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Are We Asking the Right Questions? A Scoping Review of Evaluation Tools for Simulation Technologies

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Conflict of Interest Statement
The authors of this manuscript declare no conflicts of interest.

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Structured Summary
Background: Subject matter expert review is a common and crucial part of evaluating new simulation technology; however, there is a lack of consensus guidelines or framework to conduct this review.

Objective: The present study undertakes a scoping review of research on subject matter experts evaluating simulation technology in medical education to investigate common question style, question objectives, number of subject matter experts, and common themes across specialties and modalities.

Design: PubMed was used to identify published papers, from which 171 were selected for data extraction and analysis.

Results: The majority of publications focused on a technology related to a surgical subspecialty and utilized fewer than 20 subject matter experts. The two most common modalities identified were part-task trainers and VR, AR, MR, and screen-based. Most questions for evaluating a new simulation technology focused on assessing realism, with very few addressing the usability of the model.

Conclusions: The process of evaluating new simulation technology with subject matter expert review would benefit from structured guidelines or frameworks. Such guidance can help ensure appropriate methodology aimed at collecting feedback which is actionable and supportive of developing high-quality educational tools in simulation.

Introduction
It is an increasingly common practice in healthcare education to develop new simulation technologies or adapt existing ones for novel educational purposes. These efforts are often driven by the need to address specific training goals for which no suitable tool currently exists, or to modify existing technologies so they better align with a particular learner group or learning objectives. With a newly developed or modified technology, it is best practice to review how well it meets the defined need and its functionality before being implemented with learners. This often takes the form of feedback from subject matter experts. Simulation operations specialists (SOSs), researchers, and educators must decide how to evaluate the technology and when the technology is ready for implementation based on the feedback received.

To our knowledge, there is no widely accepted framework for evaluating simulation technology using subject matter expert (SME) feedback. The Healthcare Simulation Standards of Best Practice for Simulation Design describes general guidelines for evaluation prior to implementation, emphasizing the importance of selecting measures to assess validity, consistency, and reliability, as well as identifying underdeveloped elements (Watts et al., 2021). While this serves as a helpful outline, it does not offer explicit guidance on how to conduct such evaluations in practice.

Several comprehensive frameworks exist for validating simulation technology, including Messick's validity framework (Joint Committee on the Standards for Educational and Psychological Testing, 2014), Kane's validity framework (Cook et al., 2015), and classical validity (Cook & Hatala, 2016) approaches. These frameworks are well-established and extensively documented, offering detailed resources for implementation. However, not all simulation technologies require formal validation. While formal validation is essential for technologies intended for testing or high-stakes assessment, many educational tools do not fall into this category. Given the intensive, multi-step nature of validation and the statistical expertise it demands, it may not be appropriate for early-stage evaluation or for simulations not intended for assessment.

In the absence of a framework, researchers, SOSs, and educators often must rely on non-specific resources to develop evaluation tools. This typically involves referencing general guidelines for survey development (Gehlbach & Artino, 2017; Hill et al., 2022) and searching the literature for SME feedback approaches applicable to their specific simulation technology. Given the lack of clear guidance, the field of healthcare simulation may benefit from a better understanding of how to conduct SME reviews. While SME input is frequently used to evaluate simulation technologies, there is wide variability in how these reviews are conducted and reported. Inconsistent approaches can limit the utility of feedback. A recent umbrella review of simulation-based education identified a pervasive lack of rigor in methodology, limiting definitive conclusions (Palaganas et al., 2025). To address this gap, a scoping review was conducted to examine how SME reviews have been previously used to evaluate simulation technologies and to identify common practices and methodological patterns. This review aimed to fulfill the following objectives:

1. Provide an overview of published evaluations of simulation technology and understand the gaps and inconsistencies in methods.
2. Introduce a resource for those involved in simulation operations to use when conducting subject matter expert review.
3. Explore how these findings can inform future approaches to simulation technology evaluation.

Methods

The scoping review methodology was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). A full description of the scoping review methodology, including search strategy and inclusion criteria, is available in Supplemental Material 1.

