the integration of VR technology with the

BOPPPS model proves to be a more effective method for enhancing trainee understanding and proficiency (34, 35).

In this study, an analysis of urology theoretical knowledge assessment scores revealed a significant difference between the control group and the group exposed to a combination of VR technology and the BOPPPS teaching model. Despite both groups achieving a 100% pass rate, it is evident that students in the VR technology combined BOPPPS model group exhibit a superior grasp of complex concepts. Specifically, students in the experimental group achieved notably higher scores. Examination of Figure 2 further illustrates this disparity, with a greater number of students in the control group scoring between 60–70 and 71–80 compared to those in the experimental group. Conversely, students in the experimental group outperformed their counterparts in the control group when scores fell within the 81–90 and 91–100 range. Our study provides additional evidence to support the assertion that the experimental group exhibited a higher proportion of students with good grades compared to the control group. This suggests that the integration of VR technology with the BOPPPS model may facilitate the advancement of students from passing grades to higher levels of academic achievement. This finding aligns with the conclusions drawn by Hu et al. in their research on thoracic surgery education (29). The findings of the meta-analysis indicated a statistically significant increase in final knowledge examination scores among students in the BOPPPS group compared to those in the LBL group. This suggests that the BOPPPS teaching strategy has the potential to enhance students' skills, intrinsic motivation in learning, and self-directed learning abilities, ultimately improving academic performance. Given the practical nature of urology, which places a strong emphasis on clinical reasoning and complex problem-solving skills, it is imperative for physicians to attain proficiency in clinical skills. In this study, the clinical skills assessment was segmented into the clinical practice operation assessment and the clinical comprehensive ability assessment. The findings indicated that, within the clinical skills assessment, the average scores of the VR technology combined with the BOPPPS teaching model group were significantly higher than those of the LBL model group in the more intricate subjects, such as urinary catheterization, suprapubic bladder puncture ostomy, cystoscopy, and laparoscopic basic operation. In the context of relatively straightforward topics such as urethral dilation and digital prostate-rectal examination, there was no statistically significant variance in the mean scores of the two cohorts. This finding suggests that the integration of virtual reality technology with the BOPPPS instructional approach may enhance students' acquisition and proficiency in technical skills required for practical courses. In the context of a clinical comprehensive ability assessment, the mean scores of the group utilizing virtual reality technology in conjunction with the BOPPPS teaching model consistently surpassed those of the group employing the LBL model across the domains of bedside consultation, physical examination, medical record analysis, and clinical reasoning. The meta-analysis revealed that, relative to the LBL group, the BOPPPS group exhibited significantly elevated scores in practical skills, suggesting that the BOPPPS teaching strategy has the potential to enhance the motivation and engagement of medical students.

An additional significant metric for assessing the benefits of integrating VR technology with the BOPPPS teaching model is the efficacy of the course and student satisfaction. To mitigate the potential physical and mental strain associated with traditional "cramming" pedagogy, it is imperative to cultivate student engagement from the

outset, as student satisfaction serves as a proxy for course effectiveness. The findings of this research indicate that participants in the experimental cohort expressed high levels of satisfaction with the instructional approach employed in the course. In contrast to conventional theoretical teaching methods, the BOPPPS model imposes elevated demands on educators, necessitating a departure from the traditional teacher-centered instructional approach. The involvement of students in the learning process poses challenges for educators, necessitating a high level of theoretical knowledge and extensive clinical practice experience. Upon further examination of the findings of this study, it was observed that students perceive the integration of VR technology with the BOPPPS teaching model as more effective in optimizing classroom time, increasing engagement with course material, and enhancing participation in hands-on activities compared to the traditional LBL approach. These results align with previous research in the field (26).

Nevertheless, this study was subject to various limitations. Firstly, the systematic literature search was limited to the databases of PubMed and CNKI, with criteria for inclusion and exclusion that may have been inadequate, suggesting a need to broaden the scope to include additional databases. Secondly, the absence of established guidelines for the implementation of BOPPPS in medical fields, as well as standardized criteria for evaluating the effectiveness of the BOPPPS teaching strategy in China, further constrained the study. Furthermore, this study utilized questionnaire surveys as an additional measurement to evaluate the efficacy of the BOPPPS teaching model, potentially introducing subjective bias. The study specifically focused on Chinese medical students and compared the impact of the BOPPPS teaching strategy versus LBL alone. Future research should aim to assess and contrast the effectiveness of BOPPPS in comparison to other teaching methodologies through Bayesian network meta-analysis.

In conclusion, the BOPPPS model is recommended as an open instructional design framework. Educators are encouraged to incorporate their extensive teaching expertise into their daily instructional routines while adhering to the principles of the BOPPPS teaching model. It is important to tailor the instructional design to the specific content being taught and the students' existing knowledge base in order to align with their psychological characteristics and cognitive processes.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. All participants provided informed consent for their involvement in the study.

Author contributions

R-LZ: Funding acquisition, Investigation, Writing – original draft. KG: Methodology, Software, Writing – review & editing.

HZ: Methodology, Visualization, Writing – review & editing. DH: Funding acquisition, Validation, Writing – review & editing. KS: Resources, Validation, Writing – review & editing. JW: Data curation, Resources, Writing – review & editing. KZ: Formal analysis, Funding acquisition, Writing – review & editing. WJ: Data curation, Resources, Validation, Writing – review & editing. DW: Data curation, Methodology, Writing – review & editing. YL: Conceptualization, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Digital recordings of a clinical encounter facilitate reflection in physical therapy students and clinicians

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Background: Medical and health professions students use digital media in their educational pursuits. No studies have examined the process or utility of reviewing digital recordings of a clinical encounter. This pilot study examined how physical therapy students varied in their approach when compared to practicing physical therapists, in their self-reflection and assessment of a recorded physical therapist (PT) encounter with a standardized patient (SP).

Methods: A single site, cross-sectional, mixed-methods design was used. Participants reviewed an 11-minute digital recording of a patient encounter and completed survey questions. Post-survey interview sessions were used to gain additional perspective from participants.

Results: Ninety-two physical therapy students across three levels of training and twenty-seven physical therapists participated in the study. Self-ratings of perceived clinical ability increased with each year of training. First-year students (PY1) gave higher performance ratings to the PT than other groups. Seventy-five percent of respondents found the review of the digital recording to be a useful tool for reflection. A variety of approaches in the review process were found across groups, especially between clinicians and students.

Conclusion: Review of a recording of a physical therapist's encounter with an SP can be a useful educational tool for reflection across training levels of students and clinicians.

KEYWORDS

digital recording, health professions education, physical therapy, standardized patients, simulation, reflection

Introduction

With the advent of handheld devices and online video sharing platforms, using prepared digital media to train medical and health science students has become easier and more acceptable. Access to digital recordings in education has resulted in students observing and analyzing video as a resource for learning. Increasing numbers of medical students are opting to watch recorded lectures of content at their convenience instead of attending in-person lectures (1). Previous research has found that medical students prefer

the use of video recordings over reading materials (2). Medical educators in the 21st century need to be purposeful, proficient and intentional with incorporating video technology to develop future clinicians (3).

An example of intentional technology in medical education is the use of virtual patients to train clinicians. Virtual patients can be two-dimensional patients in a computer game or standardized patients (SPs). Virtual patients allow for the training and development of future clinicians by providing a standardized safe practice, and an on demand environment in which to learn (4). Video and virtual patients can prepare the developing clinician for challenging “real life” clinical encounters and developing reflective practice (5, 6). Scherer et al. (7) found that videotape review of trauma resuscitations resulted in behavioral change in team compared to verbal feedback alone.

Video is utilized in physical therapy education, but its impact on student development is not clear. Previous research has reported mixed results in using video to facilitate student physical therapists’ clinical development (8–10). The results differed as the previous studies used varying methodologies, including utilization of video and outcomes. A recent educational case study indicated that physical therapy students found benefits in reviewing their own Integrated Standardized Patient Examinations (ISPEs) (11). Exploring how students, at various semester levels in a program, view and analyze a recording of a physical therapist’s encounter with a standardized patient may lead to the development of a subsequent framework for guiding students viewing of recordings to maximize educational gains. The purpose of this study was twofold: (1) to determine whether watching a video of a physical therapist’s (PT) encounter with a standardized patient (SP) facilitated the viewer’s learning and self-reflection and (2) to explore how students at various educational levels viewed and analyzed a training video as compared to practicing clinicians.

Methods

The IRB gave a certificate of exemption for this study. A mixed-method research design approach was used to allow for in-depth exploration and context of the subjects’ experience (12). Survey responses were collected, recorded, and managed online using

REDCap (Research Electronic Data Capture) a secure, web-based software platform designed to support validated data capture for research studies (13, 14). In addition, participants were asked to participate in an optional post-experience individual interview or group sessions.

Participants

Participants in the study were recruited from two groups. Graduate students enrolled in an entry level physical therapy education program were deemed “students” with the naming system based on professional year (PY1 for first-year students, PY2 for second year, PY3 for third year). Associated practicing clinical faculty who taught in the entry level PT program participated as PTs. Descriptive information of the student (PY) and clinician (PT) participants is presented in Tables 1, 2.

TABLE 1 Descriptive information of students (PY) reviewing recording.