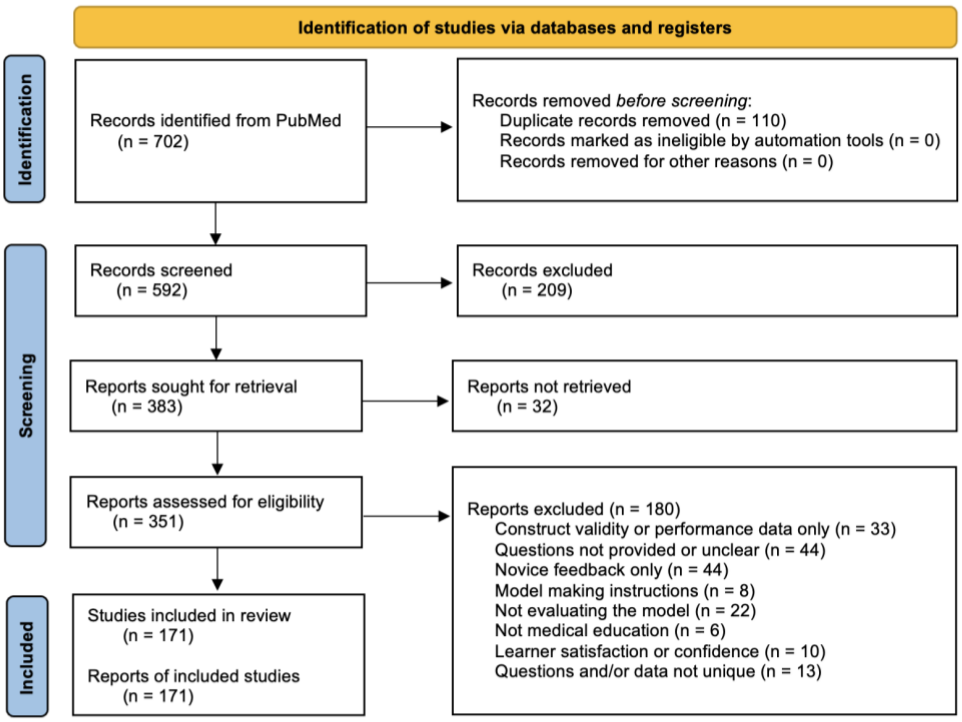
Results

Literature search

Figure 1 summarizes the data selection and screening process according to PRISMA-ScR guidelines (Tricco et al., 2018). There were 702 records retrieved, of which 171 were identified as eligible and included in this scoping review. The included records are listed in Supplemental Table 1, along with the extracted data: model description, modality, number of experts, primary specialty, sub-specialty, type of participants, question format, and question objective.

Figure 1

PRISMA Diagram



Note. Source for 2020 PRISMA Diagram: Page et al., 2021.

Characteristics of included studies

The included studies' citation, model description, modality, number of subject matter experts, specialty, sub-specialties, participant description and question style are represented in Supplemental Table 1.

Modality

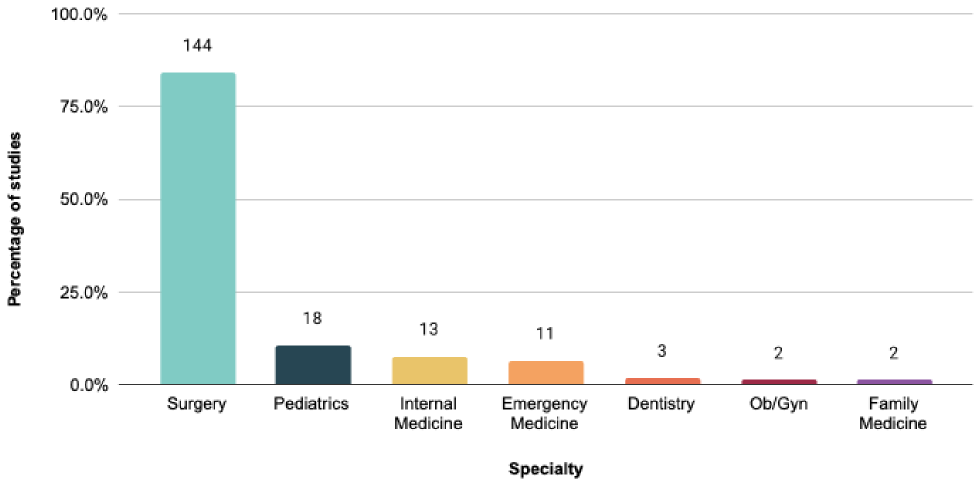
Among the 171 studies included in this scoping review, the most commonly used simulation modality was VR, MR, AR, or screen-based technology (92 studies, 53.8%). Part-task trainers were used in 62 studies (36.3%), while cadaver or live tissue models were reported in 16 studies (9.4%). Only one study (0.6%) used a manikin-based simulator.

Specialty

Across simulation modalities, surgery was the most frequently represented specialty overall (84.2%), accounting for 82.3% of part-task trainer studies, 81.3% of cadaver and live tissue studies, 85.9% of VR, AR, MR, and screen-based studies, and the only manikin-based study (Figure 2). Other specialties such as pediatrics, internal medicine, emergency medicine, and dentistry were less represented. Sub-specialties are described in Supplemental Table 1.

Figure 2

Specialty by Modality



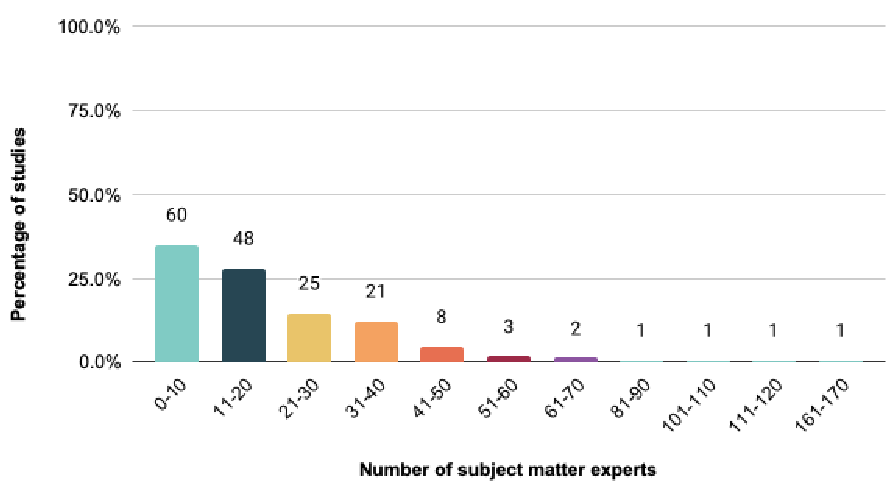
Note. Percentages reflect the proportion of studies (n = 171) assigned to that specialty, with each bar annotated with the number. Studies could be assigned to more than one specialty.

Subject matter experts

Most studies across all simulation modalities involved a relatively small number of subject matter experts (SMEs), with over one-third (35.1%) including 0-10 SMEs overall (Figure 3). Another 28.1% of studies included 11-20 SMEs, and 14.6% included 21-30 SMEs. Studies with more than 40 SMEs were uncommon, with only a small proportion (under 5%) involving over 50 SMEs. The one manikin-based simulator study had 81-90 participants. A description of the subject matter expert participants for each study can be found in Supplemental Table 1.

Figure 3

Number of Subject Matter Experts



Note. Percentages reflect the proportion of studies (total n = 171) for each number of subject matter experts, with each bar annotated with the number.

Characteristics of included questions

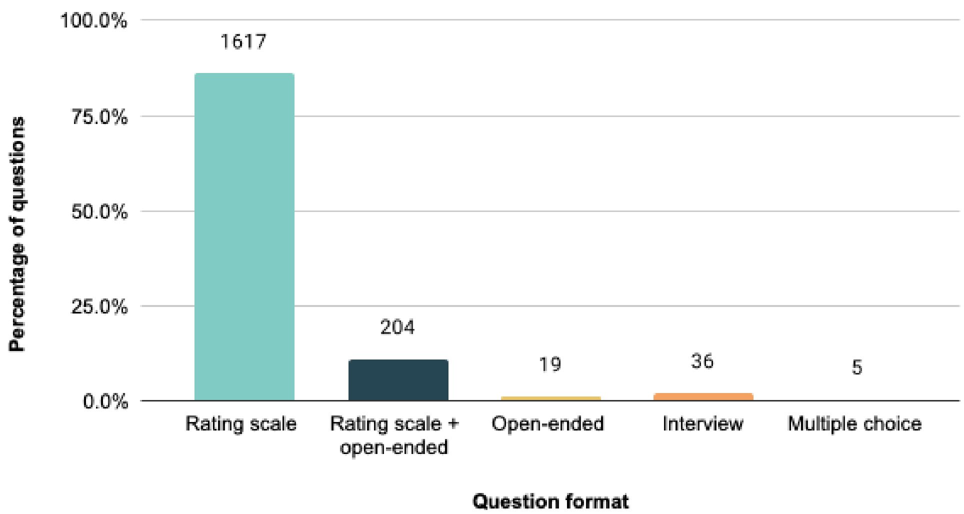
There were 1881 questions extracted from included studies. These questions were categorized based on question format and question objective.

Question format

There were 1881 questions categorized based on question format (Figure 4). Across all simulation modalities, most questions (86.0%) used a rating scale format to gather input from subject matter experts. This trend was consistent across all individual modalities: 87.1% of part-task trainer questions, 86.0% of cadaver and live tissue questions, 85.0% of VR, MR, AR and screen-based questions, and 100% of manikin-based simulator questions used rating scales. A smaller proportion of questions used a combination rating scale and open-ended format, accounting for 10.8% of questions overall. Open-ended questions (1.0%), interview formats (1.9%), and multiple-choice questions (0.3%) were all used very infrequently.

Figure 4

Question Format



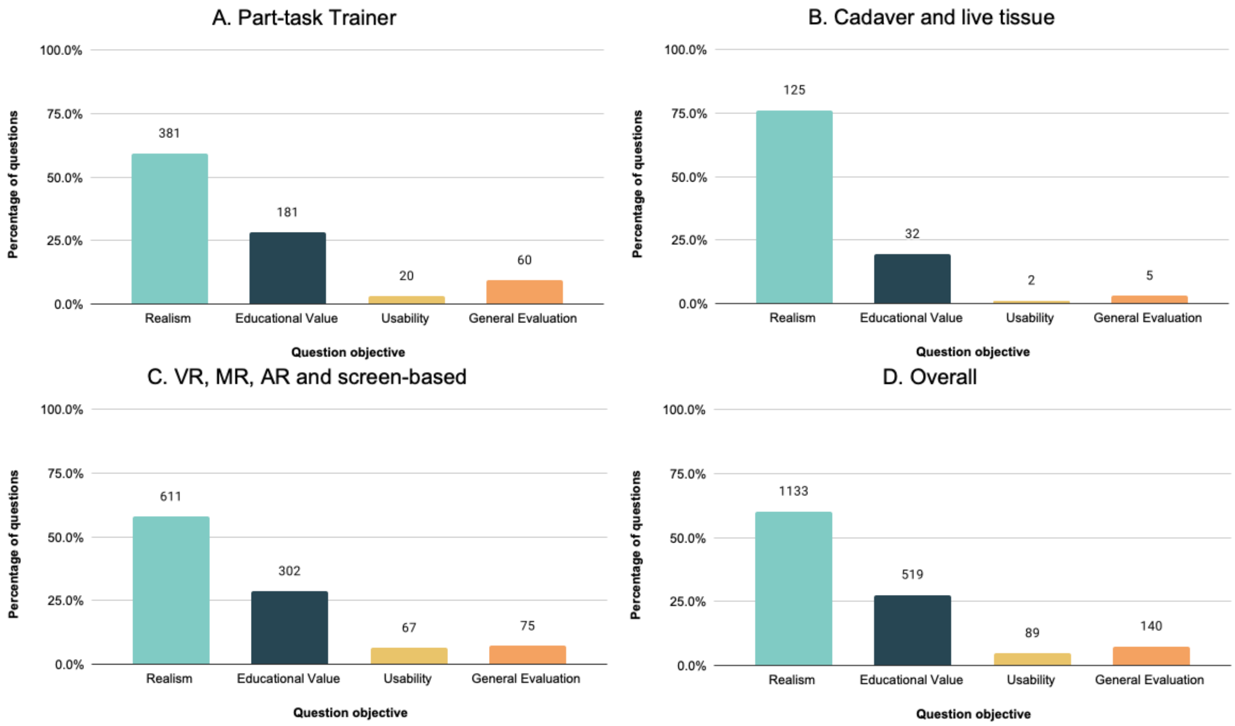
Note. Percentages reflect the proportion of questions (total n = 1881) assigned to that question format, with each bar annotated with the number.