Student year	Total number (number by gender)	Self-perceived ability
		0 = beginner 100 = expert
		Mean (\pm S.D.)
PY1	33	9.71 (\pm 18.24)
	Female = 27	
	Male = 5	
	Agender = 1	
PY2	33	17.47 (\pm 21.42)
	Female = 20	
	Male = 10	
	Agender = 2	
	Non-binary = 1	
PY3	26	25.62(\pm 27.56)
	Female = 22	
	Male = 4	

TABLE 2 Descriptive information of physical therapists (PTs) reviewing recording.

Gender	Number	Years experience mean (\pm S.D.)	Self-perceived ability 0=Beginner; 100=Expert Mean (\pm S.D.)	Board certification	Fellowship trained	Practice setting (All that apply)
Female	17	12.54 (\pm 10.17)	82.69 (\pm 10.44)	10	4	8-Outpatient 4-Inpatient 4-Private Practice 1-Home Health 1-Other
Male	10	11.70 (\pm 7.83)	77.70 (\pm 16.87)	6	0	7-Outpatient 2-Private Practice 2-Other

Clinical scenario and recording

An 11-minute case video portraying a middle-aged man presenting to physical therapy under with reports of low back pain (LBP) and abdominal pain was videoed using best practice standards (15–17). The video was designed to highlight a common reason (LBP) for a patient to seek physical therapy care, and to rule out possible systems (gastrointestinal) involvement, through interviewing and physical exam. A script and written and verbal instructions were provided to both the PT and SP prior to the rehearsal of the scenario. A pilot test simulation of the scenario was conducted, and feedback was provided to the PT and SP prior to recording. The PT was instructed to perform at an intermediate level of PT skill throughout

the encounter. A sequence of screenshots with guiding instructions and time stamps from the recording can be found in [Figure 1](#).

Survey design and distribution

A survey was developed which included demographic data, observation and debriefing questions ([Appendix A](#)). Two questions (#9 & #10) were based on the Plus-Delta approach to simulation debriefing (18, 19). After consenting to the study, participants immediately viewed the 11-minute video. Participants subsequently submitted proof of completion of video review then answered the survey questions. Survey responses were anonymous. Participants were also invited for post-study interviews with the secondary author. Interviews were conducted via Zoom, which is considered a viable resource for collecting qualitative data (20). A script (see [Appendix B](#)) was used for each interview session.

Data collection

Deidentified data were exported from REDCap to an Excel file. Descriptive statistics, plots and linear and logistic regressions were performed in R (21). Narrative responses were downloaded and assigned a unique identifier for thematic review. NVivo, (Luminvero) was used to sort narrative responses. Transcripts were recorded from the interview sessions. The primary and secondary author independently reviewed narrative responses from the survey and interviews to prevent bias of results. Both authors independently generated codes and themes for the narrative responses from the survey and interviews, respectively. Both authors used a team-based, iterative approach to explore the respective data (22). All themes were developed by the reviewing, comparing, and analyzing codes. To ensure trustworthiness, the authors followed the constructs outlined in the Standards for Reporting Qualitative Research (23).

Results

Out of 217 eligible students, 92 students participated (42.39%). The participation rate for clinicians was 26% (27 clinicians out of 104). Descriptive information of students (PYs) and clinicians (PTs) is found in [Tables 1, 2](#). Students (PY) and clinicians (PT) provided self-ratings of their own perceived clinical ability ([Tables 1, 2](#)). The mean self-ratings increased with each year of training. The clinician self-ratings were closer to the expert rating, and higher for those who self-identified as female, rather than male.

The mean rating of the physical therapist's performance rated by clinicians was 62.32 (± 16.69). First-year physical therapy students (PY1) rated the PT more highly than clinicians or other students. A comparison of participant's own self-rating to the rating which they assigned to the PT in the recording is provided in [Figure 2](#). Self-rating of ability in comparison to the rating of the PT in the recording is necessary to demonstrate context and engagement of the participant.

A summary of multi-tasking methods which students and clinicians used while reviewing the recording can be found in [Table 3](#). Students across all levels of training appeared to use the fast play speed (e.g., 1.5x, 1.75x) setting while reviewing the recording, with PY3

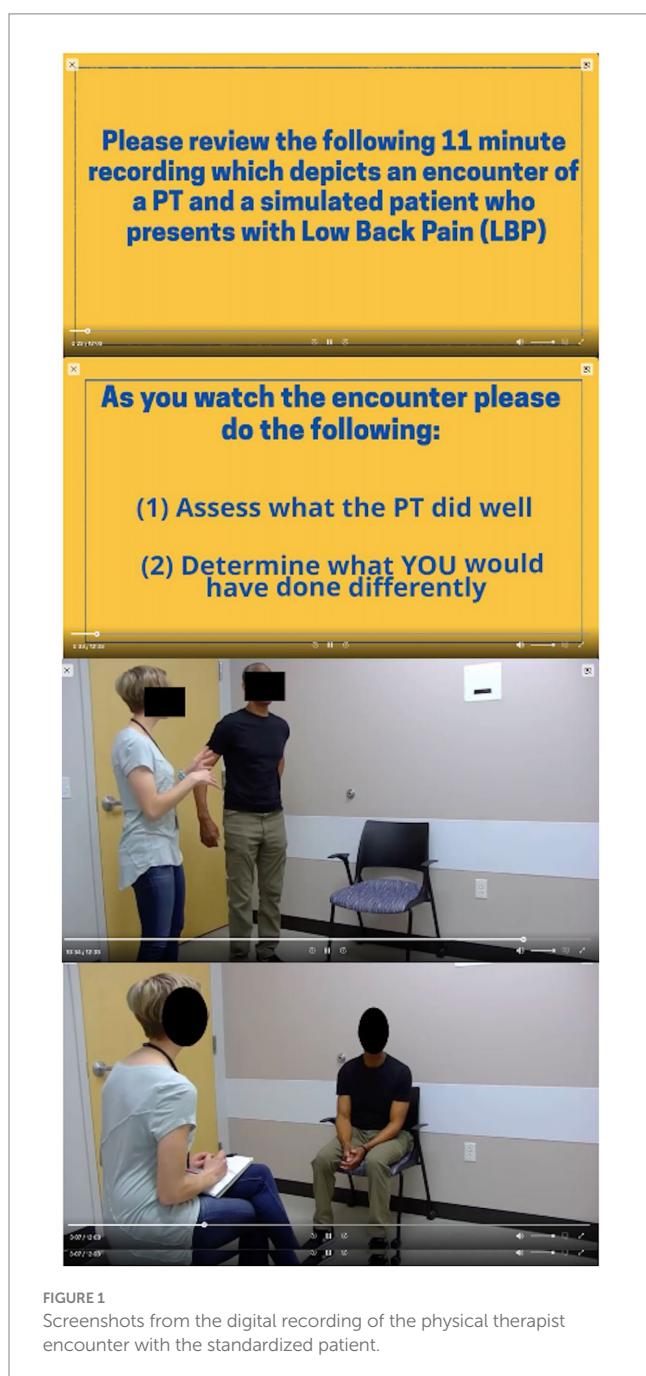


FIGURE 1
Screenshots from the digital recording of the physical therapist encounter with the standardized patient.

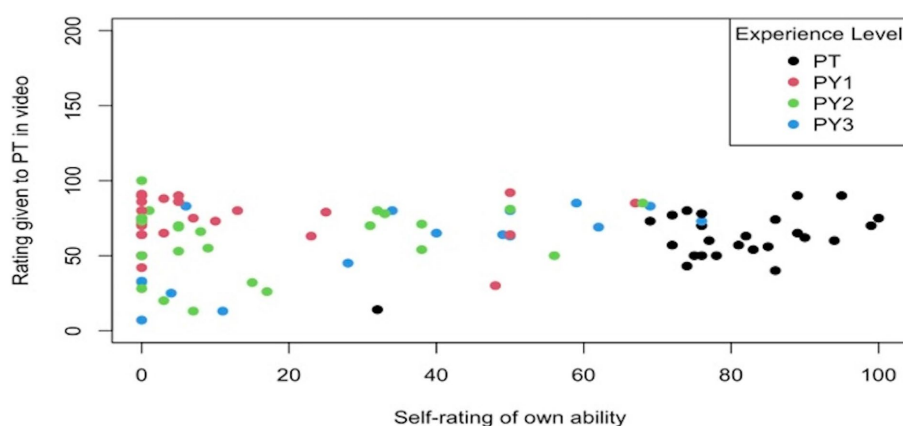


FIGURE 2

Scatterplot of rating of PT in recording with self-rating of perceived ability across level of experience. PY1, professional year 1; PY2, professional year 2; PY3, professional year 3; PT, licensed physical therapist.

students using it the most. Clinicians were less likely to use the fast play setting, although 25% of clinicians utilized the feature. The use of fast-forwarding through the recording was not used at all by clinicians (PT = 0%), but was by some students, mostly in PY2. Clinicians (PT) were more likely to take notes, whereas the method was much less utilized by all student groups. The pause feature was most utilized by PY3 students, with PTs utilizing it next most commonly. Clinicians (PT) had a higher mean rating of self-reported review focus as compared to all student groups, with 3rd year (PY3) students reporting the most focus of the three student groups (Figure 3).

Overall, 74.79% of all respondents (89/119) answered either “Agree (3)” or “Strongly Agree (4)” when asked if reviewing the recording was “a useful tool in reflecting on my own professional ability and development.” Third year students (PY3) appeared to find the review of the recording most helpful in reflecting on professional ability and development, with a mean response of $3.22 (\pm 0.52)$. PY1 students also agreed, with a mean response of $3.10 (\pm 0.94)$. PT and PY2 tended to fall just below “Agree,” with means of $2.92 (\pm 0.76)$ and $2.96 (\pm 0.82)$, respectively. A boxplot of responses separated by level of training can be seen in the in Figure 4. Two linear regression models were performed (see Appendix C). Regression 1 was used to examine whether the usefulness of digital recording was associated with year in training/experience as a clinician, controlling for demographic characteristics. No associations were found to be significant.