Question objective

There were 1881 questions categorized by question objective (Figure 5). The most common focus was on realism, accounting for 60.2% of all questions. Questions related to educational value made up 27.6% overall. Usability questions were less common, comprising only 4.7% of all questions. These appeared most often in VR, AR, MR, and screen-based studies and were rarely used in other modalities. Of the 20 questions from the mannikin-based simulator study, 16 (80%) were categorized as realism and 4 (20%) were categorized as educational value.

Figure 5

Question Objective by Modality



Note. Percentages reflect the proportion of questions within each modality assigned to that question objective, with each bar annotated with the number. Panel A: Part-task trainer (total n = 642). Panel B: Cadaver and live tissue (total n = 164). Panel C: VR, MR, AR, and screen-based (total n = 1055). Panel D: Overall (total n = 1881).

(continued on next page)

Realism

Of the 1881 questions included in the study, the most common focus was on realism, accounting for 1133 (60.2%) of all questions. For all modalities, realism questions accounted for over 50% of questions asked: 59.3% of part-task trainer questions, 76.2% of cadaver or live tissue questions, 57.9% of VR, AR, MR, and screen-based questions, and 80.0% of manikin-based simulation questions. There were 10 themes related to realism identified across the different modalities that had more than 10 questions (Table 1).

Table 1

Realism Themes

Theme	Examples	Citation
Overall global realism assessment	"How real/natural did you think the trainer was?"	Elisei et al., 2024
	"How realistic is the model?"	Hung et al., 2015
Visual realism	"Appearance of vocal cords."	Hsiung et al., 2017
	"Realism of intra-articular joint space size."	Stunt et al., 2014
	"The skin color looks realistic."	Sadovnikova et al., 2020
Tactile realism and tissue behavior	"Realism of amount of resistance necessary to view the vocal cords."	Hsiung et al., 2017
	"How realistic is the texture of rib graft material?"	Reighard et al., 2019
	"Incising the cricoid cartilage feels realistic."	Deonarain et al., 2020
Realism of anatomy and pathology	"The bladder neck was anatomically accurate."	Johnson et al., 2019
	"Approximated the correct anatomical course of the ureter."	Yousuf et al., 2017
	"This model provides a realistic representation of the inguinal canal."	Nazari et al., 2019
Procedural or task realism	"How realistic is the umbilical vein catheter insertion?"	Takahashi et al., 2019
	"Similarity of superficial temporal artery dissection simulation."	Ferrarez et al., 2020
	"Realism of retrieval of airway foreign body."	Hsiung et al., 2017
Instrument interaction realism	"How realistic are the instrument movements in the translocation task?"	Botden et al., 2007
	"The ultrasound probe had a realistic range of motion."	Chalasani et al., 2011
Physiological realism: pulsations, bleeding, etc.	"The pulsations of the basilar atery were realistically reproduced."	Weinstock et al., 2017
	"The CSF flow in the ventricles was realistically reproduced."	Weinstock et al., 2017
	"Realism of bladder distension."	Moore et al., 2022
Environmental and model setup realism	"Does the device workspace feel realistic?"	Abinaya & Manivannan, 2024
	"How would you rate the realism of the simulator hardware (grippers, foot pedals, stereoscope)?"	Sethi et al., 2009
	"The arrangement of the simulator and the instruments adequately represents the surgical reality."	Mery et al., 2021
Comparative realism	"Realism of simulator's graphics to that of the da Vinci robot."	Harrison et al., 2018
	"The simulated fetoscopic repair exposes the trainee to a stress similar to that in the clinical operating room."	Joyeux et al., 2021
	"Performing the skill was as real as in the operating room."	Schlottmann et al., 2017
Task difficulty/self-performance assessment	"Skills necessary for the model are similar to skills necessary for real pyeloplasty."	Timberlake et al., 2020
	"How difficult was it to perform the repair of esophageal atresia on the simulator?"	Barsness et al., 2023
	"The simulated fetoscopic repair is as difficult as the procedure in humans."	Joyeuz et al., 2021

Educational Value

Of the 1881 questions included in this study, there were 519 questions (27.6%) related to educational value. Questions about educational value were evenly represented across modalities, ranging from 19.5% to 28.6% of questions within each group. Across the different modalities, eleven themes related to educational value were identified (Table 2).