The second regression examined the relationship between level of focus in video review and year in training/experiences as a clinician. All students reported lower average levels of focus than licensed PTs, but only PY2s were significantly lower, by 0.69 points. There was no significant difference in levels of focus by gender.

On average, 1st year (PY1) students identified $2.25 (\pm 1.24)$ distinct observations of actions or behaviors (items) that the physical therapist did well in the recording. Items that the PY1 group tended to focus on more were about the approach and interaction with patient. The average gradually increased by level of training (PY2 = 2.41 ± 1.43 , PY3 = 2.63 ± 1.52). Licensed physical therapists identified $3.58 (\pm 1.70)$ items that the physical therapist did well in the recording. Example of items included comments concerning the PT’s skill with inquiry, explanation, screening, analysis, and assessment (Table 4).

Themes that emerged for potential improvement in the encounter included improving the subjective interview, refining the clinician-patient

interaction, and the need for more thorough medical screening. First year (PY1) and second year (PY2) students identified $1.53 (\pm 1.30)$ (1.63 ± 1.43) items, respectively, that the physical therapist could have done differently in the encounter with the SP. There was a noticeable increase in items and variation (2.96 ± 2.98) in 3rd year (PY3) students who have had more clinical experience through internships. Licensed physical therapists identified $3.69 (\pm 2.56)$ items that the physical therapy could have done differently in the encounter (Table 5).

Four clinicians and two PY3 students participated in the interviews. Transcripts from the interviews were independently reviewed by the primary and secondary authors. The authors held discussions following their review and agreed on three main themes that materialized from the interviews: the importance of instructions prior to recording review, a review of a patient encounter allows for and enhances self-reflection, and the importance of a rubric or guide concurrently in reviewing video. Themes and exemplar quotes can be found in Table 6.

Discussion

Results from this study indicate that the majority of participants found that the digital recording was a useful tool for reflecting on their professional ability and development. However, a variety of approaches in the review process were found across groups, especially between clinicians and students. Students across groups used “fast speed” and “fast forward,” while clinicians appeared more likely to take notes. In general, all groups described being focused throughout the digital recording review; clinicians appeared to have more consistent focus compared to students. These findings align with previous research which found benefits in the use of video recordings to reflect on medical interventions in a neonatal intensive care unit (24). Observing another clinician’s encounter with a patient allows the opportunity for objective comparison, and self-identification of clinical strengths and areas for improvement.

A secondary purpose of the study was to explore how review of a digital recording of a standardized patient encounter varied by level of student training, and between students and expert clinicians. There were increases in the number of observable items identified and the degree of analysis across levels of experience. The smaller numbers and depth of responses in the early (PY1 & PY2)

TABLE 3 Self-reported multi-tasking while watching recording separated by experience.

Experience	Fast forward	Fast speed	Paused	Reviewed other websites	Text messaged	Took notes	Listened to music	Watched TV, movies and/or other videos	None of the above
PY 1	6%	51.52%	15.15%	0.00%	12.12%	9.09%	0.00%	0.00%	27.27%
PY 2	15.15%	51.52%	15.15%	3.03%	12.12%	9.09%	3.03%	0.00%	12.12%
PY 3	3.85%	53.85%	34.62%	7.69%	15.38%	15.38%	0.00%	0.00%	7.69%
PT	0%	25%	29.60%	11.11%	3.70%	40.70%	0.00%	0.00%	18.52%

PY1, professional year 1, PY2, professional year 2, PY3, professional year 3, PT, licensed physical therapist.

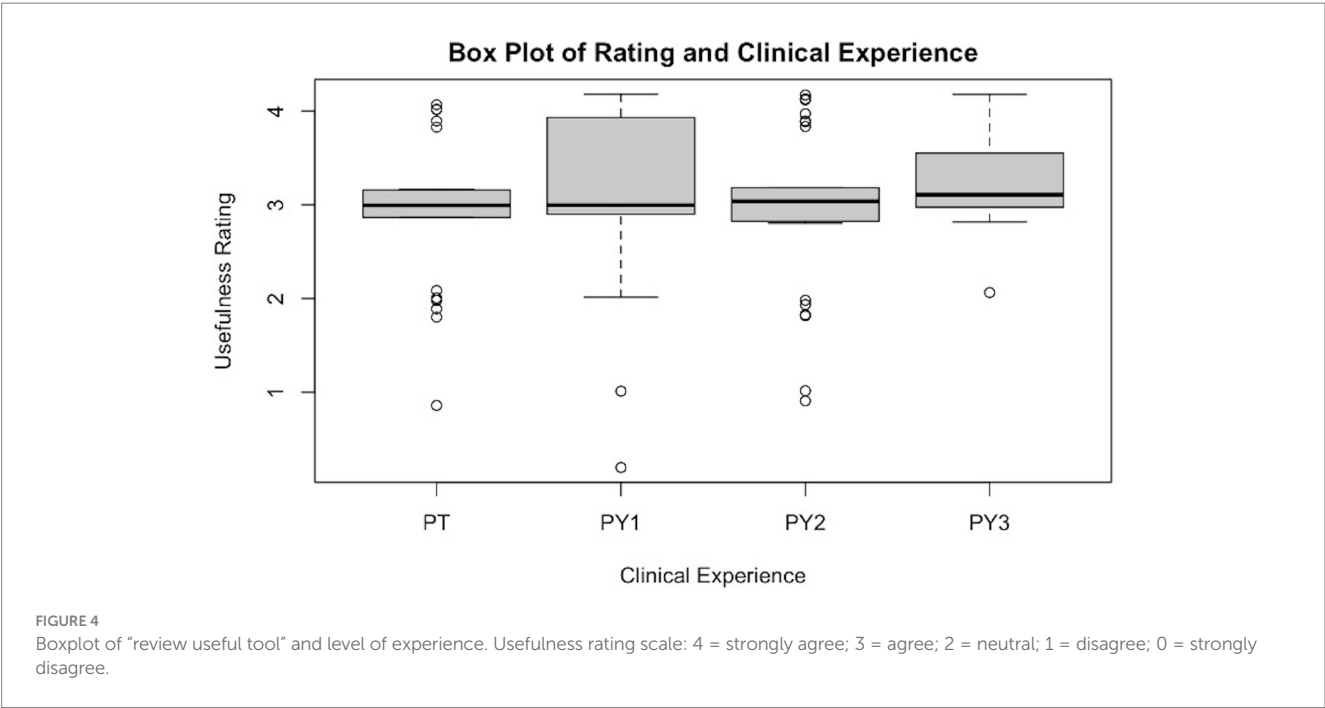
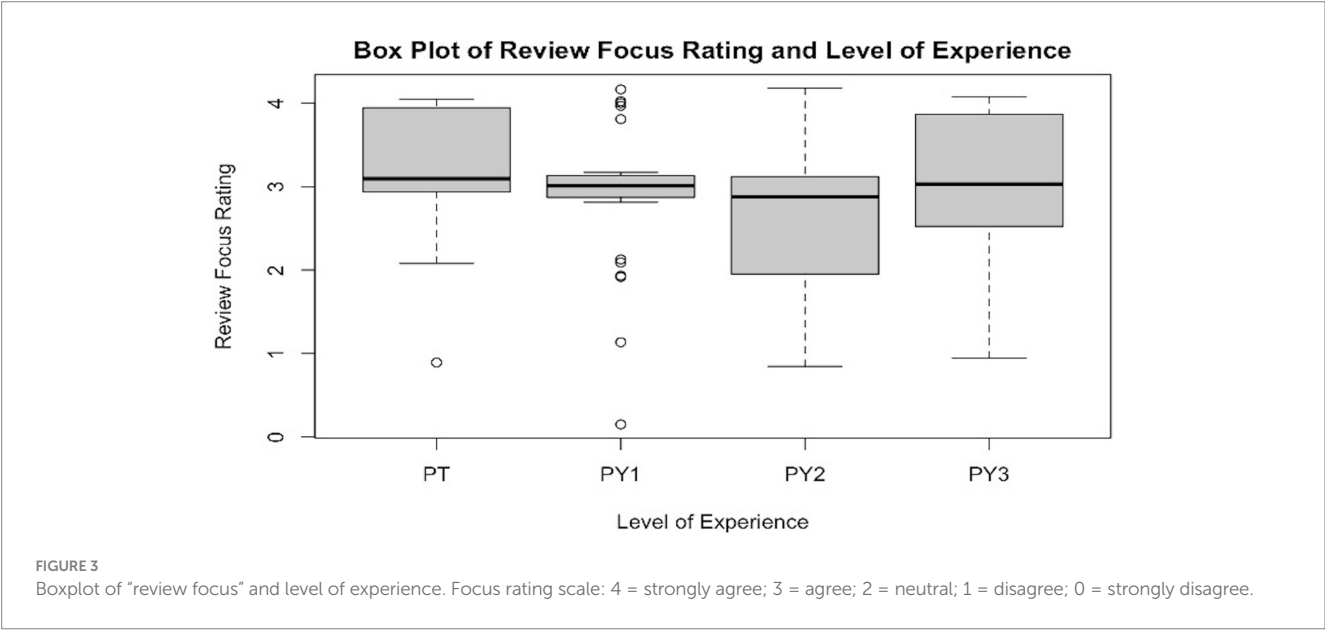


TABLE 4 Counts, themes and example quotes from narrative responses to what the reviewer identified the PT in the recording doing well.