Table 2

Educational Value Themes

Theme	Examples	Citation
General educational value and usefulness	"What is the value of the simulator as a training tool?"	Reighard et al., 2019
	"The neuroendoscopic ultrasonic surgery tumor removal task is a valuable training exercise."	Licci et al., 2020
Useful for general skill acquisition or training	"Value in learning basic laparoscopy skills"	Duboureau et al., 2021
	"This model is useful for improving hand-eye coordination."	Porto et al., 2022
	"The curriculum improved my camera handling skills."	Shetty et al., 2012
Useful to improve competency or performance	"Use of this model will increase trainee competency when performing a tracheostomy."	Deonarain et al., 2020
	"This model could shorten learning curve and improve learning outcomes."	Schlottmann et al., 2017
	"Training with this model would help trainees improve their overall ear surgery skills."	Stramiello et al., 2022
Useful for building confidence in learners	"Using the silicone DRE task trainer will help increase the trainees' confidence."	DeZeeuw et al., 2020
	"In your opinion, how effective is the new trainer in increasing trainees' confidence to perform IO insertion?"	Engelbrecht et al., 2020
	"This model can help to improve trainee's confidence in performing a TURBT."	Berridge et al., 2021
Useful to prepare for real procedures	"This simulator is necessary before actual procedure."	Feng et al., 2024
	"This simulator is useful for warmup for robotic surgery."	Schreuder et al., 2014
Useful as an assessment tool and to provide feedback	"This model is useful for assessing trainee's skill to perform an OA TOF repair."	Neville et al., 2022
	"This model can evaluate PCNL performance."	Ghazi et al., 2017
	"This model could serve as a tool for neurosurgical skills examination."	Mellal et al., 2024
Recommendation for curriculum integration	"The model would be a valuable addition to current simulation-based medical education."	DeZeeuw et al., 2020
	"This model should be included in the resident training curriculum."	Lee et al., 2022
Training value for specific learner groups	"The model is useful for training of otolaryngologists."	Albrecht et al., 2022
	"How would you rate the relevance in the training of the first-assistant for robotic surgery?"	Sessa et al., 2018
	"Is the model an effective training tool for experts new to robotic partial nephrectomy?"	Hung et al., 2015
Useful to improve knowledge or understanding	"Educational potential for learning ostia identification."	Panel et al., 2012
	"I think this application will enhance the understanding of surgical trainees regarding the Le Fort I application."	Pulijala et al., 2018
Useful for specific skill acquisition or trainnig	"Is this simulator useful to acquire skills for relocation of stone by basket?"	Orecchia et al., 2023
	"This model helps to develop skills in performing balloon dilation."	Chang et al., 2017
	"This model is useful for teaching carotid artery injury repair."	Porto et al., 2022
Comparative value to other training methods	"Rate the usefulness of the simulation in learning hand-eye coordination skills compared to a pig model."	Dorozhkin et al., 2016
	"MMCIS is more realistic than existing mass casualty incident training tools."	Pucher et al., 2014
Useful for learning anatomy	"Beneficial to understanding spinal anatomy."	Feng et al., 2024
	"Please rate how effective the simulator is in teaching venous anatomy."	Reznek et al., 2002

Usability

Of the 1881 questions included in this study, usability questions were least common, comprising only 89 (4.7%) of all questions. These appeared most often in VR, AR, MR, and screen-based studies, accounting for 67 of the 89 usability questions, and were rarely used in other modalities. There were eight themes related to usability identified (Table 3).

Table 3

Usability Themes

Theme	Examples	Citation
Overall usability	"I found it easy to use the VR software."	Botelho et al., 2024
	"On a scale from 1 to 10, how would you rate the usability of the module?"	Wiltvank et al., 2024
	"Is it easy to learn how to use the application?"	Negrillo-Cárdenas et al., 2022
Setup and instructions	"The instructions on how to use the simualtor by the research assistant were clear."	Leijte et al., 2021
	"Ease of model set-up."	Biswas et al., 2020
Comfort and motion sickness	"I experienced discomfort wearing the HoloLens."	Amiras et al., 2021
	"Have you felt any dizziness during the simulation?"	Negrillo-Cárdenas et al., 2022
	"I found the headset comfortable to wear throughout the application usage."	Pulijala et al., 2018
Cost and reproducibility	"Model is cost effective."	Yousuf et al., 2017
	"I believe the simulator has the potential to be a cost-effective simulator laparoscopic cholecystectomy."	Schijven & Jakimowicz, 2002
	"Model is easily reproducible."	Yousuf et al., 2017
Equipment accessibility and handling	"The simulator interface (its on-screen design) is user-friendly."	Leijte et al., 2021
	"Was the navigation menu of the tool user-friendly?"	Alvarez-Lopez et al., 2020
Model functionality: performance during the task	"The simulation runs smoothly without lag."	Wang et al., 2022
	"The simulation runs stably without crash or exception."	Wang et al., 2022
	"The simulation umbilical cord worked well during my simulation session."	Sawyer et al., 2009
Feasibility of integrating the simulator into the existing curriculum	"How feasible is incorporating the simulator into the training program?"	Ebbing et al., 2021
	"Please rate the feasibility of integrating the simulator into surgical training."	Whittaker et al., 2016
Task independence and intuitiveness	"Were you able to do the task without any assitance?"	Abinaya & Manivannan, 2024
	"Is the application intuitive and easy to use?"	Negrillo-Cárdenas et al., 2022

Discussion

In this scoping review, we identified 171 studies evaluating simulation technology using subject matter expert feedback. One of our objectives in completing this scoping review was to provide an overview of published evaluations of simulation technology and understand the gaps and inconsistencies in methods.

Simulation Modality

The most prevalent simulation modality identified was VR, MR, AR or screen-based technologies. While this may in part reflect our search strategy, it also aligns with the increasing integration of virtual and mixed reality into medical education (Jiang et al., 2022). The second most common modality was part-task trainers, with very few cadaver or live tissue models and only one manikin-based simulator. This distribution suggests that much of the evaluation activity has centered on technologies for a specific technical skill. Given the growing use of immersive and screen-based simulation technologies, developing frameworks for subject matter evaluation will be increasingly important.