Level of experience	Item count for what the PT did well in the recording (Mean counts \pm SD)	Themes	Example quote from narrative responses
PY 1	2.25 \pm 1.24	Inquiry Explanation	PY1c: "Asked how the patient would like to be referred to. Restated what the patient reported to confirm accuracy. Warned patient about the experience of uncomfortable sensations throughout the various movements." PY1k: "Explained what she was going to have him do and the reasoning behind it." PY1bb: "She [PT] asked good questions. She did a good job learning about him [SP], how this affects his daily life and his goals."
PY2	2.41 \pm 1.43	Inquiry Explanation Screening	PY2a: "The PT explained all the steps well and ensured that the patient and her were on the same page throughout the examination." PY2i: "She [PT] did a good job checking functional movement and mechanics with lifting. This gave her a good idea of what's going on." PY2k: "Screen for red flags, thorough exam questions, analysis of movements." PY2u: "Screen red flags, ask about health history..."
PY3	2.63 \pm 1.52	Interaction Inquiry Screening	PY3a: "She looked like she maintained good eye contact and sat at eye level with the patient during the interview." PY3i: "She [PT] did a good job understanding the basics of the patient's back pain-- what makes it better, worse, when it started." PY3o: "She[PT]asked appropriate questions to get a better understanding of the patient's pain and examined multiple systems." PY3v: "She asked further questions when the patient stated his stomach hurt from bending forward."
PT	3.58 \pm 1.70	Inquiry Screening Analysis Assessment	PT1: "They [PT] asked all pertinent questions in an open manner. They [PT] maintained eye contact throughout. They [PT] provided the patient with an outline of what to expect with the session including that they [PT] would take notes." PT8: "Noticed abnormal response to movement and performed a fairly comprehensive screen. Performed a movement analysis." PT8: "Captured most of the data needed to understand patients complete ICF (activities, participation, current health condition)." PT7: "She [PT] developed good rapport with the patient, she asked pertinent questions, but did not dwell on the history taking portion of the exam..." PT11: "She [PT] was able to establish most of the SINSS (Missed irritability)." PT19: "... observed a functional movement that was a primary complaint for the patient, responded on her feet to new info about abdominal pain and was able to respond to appropriate screening questions." PT26: "She [PT] screened potential red flag symptoms as the patient had abdominal pain..."

PY1, professional year 1, PY2, professional year 2, PY3, professional year 3, PT, licensed physical therapist.

groups are consistent with their level of knowledge and training. The complexity of student analysis increased with training. For example, PY1 and PY2 students focused more on the PT-SP interactions than clinical skills; PY3 students identified a general need for improvement in examination items; and clinicians provided specific suggestions for the PT's approach, such as sequencing of the clinical examination and specific tests/measures to rule-in a condition. However, the fact that all levels of students and practicing clinicians identified elements of what the clinician performed well and could improve in the recording suggests that a generalized recording can be useful across multiple levels of training. These findings indicate a complex and technical approach by clinicians in the analysis of reviewing a recording.

It is important to recognize that prior to viewing the digital recording, participants in the study were instructed to consider two

questions: "What did the PT do well?" and "What would YOU have done differently?" which are a modification of the Plus-Delta approach to debriefing simulated encounters (18, 19). Dzara et al. outline the importance of session alignment to meet educational goals as one component of incorporating videos in medical education (17). A necessary element of andragogical instructional design is for the educator to provide instructions and goals for viewing the video to serve as a scaffold for learning. Providing context and objectives is a necessity to frame the context for the learner/viewer.

The idea of learning through the observation of others has been around for decades (25). The use of video as an effective tool for the viewer to observe, learn, and reflect in medical education is not well described in the literature. Recent research by Weingartner and colleagues found that premedical students have improved clinical skills by observing video recordings of standardized patient encounters (26).

TABLE 5 Counts, themes and example quotes from narrative responses to what the reviewer identified the PT in the recording could have done better.

Level of experience	Item count for what the PT could have done better (Mean counts \pm SD)	Themes	Example quote from narrative responses
PY 1	1.53 \pm 1.30	Inquiry Explanation	PY1e: "I think she[PT] could have been better about her word choice in some scenarios, such as not apologizing when asking a patient to perform a needed test..." PY1h: "The PT asked several leading questions, and bounced around frequently." PY1k: "Maybe explained a little more about what the tests are indicating after the results." PY1aa: "Asked more about the pain the patient was feeling as they were doing the movements. Rate it, where is it, worse better same?"
PY2	1.63 \pm 1.43	Inquiry Rapport with patient Examination items/sequence	PY2d: "Could have carried out conversation more after asking a question. Seemed to just go from one question to the next without having a conversation about an answer." PY2i: "She [PT] could've checked passive ROM, accessory movement of lumbar spine and prone instability test." PY2w: "Building a rapport with patient on personal experiences. Dig deeper into goals and activities that bring joy." PY2bb: "The physical therapist should have created more rapport by making the patient comfortable, creating a relationship, and also doing more hands on examination tests."
PY3	2.96 \pm 2.98	Inquiry Examination items/sequence	PY3d: "I think that she should have asked the patient a few more questions regarding his abdominal pain, and performed an abdominal exam. If she did not find anything, she could ask the patient to keep an eye on what he is eating for the next week to see if that does cause any pain changes." PY3l: "I think the PT could have done a more thorough screen of the abdomen to rule out anything more sinister causing the patient's back pain, especially after he mentioned the stomach pain." PY3s: "I think they should have checked vitals after hx of HBP and w/ report of stomach pain."
PT	3.69 \pm 2.56	Sequencing Examination items Abdominal exam	PT1: "The ROM sequencing was interesting to me. I would have started with flexion and extension first and then moved towards side-bending and rotation." PT2: "Given this patient's age, gender and medical history I would have added a screen of patient vitals, and added some red flag screen questions to the subjective section of the exam." PT8: "Capture a bit more information to understand the irritability and stability of the presentation (though could be discovered in objective exam). Captured a bit more information to understand the patients' ICF (environment, personal factors)..." PT9: "I think if she started with symptom mapping it would have saved her a lot of time and helped tailor her subjective to be more focused, it wasn't until her objective exam she realized that the patient had stomach pain as well (that may or may not be related) and she did not ask about any LE sx, numbness/tingling. This is crucial information to acquire." PT25: "She[PT] could have done more palpation. She [PT] could have measured range of motion. She could have asked more questions of type of pain." PT26: "I feel she [PT] could have explored the abdominal pain a little more in depth with potential palpation, further questioning."

The results of our study indicate that physical therapy students and physical therapists can self-reflect on their own clinical ability while observing another clinician's encounter. This study supports the work by Salminen et al. who found that the use of virtual patients can facilitate self-reflection in medical students (6).

This study supports the use of a digital recording to promote student and clinician reflection. However, there are limitations to this study. The data were from a single-site convenience sample, which may not accurately reflect the general physical therapy community, which restricts generalizability. Further, no validated survey tool met the needs for assessment of viewing the recording. The lack of a validated survey

instrument limits the reliability and consistency of the reported results. The study would have been enhanced by having more participants for interviews to gather additional perspectives and increase generalizability. Lastly, the use of blinded researchers to analyze qualitative responses from the survey and interviews would have strengthened the study by minimizing bias in data interpretation and increasing internal validity.

As online learning tools and instructional use of digital recordings becomes more prevalent; video review can be a useful low-cost learning modality. In conclusion, findings from this study provide evidence to support the use of video recordings to promote student and clinician reflection. This study demonstrates that review of a digital recording of

TABLE 6 Themes and example quotes from interviews.

Theme	Student or clinician	Example quote
Importance of instructions	PT5_7_2018	"I followed the PI's [principal investigator's] instructions and prompts."
Review of encounter allow for self-reflection	PY3_03-1986	The recording "helped me see the flow and direction of subjective and how it focuses the next phases of the examination."
Importance of a rubric or guide in reviewing video	PT7_19_2016	"I had a pen, paper and rubric to take notes."

a standardized patient encounter can be used facilitate reflection in practicing physical therapists. Future research would benefit from broader sampling and incorporation of standardized survey instruments. The development of best practices in designing the learning experience, including guidelines for student reflection and self-assessment across medical and health professions trainees would be valuable. Specifically, the use of an explicit framework to review their recordings, and the usefulness of that framework to enhance reflection-on-action and growth as a clinician, should be explored.

Data availability statement

The datasets for this study are not provided as the participants of this study did not give written consent for public sharing of their data.

Ethics statement

The studies involving humans were approved by Colorado Multiple Institutional Review Board (COMIRB). The study was declared exempt (#23-0932). The study was conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AKi: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. AN-C: Data curation, Methodology, Writing – original draft, Writing – review & editing. SK-E: Conceptualization, Methodology, Supervision,

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmed.2024.1516724/full#supplementary-material>

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Research progress of measuring tools for nursing students' clinical learning environment

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Objective: To understand the current situation and progress of clinical learning environment measurement tools for nursing students, this paper reviews the relevant research on clinical learning environment measurement tools for nursing students.

Methods: Three databases (Web of Science, PubMed, and CNKI) were searched for relevant articles. Research articles that met specific criteria were included, with identified articles initially screened by title and keyword. Then the abstracts were screened for relevance, and the full text was read for validation before inclusion. Descriptive analysis was performed with relevant findings from data retrieved from various sources.

Results: We included 19 articles that met the criteria, and introduced nine measurement scales, which completed the reliability and validity test through empirical research, providing an important reference for the assessment of clinical learning environment for nursing students. The Clinical Learning Environment and Supervision instrument (CLESII) has been translated into many languages and is widely used.

Conclusion: This review includes multiple clinical learning environment measurement tools for nursing students, which have important value in evaluating the clinical environment of nursing students and can provide reference for scholars to carry out relevant research and practice. It also introduces the research prospects in this field, aiming to inspire future research.

KEYWORDS

nursing students, clinical learning environment, measuring tools, research progress, reviewed

Introduction

Nursing is essentially a practical discipline, and clinical learning is a core link in the training of nursing students. The clinical learning environment has an essential impact on the training of nursing students.

The learning environment is a crucial conceptual category in learning science. In the 1960s, Herbert Walberg and Rudolf Moss began to study learning environment, and developed the early version of the learning environment inventory and classroom environment scale. Fraser (1) and Peer and Fraser (2) conceptualize the learning environment in a specific way, and hold that the learning environment refers to all kinds of psychological, social and teaching situations that affect students' academic performance, emotions and attitudes in the learning process. Magen-Nagar and Steinberger (3) from the perspective of constructivism, defined the learning environment as "the environmental atmosphere and atmosphere related to the behavior of teachers and students, which can take learning as a positive knowledge

construction process,” emphasizing that the learning environment should support students’ autonomous learning and cooperative interaction with peers and teachers, so as to cultivate students’ initiative and innovation in the learning process (4).

The clinical learning environment integrates all kinds of factors that affect the learning effect of students in the learning process, including hospital culture, teaching staff, doctor-patient relationship, teaching resources, learning opportunities, and other clinical staff. It is an interactive network composed of all influencing factors, which are interrelated and interactive (5, 6). The clinical learning environment provides students with opportunities to apply and practice theoretical knowledge in a real environment, realizes students’ professional socialization, builds up students’ professional confidence, and promotes students’ career role transformation (7, 8). Compared with the general learning environment, the clinical learning environment is more closely integrated with the social environment, which has certain particularity and complexity, and is difficult for teachers to predict and control. At the same time, the clinical learning environment is a working scene with a clear service object, and students are not the core subject, which is also significantly different from the traditional school learning environment.

The clinical learning environment will have a significant impact on nursing students’ caring ability (9), communication ability (10), academic participation (11), humanistic care behavior (12), academic motivation (13), career readiness (14), and so on, which must be highly concerned by educators. Conducting a clinical learning environment assessment can ensure the quality of clinical internships for nursing students, enhance their sense of professional identity, and have a significant impact on improving the quality of nursing services and patient satisfaction. In order to evaluate the clinical learning environment of nursing students and promote the development of relevant empirical investigation, scholars have developed some measurement tools of the clinical learning environment of nursing students. This paper will review the research progress of the measurement tools of clinical learning environment for nursing students, and provide a reference for promoting the evaluation of clinical teaching environment for nursing students.

Materials and methods

This review includes a systematic search, research review, and descriptive analysis of existing literature.

Search strategy

In September 2021, three databases, including Web of Science (WOS), PubMed, and China National Knowledge Infrastructure (CNKI) (15), were searched with “nursing student” and “Clinical learning environment” as key search terms.

Inclusion and exclusion criteria

Inclusion criteria

Relevance to clinical learning environment: The study must focus on measuring the clinical learning environment specifically for

nursing students, using established tools or instruments designed for this purpose.

Tool evaluation: The study should describe or evaluate tools that assess various dimensions of the clinical learning environment, such as supervision, feedback, organizational support, or student satisfaction.

Publication date: Papers published before September 2021.

Type of study: Quantitative or mixed methods.

Publication language: Unlimited.

Exclusion criteria

Irrelevant subject matter: Studies not focused on nursing students or not concerned with clinical learning environments were excluded (e.g., studies that focus on educational theory without practical application in clinical settings).

Overlap with previous studies: Studies with identical or nearly identical research questions, samples, and tools as those already included in the review were excluded to prevent redundancy and ensure the inclusion of new insights.

Missing or incomplete data: Studies with incomplete or missing data, such as those without full descriptions of the tools used or inadequate reporting on measurement outcomes, were excluded to ensure the reliability and comprehensiveness of the review.

Screening process

The authors screened the retrieved papers to assess their relevance. Only those related to the research purpose and that met the inclusion criteria were included. We screened the abstracts of articles with relevant titles, and if deemed applicable, the full text was retrieved and reviewed. A total of 19 articles were selected for further analysis.

Charting the data

Microsoft Excel created a data chart describing the literature on the measurement tools. Data were extracted independently from the articles and classified according to the following headings: title, author, compilation time, initial sample, scoring method, dimension (entry type), and internal consistency.

Collating, summarizing and reporting the results

We conducted an overall analysis of the research on clinical learning environment measurement tools for nursing students by combining all relevant findings from data retrieved from various sources to evaluate the existing research status and confirm the knowledge gap, which can provide a reference for future research.

Result

Clinical Learning Environment Scale

Dunn and Burnett (16), Queensland University of Technology, developed the Clinical Learning Environment Scale (CLES) in 1995.

The compiling process of this scale is as follows: First, 12 nursing education experts revised the Ward Learning Climate Survey compiled by Orton and completed the first draft containing 55 items. The second test was conducted with 83 Australian nursing clinical instructors and 423 nursing undergraduates and clinical nurses as a sample group. Finally, through exploratory factor analysis and confirmatory factor analysis, we finally form “Staff-Student Relationships,” “Nurse Manager Commitment,” “Patient Relationships” and “Interpersonal Relationships” “and” Student Satisfaction “are a formal scale with 23 items in five dimensions, scored by Likert 5-point method. Cronbach’s alpha for five dimensions is 0.63–0.85. With the use of the CLE Scale, educators may evaluate emotionally relevant aspects of the clinical learning environment with accuracy and dependability, focusing resources on areas that require development.

Student Evaluation of Clinical Education Environment Inventory

Sand-Jecklin (17), University of Virginia, developed the Student Evaluation of Clinical Education Environment Inventory (SECEE) in 2000. Interviews with a group of nursing teachers and a group of nursing students were conducted to determine “What are the important factors influencing student learning in a clinical setting?” Based on literature interviews and expert suggestions, the preliminary draft of the questionnaire was preliminarily established, and the students were measured many times with the compiled scale and open questions, and constantly supplemented and improved. Finally, the “Communication/Feedback,” “Learning Opportunities,” “Learning Support/Assistance” and “Department” are formed. The formal questionnaire composed of 29 items in four dimensions of Atmosphere was tested on 319 nursing students from four American nursing schools, with Cronbach’s alpha ranging from 0.89–0.94. Later, Sand-Jecklin (18) modified the scale twice and formed the modified version of the scale. The new scale consists of the “Instructor Facilitation of Learning Scale,” “Preceptor Facilitation of Learning Scale” and “Learning Opportunities Scale,” and contains a total of 32 items. Scores were scored by Likert 5-point method. Cronbach’s alpha was 0.82–0.94.

Clinical Learning Environment Inventory

Chan (19), Chinese University of Hong Kong, developed the Clinical Learning Environment Inventory (CLEI) in 2001. In this scale, the author is concerned that the clinical learning environment is a multidimensional entity with a complex social background, based on the MOOS social environment theory, which not only pays attention to the actual environment but also the match between students’ preferences and the actual environment. In the compilation process, firstly, based on the College and University Classroom Environment Inventory, the scale draft is developed. Second, five university nursing experts and five clinical experts were invited to verify the questionnaire’s contents by checking the items’ adequacy and appropriateness. Finally, a pilot study with 20 nursing students, Formed a scale with 42 items in six dimensions, including “Individualization,” “Involvement,” “Task orientation,” “Innovation,” “Satisfaction” and “Personalization.” The Likert 4 scoring method was used. After the scale was developed, 108

Australian second-year nursing students were used as test subjects for reliability and validity tests. Cronbach’s alpha of six dimensions was 0.73–0.84, and the correlation with other scales was 0.39–0.47. CLEI was developed based on the existing scale of the College and University Classroom Environment Survey (CUCEI), taking into account the specific identity of the study subjects and ensuring that the scale is suitable for the higher education environment. In 2011, Salamonson et al. (20) from the University of Western Sydney adapted the CLEI scale, choosing only two factors around “clinical tutor’s support for learning” and “student’s satisfaction with clinical practice.” A simplified version of the scale CLEI-19, consisting of 19 items from three dimensions, “Satisfaction,” “Personalization” and “Clinical Facilitator,” was formed and scored by Likert 5-point method. Cronbach’s alpha for the three dimensions is 0.92–0.94.