Specialty

Our findings indicate the majority of included studies are conducted on simulation technologies related to surgery. This emphasis likely reflects the challenges surgical trainees face in obtaining hands-on operative experience, which has heightened the importance of procedural simulation (Shahrezaei et al., 2024). The dominance of surgery in this literature underscores the need for a guiding framework to evaluate new technologies. While this focus can also be explained by the inherently procedural nature of surgical training, other procedure-intensive fields such as Emergency Medicine, Ob/Gyn, and Critical Care were less frequently represented and could benefit from developing evaluation approaches to ensure new technologies are high-quality, relevant, and more readily integrated into training. Specialties that are less procedure-intensive, such as Pediatrics, were also underrepresented, with most pediatric studies involving surgical contexts. This highlights an opportunity to expand simulation innovation into non-procedure intensive specialties, supported by subject matter expert review to guide the development and evaluation of new tools.

Subject Matter Experts

Most studies, more than 85%, used 20 or fewer subject matter experts. This is consistent with prior guidance on subject matter expert selection, which emphasizes that for technologies not undergoing formal validation, it is more important to include a representative group of experts than to achieve a larger sample size (Calhoun, 2024). For highly specialized or niche procedures, a smaller but appropriately focused group of SMEs is sufficient, whereas broader, widely applicable technologies warrant input from a larger and more diverse set of experts.

Question Format

To collect feedback, rating scale style questions were overwhelmingly used, with some studies implementing a combination of rating scale and open-ended. Although rating scales provide a structured method for comparing feedback between participants, free response questions allow for deeper insights which may have not been elicited by structured questions. Free response questions also provide an opportunity for SMEs to comment on ways to improve the model to be more clinically accurate. Incorporating both approaches in future evaluations could balance the ease of comparison with the unique perspectives from qualitative responses, enhancing the overall usefulness of SME feedback.

Question Objective

In addition to examining modalities and formats, the studies varied in the objectives their questions addressed, with many focusing on aspects such as realism, educational value, and usability. Questions focused on assessing the realism of the simulation technology most frequently, outnumbering those on educational value and usability. This emphasis may reflect a common belief that establishing a realistic model is the necessary first step before considering educational or usability outcomes. It may also stem from the assumption that realism inherently translates into educational value. However, this is not always true. For example, research has shown that high-fidelity virtual reality simulations, though highly realistic, may overwhelm novice learners with excessive cognitive load (Burkhardt et al., 2025). This underscores the need to look beyond realism and evaluate whether a model meaningfully supports learning.

In contrast, usability was rarely the focus of questions, despite being critical for determining whether a technology can be adopted in a curriculum. One possible explanation is that evaluations of new technologies often prioritize realism and educational value, leaving considerations such as cost, reusability, or ease of setup for later. Another possibility is that developers address these issues earlier in the design process but do not report them when publishing feedback from subject matter experts. Regardless of the reason, overlooking usability in published assessments limits the information available to stakeholders. Even the most realistic or educationally promising technology has little impact if it cannot be implemented practically and sustainably within training programs.

During the process of grouping questions thematically, the authors observed that certain items were difficult to assign to a single group because they lacked contextual detail, combined multiple constructs within a single question, or were ambiguously worded. Although this was not assessed systematically, it is an important consideration, as unclear or compound questions may also present challenges for those responding. This ambiguity in what is being asked can not only make it difficult for experts to determine the construct being evaluated (e.g., visual versus tactile realism) but also reduce the reliability of the responses (Hill et al., 2022). This consideration is key for designing expert questionnaires that yield clear, interpretable, and meaningful data for evaluating new technologies.

Limitations

Our scoping review has some limitations. To make our review more feasible, the review was limited to peer-reviewed publications indexed in PubMed. As a result, studies evaluation simulation technology with SMEs published outside of PubMed-indexed journals may have been excluded. The categorization of questions by objective was subjective, based on the authors interpretation of the question. The authors sought to align our categorization with the definitions provided in the Simulation Dictionary; however, these results may be subject to potential bias (Lioce et al., 2024). In addition, the scoping review methodology does not evaluate the included studies for bias or other quality assessment.

Future Directions

One of our objectives was to create a resource for those involved in simulation operations to use when conducting their own subject matter expert review. Currently, our findings are available in Supplemental Table 1. In the future, we are planning to create a public dashboard with the extracted data to serve as a resource for researchers and simulations operations specialists to guide the design of feedback questions. We also plan to use our findings from this scoping review to inform a more focused and systematic review to critically evaluate the quality of methods and results in the included studies. Because prior evidence shows that engaging subject matter experts and selecting modalities that align with learning objectives enhance the effectiveness of simulation-based education, our work aims to support the development of more rigorous and consistent approaches (Palaganas et al., 2025). Ultimately, these efforts can help lay the groundwork for consensus guidelines or a framework to guide the evaluation of new simulation technologies.

Supplemental Material 1

The detailed methods are available in the online supplemental material for this article at https://docs.google.com/document/d/1sc4yjDpf5o4aD_v7e3kkpx2Ha8wJCjjS8yjNyMrUvN8/edit?usp=sharing

Supplemental Table 1

The included studies are available in the online supplementary table for this article at https://docs.google.com/spreadsheets/d/1_n1xex98KwBeemINK0e-LKCmvxWOpm-x1oK3xB6pAbM/edit?usp=sharing

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Innovation on a Budget: Customizing a Free App for Program Inventory

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Brief Description

The simulation center operations depend on the efficiency of maintaining a robust inventory. An inventory management system is helpful in tracking the available resources at regular intervals. The Glide app provides a low-cost solution for simulation centers. Glide is an AI generator app and does not require any knowledge of computer coding. It helps create a customizable inventory, where data can be easily uploaded and accessed by multiple users. This article describes in depth how to set up an inventory management system using this app.