Clinical Learning Environment and Supervision Instrument

Saarikoski et al. (21) of the University of Applied Sciences, Turku, Finland, Clinical Learning Environment and Supervision Instrument (CLESI) in 2002. The scale includes “Ward Atmosphere,” “Premises of Nursing,” “Premises of Learning,” “Leadership Style of the Ward Manager” and “Supervisory” There are 27 items in five dimensions of Relationship, scored by the Likert 5-point method. The reliability and validity test is conducted through the empirical test of 416 Finnish nursing students. Cronbach’s alpha of five dimensions is 0.73–0.94. In 2008, Saarikoski et al. (22) adapted and completed the (Clinical Learning Environment Assessment Scale on the basis of CLESI. Supervision and Nurse Teacher Evaluation Scale, CLES+T), the new scale pays more attention to nursing teachers in clinical teaching Settings, Contains “Pedagogical Atmosphere on the Ward,” “Role of Nurse Teacher,” “Premises of Nursing on the Ward,” “Leadership Style of the Ward Manager,” “Supervisory Relationship” includes five dimensions and 34 items, scored by Likert 5-point method, and tested the reliability and validity of 549 Finnish nursing students. Cronbach’s alpha for five dimensions is 0.70–0.97. The CLES+T scale has attracted a lot of attention internationally, Wang et al. (23), Mueller et al. (24), Kim et al. (25), Al-Anazi et al. (26), Iyigun et al. (27), Ziba et al. (28), Johannessen et al. (29), and Sommers et al. (30) have translated the scale into their own languages and conducted cross-cultural debugging, and introduced the scale into Austria, South Korea, Saudi Arabia, Turkey, Ghana and other countries.

Clinical Learning Environment Scale for Nursing

Zhu (31), Chinese Medical Sciences University, developed the Clinical Learning Environment Scale for Nursing (CLESN) in 2005. Initially, the dimensions and items of the scale were constructed by referring to existing kinds of literature, and the draft of the scale was formed through screening and evaluation by a group of students and experts. Forty-two items, including six dimensions of “interpersonal relationship,” “working atmosphere and team culture,” “student participation,” “task orientation,” “innovation” and “personalization,” were scored using Likert 5 points. After the scale was compiled, 248 nursing undergraduates from seven nursing colleges in China were

used as test subjects to test the reliability and validity of the scale. The Cronbach's alpha of six dimensions was 0.871 to 0.927, the retest reliability was 0.769 to 0.868, and the KMO was 0.934.

Undergraduate Clinical Education Environment Measure

Strand et al. (32), Lund University in Sweden, developed the Undergraduate Clinical Education Environment Measure (UCEEM) in 2013. The scale focused on contemporary workplace learning theories and, based on literature review, semi-structured focus group interviews, and individual interviews, initially formed a list of five core themes and 45 items. Feedback from interviews with 15 stakeholders was obtained, 38 preliminary entries were formed, 77 medical students underwent pre-testing, and 463 medical students underwent measurement and evaluation. A scale consisting of four dimensions, "Quality of Supervision," "Preparedness for Student Entry," "Workplace Interaction Patterns and Student Inclusion," and "Equal treatment," with 25 items, was ultimately formed. The Cronbach's alpha for these four dimensions was 0.79–0.91. Although the scale was developed with medical students as the initial sample, scholars such as Sharifpour et al. (33) and Chun et al. (34) have also applied the scale to surveys of nursing students in Iran and South Korea, verifying its applicability among nursing students.

The detailed information of measurement tools is shown in Table 1.

Discussion

The clinical learning environment is a multi-dimensional concept with rich connotations, which includes all the factors affecting students' clinical learning and is of great significance to students' clinical practice. Nursing is essentially a practical discipline, and clinical practice is the core link of nursing students' training. Therefore, great attention must be paid to the clinical learning environment. In order to measure the clinical learning environment of nursing students, scholars have developed several tools. In the process of developing these measurement tools, researchers have carried out a large number of interviews, observed the actual situation of clinical learning, and also made good use of the Fraser classroom assessment method, MOOS human-environment interaction framework, workplace learning theory, and so on. All these have greatly improved the scientificity of the scale, especially some of the scales that have been concerned by many countries (regions), translated into many languages, and widely used, and these completed scales provide an essential reference for the evaluation of the clinical learning environment of nursing students.

However, these tools also have some limitations. The Clinical Learning Environment Scale (CLES), while widely used to assess the clinical learning environment, has several limitations. It tends to overlook the complexity and variability of real-world healthcare settings, such as differences in hospital size, resource availability, and patient demographics. For instance, larger teaching hospitals may offer more structured learning opportunities, while smaller or rural settings may provide fewer resources, which the CLES does not fully account for. It also fails to measure how these environmental factors—along with emotional and psychological support for students—affect learning outcomes, particularly in diverse or

high-stress settings. The Student Evaluation of Clinical Education Environment Inventory (SECEE) is a useful tool for assessing the clinical education environment, but it focuses primarily on student perceptions of the learning environment, potentially overlooking more objective measures of educational quality, such as specific skill development or clinical outcomes. The tool has limited consideration of emotional and psychological support, which is critical in high-stress clinical settings where students face complex, emotionally demanding situations. The Clinical Learning Environment Inventory (CLEI) is primarily focuses on general factors like organizational support, educational quality, and feedback, without fully accounting for the variability across different clinical settings. It tends to overlook the emotional and psychological aspects of the learning experience, such as stress management or peer support, which are vital in challenging clinical environments. Finally, the tool may not fully reflect the complexity of interprofessional collaboration. The Clinical Learning Environment and Supervision Instrument (CLES) tends to focus more on the quality of supervision and feedback, without fully addressing the broader complexities of clinical practice, such as interprofessional collaboration or the emotional and psychological support students may need. The instrument may not adequately capture the variability in learning experiences across different clinical specialties or settings, limiting its generalizability. The Clinical Learning Environment Scale for Nursing (CLESN) is a useful tool for evaluating the clinical learning environment in nursing education. The CLESN also tends to focus on students' perceptions of supervision and support, without adequately addressing other critical factors like technological integration in clinical practice, interprofessional collaboration, or emotional and psychological challenges faced by students. These gaps limit the tool's ability to capture the full complexity of modern clinical learning environments. The Undergraduate Clinical Education Environment Measure (UCEEM) is valuable for assessing clinical education environments, but it has notable limitations. Primarily, it focuses on general aspects of the learning experience, such as student engagement and supervision, without fully considering the variability in clinical settings. Additionally, the UCEEM does not adequately capture emotional and psychological support for students, which is critical in high-pressure environments. Finally, while it measures aspects of the educational climate, it does not thoroughly assess the impact of interprofessional collaboration or the dynamic nature of clinical practice, potentially limiting its ability to reflect the full scope of modern healthcare education.

In addition, we should see that although scholars have recognized the richness of the content of the clinical learning environment, including the "physical space of the hospital," "psychological and interactive factors," "organizational culture of the hospital," "learning atmosphere of the hospital," "clinical teachers," "student satisfaction" and many other aspects, but at the specific measurement level. It is necessary to make the focus of attention clear according to the core content of the study. Frequent public health events significantly impact the entire medical environment, putting higher requirements for hospital emergency management, nosocomial infection prevention and control, risk assessment, student protection, teaching organization, etc. Kells and Mathis (35) pointed out that the impact of COVID-19 on nursing students should not be ignored, and more mental health services should be given to students in clinical teaching. In 2020, the publication of "IWA 35:2020: Quality of Learning

TABLE 1 Summary analysis of measuring tools.

Name of the tools	Initial sample	Author	Compilation time	Scoring method	Dimensions (number of entries)	Internal consistency
Clinical Learning Environment Scale (CLES)	Australian nursing students	Dunn	1995	Likert 5	Staff-Student Relationships (4), Nurse Manager Commitment (5), Patient Relationships (4), Interpersonal Relationships (6), Student Satisfaction (4)	0.63–0.85
Student Evaluation of Clinical Education Environment inventory (SECEE)	American nursing students	Sand-Jecklin	2000	Likert 5	Communication/Feedback (7), Learning Opportunities (8), Learning Support/ Assistance (8), Department (6)	0.89–0.94
Clinical Learning Environment Inventory (CLEI)	Australian nursing students	Chan	2001	Likert 4	Individualization (7), Involvement (7), Task orientation (7), Innovation (7), Satisfaction (7), Personalization (7)	0.73–0.84
Clinical Learning Environment and Supervision instrument (CLESi)	Finnish nursing students	Saarikoski	2002	Likert 5	Ward Atmosphere (5), Premises of Nursing (4), Premises of Learning (6), Leadership Style of the Ward Manager (4), Supervisory (8)	0.73–0.94
Clinical Learning Environment Scale for Nursing (CLESN)	Chinese nursing students	Zhu	2005	Likert 5	Interpersonal Relationship (7), Working Atmosphere and Team Culture (7), Student Participation (7), Task Orientation (7), Innovation (7), Personalization (7)	0.87–0.93
Clinical Learning Environment, Supervision and Nurse Teacher Scale (CLES+T)	Finnish nursing students	Saarikoski	2008	Likert 5	Pedagogical Atmosphere on the Ward (9), Role of Nurse Teacher (9), Premises of Nursing on the Ward (4), Leadership Style of the Ward Manager (4), Supervisory Relationship (8)	0.70–0.97
Student Evaluation of Clinical Education Environment inventory (SECEE V3)	American nursing students	Sand-Jecklin	2009	Likert 5	Instructor Facilitation of Learning (11), Preceptor Facilitation of Learning (11), Learning Opportunities (10)	0.82–0.94
Clinical Learning Environment Inventory (CLEI-19)	Australian nursing students	Salamonson	2011	Likert 4	Satisfaction (7), Personalization (7), Clinical Facilitator (5)	0.92–0.94
Undergraduate Clinical Education Environment Measure (UCEEM)	Swedish medical students	Strand	2013	Likert 5	Quality of Supervision (11), Preparedness for Student Entry (6), Workplace Interaction Patterns and Student Inclusion (6), Equal Treatment (2)	0.79–0.91

Environments for Students in Healthcare Professions—Requirements for The Healthcare Education Providers in Care Settings” (36) by the International Organization for Standardization provides new guidance for our understanding of the clinical learning environment.

The ongoing effects of the COVID-19 pandemic have profoundly shifted the landscape of clinical learning. During the pandemic, clinical education faced unprecedented disruptions, including the suspension of in-person clinical rotations, increased reliance on virtual learning, and a surge in the use of simulation-based training. Many of the tools previously employed to assess clinical learning environments were not designed to capture the nuances of these new, virtual or hybrid environments. Furthermore, the abrupt shift to online learning raised questions about how well students were engaging with the material and whether they were receiving adequate feedback and mentorship from instructors. A critical examination of existing tools reveals that many of them struggle to evaluate this new

context effectively. Tools that measure aspects like “clinical exposure” or “student-instructor interaction” might not fully encompass the challenges of online learning or the altered dynamics in virtual learning environments. It’s essential for tools to incorporate measures that reflect these shifts, assessing not only knowledge acquisition but also the emotional and social dimensions of remote learning, which were previously overlooked. The development of artificial intelligence has also put forward new requirements for traditional clinical teaching. Promoting the integration of virtual and real practical teaching, allowing students to directly use artificial intelligence technology for medical project practice and exploration, and applying artificial intelligence to clinical teaching scenarios is an important trend for the future development of medical education. Learning based on digital learning platforms and artificial intelligence will become an important component of evaluating clinical learning environments and requires more attention.

Therefore, on the basis of carefully combing and analyzing the existing research on clinical learning environment measurement tools for nursing students, paying attention to the development of the actual health industry, and adapting the existing clinical learning environment measurement tools can better promote the development of relevant empirical investigations.

Conclusion

This review contains a wealth of research articles on measuring the clinical learning environment of nursing students. These articles trace the development process of measuring tools for the clinical learning environment of nursing students, which is of great value for better conducting clinical learning environment assessment of nursing students and can provide reference for scholars to conduct related research and practice. At the same time, this review also proposes some improvement areas in this research field and looks forward to the research prospects in this field in order to inspire future research.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

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A student's perspective: utilizing the lived experience of healthcare leaders as a professional development tool

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Recent events like the COVID-19 pandemic or operational innovations such as the increased use of advanced providers have compelled physicians to take on additional roles like public health spokesperson or team leader. Lectures and workshops are common educational tools utilized to address these changing roles but require significant time, resources, and are often overshadowed by preference for personal experience. The purpose of this commentary is to suggest that the lived experience of healthcare leaders, as expressed through qualitative research-based interviews, offer an engaging educational tool for professional development of the interviewee and the interviewer, especially when a student is the interviewer. Through a student's perspective, and building off a class project, three healthcare leaders were interviewed, and the responses analyzed. Common themes such as approachability, perspective taking, vision establishment, and team empowerment were identified. The student's, and the supervising faculty co-author's, reflections illustrate the impact of using this qualitative research approach to broaden their insights into the complexities associated with being a leader in a healthcare system that incorporates clinical care and educational requirements. However, scaling this tool to a medical school class, or student body, would require altering the method such as group interviews.

KEYWORDS

professional development, leadership, lived experience, qualitative research, constructivist learning theory

Introduction

Physicians have increasingly found themselves in leadership roles beyond clinical care. For example, whether managing interprofessional healthcare teams or guiding the public through the COVID-19 pandemic, physicians are often called upon to lead in ways that extend far beyond their traditional medical training (1–6). Team leader and the more recent role due to the COVID-19 pandemic as a public health spokesperson are examples of roles physicians can take on but not ones their traditional training has necessarily addressed (7–9). In general, undergraduate medical education (UME) in the United States (US) has not effectively prepared physicians for such non-clinical leadership roles (5, 10–12).

Preparing medical students to lead in healthcare often occurs through formal curricular, or informal cocurricular, content in UME – if not on the job when these students enter practice. In a national study, Neeley et al. (13) found that only 34%, or approximately 48, of the 144 allopathic (i.e., MD) medical schools in the United States who responded to the survey had a formal leadership program, whether elective (33%) or required (35%) (13). More recently, Korndorffer et al. found that 62% (14) of 40 sampled US allopathic schools offered

an optional professional development curriculum on leadership in medicine (11). Further evidence is needed, but it appears there has been little progress since Neeley et al.'s study (10, 13).

Arroliga and Stoller suggested that packed curricula, limited time, and competing priorities hinder progress by medical educators to provide professional development content like leadership education in medical schools (15, 16). Korndorffer's et al.'s study confirmed time constraints for faculty and staff and added lack of buy-in as other barriers (11). Additionally, leadership training often relies on lectures, mentoring, or workshops requiring significant time or resources (11, 13) and limiting broad implementation. In short, due to evolving challenges in healthcare, there is a need to train medical students to address these challenges; however, current methods and tools are limited and often superseded by other pressing curricular demands (15, 16).

Could there be a more effective and economical alternative to traditional, didactic-heavy methods that would foster professional development around an area such as leadership? Framed by constructivist pedagogical framework, and through qualitative research-based interviews, the authors suggest that the lived experiences of healthcare leaders can serve as an educational tool to teach medical students about leadership in medicine and foster their overall professional development. After describing lived experience and constructivist learning theory, the methods for a course project are outlined. Lastly, an example from a medical student's perspective of the educational impact of a course project on their, and the faculty co-author's, leadership education and overall professional development is presented.

Lived experience

Talking with front desk staff, taking a patient's medical history, and discussing the plan of care with members of the healthcare team are a few of the common daily activities for physicians. These activities are referred to in qualitative research as *lived experience* or, "everyday life or social action" to explore phenomena like leadership in medicine [(17), pp. 26]. For example, an attending physician could be observed discussing a plan of care with a diverse healthcare team. While a simplistic scenario, the researcher might frame questions regarding *why* the attending physician chose specific communication strategies. In response, the attending physician may comment on the importance of accessible language and nonverbal cues. The physician may also discuss *how* positive and negative experiences shaped their own communication and leadership style. Everyday human interactions, such as the physician example above, illuminate the rich potential of the lived experiences. Qualitative research focuses on exploring *why* and *how* to derive meaning from their lived experiences rather than testing a hypothesis [(17), pp. 6].

Constructivist pedagogical framework

The constructivist pedagogical framework, or learning theory, states that learners are not passive spectators but rather involved participants that bring prior knowledge, understanding, experiences, and preconceptions to learning (18, 19). For instance, a medical student engaging directly with a physician at a patient's bedside, or

one-on-one conversations with healthcare leaders offers a more engaging approach to learning than passively sitting in the back row of a lecture hall. These interactions transform learning from passive and transmissive with a student-observer focus to an active and constructive student-centered focus.

Before moving to a medical student's example of the impact of this approach to learning about leadership in medicine, it is important to briefly state six principles of the constructivist learning theory noted below based on the recent work of Burns, Menchaca, and Dimock (20).

- 1 Learners bring prior knowledge, experience, and beliefs to learning.
- 2 Knowledge is constructed and informed by experiences and contexts.
- 3 Learning is a mental process that is active and reflective.
- 4 Learning is a developmental process.
- 5 Learning is a contextual and social process (21).
- 6 The learner is at the center of the process controlling and mediating information.

The philosophical roots in the constructivist inquiry paradigm and nuances of constructivist learning theory are complex but are reflected by the six principles stated above (19, 21, 27, 28). Through interviews and personable narrative style, the following sections detail the methods for a course project and illustrate learning from the lived experiences of three healthcare leaders for medical student, and co-author, Sunitha Konatham (SK).

Course project methods

To explore leadership in medicine and specific to leading teams, SK interviewed three healthcare leaders as a project, and not an institutional study, in a required course during the first year of medical school. This project employed a convenience participant recruitment strategy. Participants invited to be interviewed as part of this project were based on accessibility and prior professional relationships with SK. Given the project's exploratory nature, convenience recruitment allowed for efficient recruitment of individuals with direct experience in healthcare leadership roles while ensuring feasibility within the course's time constraints. A Manager of Volunteer Services, a Cardiology Clinic Practice Administrator, and an Executive-Level Administrative Physician agreed to participate. Semi-structured interviews were conducted in-person or via ZOOM, each lasting 45–60 min. Interviews were either recorded with in-person detailed notes (i.e., Manager of Volunteer Services) or audio-recorded and transcribed verbatim. The interviews addressed four questions provided to all class participants by the co-author MD: (1) What does team leadership mean to you? (2) What are the team leader's roles and responsibilities? (3) What are strengths and challenges of team-based care? and (4) What skills & strategies help enhance the performance of a team?

With the guidance MD through project instructions, SK conducted a thematic analysis by independently reviewing interview transcripts to identify patterns and key themes related to leadership in medicine. Using an inductive approach, themes emerged from the responses with not preset coding scheme. The analysis involved reading and re-reading transcripts, grouping significant statements into units and then into broader themes.

To enhance trustworthiness, the themes were triangulated across participants, ensuring consistency in redundant data to identify themes. Themes were shared with interviewees. As analysis was conducted only by SK, steps were taken to minimize bias through reflection conversations with MD and multiple transcript reviews.

A medical student perspective on leadership from her interviews

Below are the leadership lessons SK learned from the lived experience of the healthcare leaders interviewed for the school project.

Manager of Volunteer Services

“I cannot believe you used to shadow doctors and now you are studying to become one,” the Manager of Volunteer Services (MVS) remarked as she/he walked with SK from the lobby to the outside patio of the local hospital where SK volunteered as a high school student. Sitting in metal chairs across a shaded table, SK pulled out her notepad, eager to glean advice from the person who first showed her leadership in healthcare that inspired her passion for medicine.