Introduction

Simulation Centers are designed based on the institution's needs assessment for the learners (Kumar et al., 2024). The design of a simulation lab varies based on available area, with storage capacity serving as an important considering during the planning phase (Baily, 2019; Baily, 2020). A standard to consider for storage is 10% to 25% of net assignable square feet (McCarthy et al., 2022). The storage space should accommodate all the equipment required for the different educational experiences. In order to operate efficiently, simulation centers would benefit from maintaining an inventory of all equipment. This includes assets such as high fidelity manikins, ultrasound machines, task trainers, computers, consumables such as disposable medical equipment, and non-consumables such as materials for moulage (Gore, 2024). However, maintaining an accurate inventory of all available equipment can be difficult (Kumar et al., 2024).

Inventory management systems have been offered by the industry to streamline efficiency in simulation centers (Nagle et al., 2018). They are considered an important part of efforts to manage a simulation center's inventory. Primarily, two types of systems are available, the push and pull systems. The push inventory system is frequently utilized for forecasting the demands of the supplies. This approach involves reviewing trends in previously used quantities and purchasing future supplies based on projected demand. For instance, for a simulation activity which requires intravenous (IV) lines, the quantity purchased would be based on what the simulation center forecasts the activity will need. In contrast, the pull inventory system focuses on the real-time demands of the supplies. This involves stocking items based on requests for scheduled simulation activity. For instance, for a simulation activity which requests a total of 25 IVs, specifically ten 18 gauge, ten 21 gauge IV, and five 22 gauge IV. This would be ordered after receiving the request from the simulation activity's course director (Glesmann, 2024). The initial set up and maintenance cost of industry management systems vary in cost from $500 to $10,000 depending on the package needed for the simulation center (Herrington, 2020). Free trial versions of the software have limitations on the available functions. Detailed and diverse reviews are often difficult to locate, leaving vendor-provided information as the primary source, which may lack objectivity. These limitations lead simulation centers to seek customizable options for their inventory needs.

Innovative, sustainable, and affordable inventory management is essential for meeting the demands of the operations of a simulation center. This article will elaborate on how to maintain an inventory for the simulation centers equipment and supplies. In addition, we will discuss the challenges, development and implementation of an inventory management system at our simulation center. This is a novel method using cost-effective resources that can be customized for any simulation center.

Simulation Center Details

Brody School of Medicine (BSOM) Interprofessional Clinical Simulation Program is a 10,000 square foot space that offers simulation-based medical educational experiences to a wide variety of learners. It has 21 rooms, including an on-site supply room, a 720 square foot storage room in the school basement, a mobile unit, and an off-site Osprey trainer. The program serves medical, physician assistant, dental, and nursing students, graduate medical residents and fellows, local community colleges, the military, critical care flight teams, and various other groups. In fiscal year 2021, the program had 6,021 learner contact hours. In fiscal year 2025, we had over 18,000 learner contact hours. This rapid expansion had led to the need of additional equipment. During this same period, the simulation program received over $1.5 million USD in funding for equipment. Additionally, the Center's budget increased over $120,000 annually to meet demand. This rapid expansion prompted the BSOM Simulation Center to seek novel ways to track and inventory the equipment and supply needs for its expanding program.

Challenges

The initial solution was an investment in an inventory management product. In 2018, the simulation center purchased an industry product to track inventory which cost of $8,225.10. This purchase included software, a laptop, barcode scanners, labeling system, and 2-hour training from the vendor. During the selection process, the online backup system was a key priority for ensuring data protection. However, implementation revealed significant challenges. The inventory input process proved not only time-consuming but also inflexible to our specific requirements, requiring months of dedicated effort to transfer data into the system. After several months of entering data, the system crashed. Despite having prioritized the online backup feature, the vendor was unable to access it, resulting in complete data loss.

After the vendor-management system failed, we next sought to use the same inventory system used by our university for purchasing. However, this system proved to be slow in processing each step, making data entry cumbersome. Additionally, there were predetermined data fields which did not align with our center's needs. There was significant difficulty searching for items, as it involved multiple sign-ins to access, timed out after several minutes, and required very specific search terminology or item number. Our team quickly pivoted from this system, recognizing the enormous time cost to personnel.

The next approach to finding an inventory management system was to create a personalized system for the center. The information technology department at BSOM was contacted to help with this task but was unable to help due to time constraints. Another strategy discussed was to input all inventory into a Microsoft Excel (Version 2502) document. The simulation technician began entering all data in Microsoft Excel, continuously refining the spreadsheet to include serial numbers, room and shelf locations, and quantities. This process was tedious and unpopular with faculty and staff. The team found using Excel sheet had significant limitations. The file was housed on the shared department drive, limiting access to only one team member at a time. It was also difficult to search for items and identify duplicate entries due to the multiple tabs, lengthy spreadsheets, and variation in naming conventions. Additionally, the format was not compatible with use on a mobile device. There was also a risk of accidental errors or deletions since all team members had editing access.

One of our simulation technicians attempted to create an app using Python and Javascript. However, this process required significant time and knowledge about using these applications.

Finding and maintaining an inventory system was difficult for our simulation center as we have multiple storage areas. The simulation center utilizes a supply room for frequently used equipment, a basement storage area for less frequently used equipment, and an offsite storage area for the Osprey trainer. Because staff cannot monitor all areas simultaneously, equipment could get moved without their knowledge, making items difficult to locate when needed. In addition, our center serves a variety of specialties, each with unique equipment needs. Given these constraints and the lessons learned from previous attempts, we recognized the need to develop a customized solution that could adapt to our center's specific requirements.