SK and the MVS discussed SK’s time working at the front desk and visiting patients with a care cart to make their stays more comfortable, and SK shared how she initially saw these roles as less clinically important but grew to realize that friendly faces and willingness to serve were also a form of care. The MVS nodded, emphasizing that emotional intelligence is just as vital as cognitive intelligence when caring for those in pain.

The MVS also described her/his role as a “mediator” to facilitate collaboration between departmental leaders and volunteers. Department leaders seek more direct patient time, and volunteers want to contribute to a patient’s care, so they identify tasks volunteers can handle to free up providers to focus on patient care.

SK thanked the MVS for assigning her to the Medical Surgical Unit where she gained valuable insights into her desired career by observing how physicians interacted with patients and their families. SK commented, “I learned more about the type of doctor I wanted (or did not want) to be.”

The MVS chuckled and asked, “Do you want a tip?” She/he explained that this question sets a positive tone for advice or criticism. Support is vital with this strategy, as everyone should feel comfortable giving and receiving help. She/he demonstrates this support by keeping an open-door policy, developing connections with, and advocating for, volunteers.

As the lunch hour ended, SK asked the MVS to outline her/his job as a healthcare leader. She/he listed the five C’s guiding their leadership style, punctuating each one with a raised finger to count them off: compliance, compassion, calling, collaboration, and constructive criticism. SK and the MVS ended their time with a high-five, symbolizing how she/he had passed on those five attributes.

Cardiology Clinic Practice Administrator

SK’s next meeting was with the Cardiology Clinic Practice Administrator’s (CCPA) on the same hospital’s second floor, where SK had shadowed during her undergraduate studies. The CCPA’s managerial experiences and formal education in business

administration made her/him an ideal resource for learning more about leadership in medicine.

SK noted how the sunlight streaming in through the large windows contrasted with their old windowless office. The CCPA smiled and agreed, sharing that the decision to move offices was tougher than anticipated. While the new office was pleasant, she/he was no longer in the middle of the action and needed to intentionally, “go walk around and be involved in the day-to-day things that impact patient experiences” to build trust.

As a leader in the cardiology clinic, the CCPA set staff objectives without micromanaging, believing that true leadership inspires people to do the right thing without being asked. She/he also explained that allowing people to fail can be a learning opportunity, and leader can empower people to use mistakes positively.

The CCPA also shared an example of how she/he resolved an operational concern for the in-basket – an inbox for labs, imaging, and messages – allowing staff to work more effectively. Physicians expressed concerns about needing to reduce appointment times to meet growing demand, leaving less time for the in-basket. The team devised a triage system for the in-basket and the CCPA emphasized that everyone should, “practice at the top of their license.” For example, registered nurses (RNs) handle 60% of in-basket communications, while physician assistants (PAs) manage 30–35%, leaving 5–10% for the physician. She/he highlighted that listening is critical and does not always require having a solution. It is important to allow time and space for the team to voice concerns or develop a solution.

Executive-Level Administrative Physician

The Executive-Level Administrative Physician (ELAP) is a pediatrician and preventive medicine specialist who earned a master’s in public health and over a decade of experience working in different public health positions at the county and state levels.

Between their busy schedules, SK and the ELAP settled on a 10:30 pm meeting over Zoom. While the ELAP searched the dimly lit hotel lobby for a Wi-Fi connection, SK perched her laptop on the counter in my medical school’s kitchen, eager for the ELAP’s authentic, and unfiltered, perspective on leadership in medicine.

Personal and professional experiences taught the ELAP that leadership as a physician is two-fold: positional and influential. She/he stated that positional leadership is founded on technical understanding in an area, whereas influential leadership is founded on interpersonal skills. However, she/he emphasized that authority is responsibility earned, not a right. Although leadership can be positional, an impactful leader influences those they lead by modeling positive behavior, building relationships, and equipping others to excel in their roles.

Many physicians enter medicine focused solely on patient care, often lacking the essential skills to take on administrative roles due to limited training in medical school. The ELAP explained that “the M.D. behind your name gives you credibility – if I say something, people listen (adding in jest, ‘and sometimes they should not).” To build credibility and level the hierarchy, she/he prefers being addressed by first name. She/he further emphasized that the team’s purpose is to help the community, not personal agendas, and stress the importance of healthy debate behind closed doors while presenting a united front publicly.

Student interviewer's reflection about the interviewing process

Informally interviewing these healthcare leaders gave me a better grasp of the complexities of leadership in healthcare and revealed the value of learning from lived experiences. I used to view myself as a leader because of my title on a student leadership team, but these interviews also reminded me that leadership is about relationships. Leaders can be found at all levels and positions in healthcare, as demonstrated by these leaders. Afterward, I conducted a basic comparative analysis, identifying commonalities and extracting excerpts to illuminate the participants lived experiences. I grouped the commonalities under the themes of approachability, perspective-taking, vision establishment, and team empowerment (Table 1).

Just as our medical knowledge is developed in the classroom and nurtured in the clinic, leadership skills can be cultivated by observing experiences of individuals working in healthcare. These interviews were completed during my preclerkship coursework, and now as a current third-year medical student rotating through various clerkship experiences, I have continued to identify these themes in the leadership styles of faculty. One key takeaway from these interviews is that leadership may seem like a soft skill, but it's hard. Leadership is often regarded as a personality trait that is not easily measured or defined. Yet, students are expected to graduate with the ability to lead their peers and patients. Even those appearing naturally inclined for leadership need education, examples, and insights from the lived experiences of other healthcare leaders.

Discussion

As SK established through her interview narratives, learning from the lived experiences of healthcare leaders broadened her understanding of leadership in medicine. The literature in medical education points to the broad use of qualitative research-based interviews to research phenomena such as student perspectives on outpatient education, the patient experience, or improving clinical outcomes (22–24). However, despite scant evidence in the nursing literature (14), utilizing lived experiences of healthcare leaders as an educational tool is largely absent.

Not only did SK hear what was stated in the interviews, SK synthesized the information and drew connections through themes communicated from each leader – supporting the efficacy of lived experiences as an educational tool. For instance, in-basket communication became an opportunity to deconstruct leader's

approach and provide a rich learning experience. Rather than learn about leadership in a lecture hall, SK engaged in meaningful discussion with the healthcare leaders, fostering mentoring relationships that proved beneficial to her professional development.

While the benefits of a constructivist-based approach to learning include active involvement of the learner, there are limitations. SK's learning was based on only three healthcare leaders. While the small participant pool may limit generalizability, the goal was not broad representation but rather in-depth exploration of lived experiences. Next, this approach requires time from healthcare leaders to be interviewed; which may be difficult to secure. Lastly, SK's existing relationships with the participants likely fostered mentoring discussions. Mentoring is widely regarded as another important method for training medical students (25) which was an advantage for SK but may not be for future students who did not have existing relationships with healthcare leaders.

Interviewing healthcare leaders can be educationally fruitful. However, scaling interviewing healthcare leaders to entire student body of 600+ students would require adjusting the methods. Implementing lived experience interviews on a larger scale would require adjusting the methods. For example, instead of one-on-one interviews, a group of students in a course focused on the practice of medicine could interview a set group of healthcare leaders in person or virtually. Additionally, medical schools are increasingly implementing faculty-led longitudinal small groups, also known commonly as learning communities, for the entire student body to address aspects like mentoring, education, and wellbeing (26). For schools with these learning communities, another option is to use these groups as the setting for students to interview their faculty leaders (i.e., group-on-one). Learning communities could even trade leaders to give students the option to hear from multiple faculty. In groups, the students then could collaboratively construct an understanding of the interviews as well as commonalities, differences, strengths, and challenges between the lived experiences of the faculty interviewed – promoting critical thinking and further supporting the constructivist pedagogical framework.

Conclusion

Traditional efforts to promote professional development (e.g., teaching leadership in medicine) often rely on passive methods such as seminars or workshops (11, 13). Moreover, medical students often elevate personal experience over the classroom teaching of leadership; opting to learn while “on the job.” Exploring the lived experiences of healthcare leaders through qualitative research-based interviews offers an engaging way for students to learn directly from those working daily in the medical field. In addition, the potential ancillary

TABLE 1 Common themes of leadership from interviews.

	Approachability	Perspective taking	Vision establishment	Team empowerment
Management of Volunteer Services (MVS)	Open door policy	Individual meetings with volunteers and employees	Common vision and goals for all personnel	Delegate non-clinical tasks to other personnel
Cardiology Clinic Practice Administrator (CCPA)	Listening without judgement	Understanding roles to identify overlap or conflict	Break down hospital goals into objectives	Encourage autonomy
Executive-Level Administrative Physician (ELAP)	First name-basis connection	“Management by walking around”	Data analysis, resource assessment, and political engagement	Providing resources, autonomy, and vision

opportunities of mentoring and collaboration between faculty and students, as exemplified by SK's example, offers additional educational benefits to enrich student learning.

With Artificial Intelligence (AI) becoming more integrated into medical practice, physicians will be tested again as to what role they will play in this next era of innovation. Medical educators must adapt not only in teaching the basic sciences (e.g., Anatomy), but also effectively prepare physicians for another change in the medical field. Actively learning at the bedside, one-on-one, or group-on-one conversations with healthcare leaders situates students at the center of a more engaged and practical learning process than at the back of a lecture hall.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

MD: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. SK: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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