Development of the Inventory Management System

Extensive research regarding available products identified the Glide app (No Code App Builder, n.d.). The Glide app is an artificial intelligence program that helps users to make an application without prior knowledge of coding. On reviewing its features, we were able to accomplish our goal using the free basic version. However, there is an option to access advance features with an annual charge.

To start, an account needs to be created on the Glide App website (www.glideapps.com) (Figure 1). Once an account has been established, the next step is to identify what data to upload and determine how to label equipment and supplies. The terminology used for search features must align with the language users naturally employ. For instance, to locate the high-fidelity pediatric manikin, Sim Junio, users could search using descriptive terms such as “pediatric”, “Hi fi”, or “manikin.” An advantage of the app is its ability to customize and update equipment labels in real time.

This data is then entered into a Microsoft Excel (version 2502) sheet or google sheet, which can be directly imported into the program. This is then converted into the default format for the app (Figure 2). Once created, all data can be edited by clicking on the individual items (Figure 3). The layout of the app can be personalized by selecting the available options for format under the “layout” section (Figure 4). Under the “General” tab, the options for “Label” can be customized to fit the individual items. The “Items Data” section allows users to select the display of the information. The available options for the individual items are, “Title”, for the item label, “Description”, for the item location, and “Meta”, for the item category (Figure 5). All data for these can be interchanged depending on the preference of the display of the information.

The “Show Search Bar” option can be customized to the user’s preference. Making this easily accessible is crucial for ensuring a user-friendly experience. Utilizing the “Settings” tab, the appearance and user access can be edited (Figure 6). Following these instructions will help create a customizable inventory for the simulation center (Figure 7). The learning curve to operate the program is minimal, making it easy for individuals to start up quickly. The website also has videos to help with creating an app.

The time required to create the app varies by individual. The simulation technician at BSOM has a degree in an Information technology related field, an emergency medical technician, and ten years of experience in the field of simulation. The initial development of the Microsoft excel sheet for the Glide App did take considerable time. Once uploaded into the program, it took about 4 hours to create the app and test it. The overall time in creating this app was significantly less when compared to other inventory systems.

Implementation of the Inventory Management System

Once the app was developed, the senior simulation staff were given access to edit the data and test the app. This group consisted of individuals with and without clinical experience, technical experts, and administrative experts. Everyone was familiar with the planning process and commonly used equipment. They were able to successfully search for equipment using different terms (item brand name, procedural skill, or discipline) on both their laptops and mobile devices. For example, searching for a urethral catheterization model can be found by entering the words “Foley”, “urethral”, or catheterization”. These search results also populate related items such as urethral catheter kit supplies on shelf C5 of the supply room and male, female and pediatric models in room 1L04 and shelf D2 of the supply room. The app also includes a picture of the item, to assist someone who isn’t familiar with its appearance (Figure 8). Additionally, the app searches as the word is being typed, which is helpful if unsure of the entire procedural skill name.

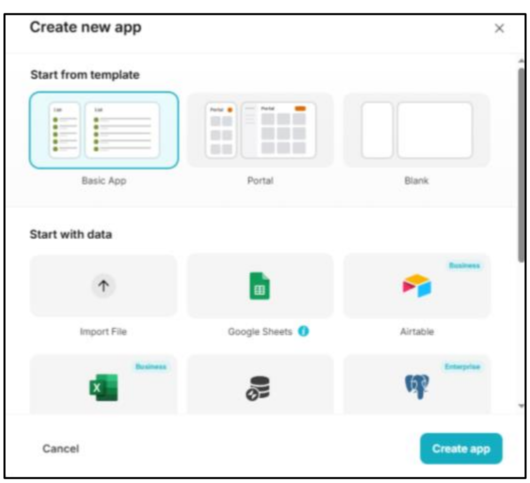
When planning sessions with faculty, it assists in identifying how many of the requested skill trainers are currently available. Any staff member can easily look up the number within the mobile phone app without having to search an Excel sheet or find a simulation technician who may or may not know the answer immediately. Another advantage of using the Glide interface is the user can quickly identify duplicate entries for the same product, since it will appear twice on the screen. When this occurs, the simulation technician can easily update the raw data spreadsheet and re-upload the correct data into the app.

Considerations

Each institution has their own rules regarding development and implementation of an AI tool for educational and operational benefits. Our institute is supportive of using AI-based apps for operations programs. We recommend each program review the guidelines and best practice standards for utilizing AI generated app at your local institute.

Figure 1

Glide App – creating the app



Note. Opening page of the app with options for creation.

Figure 2

Default format with imported data

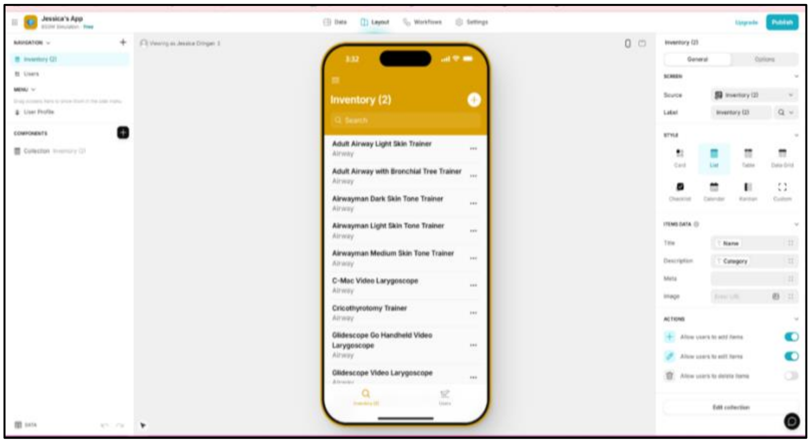
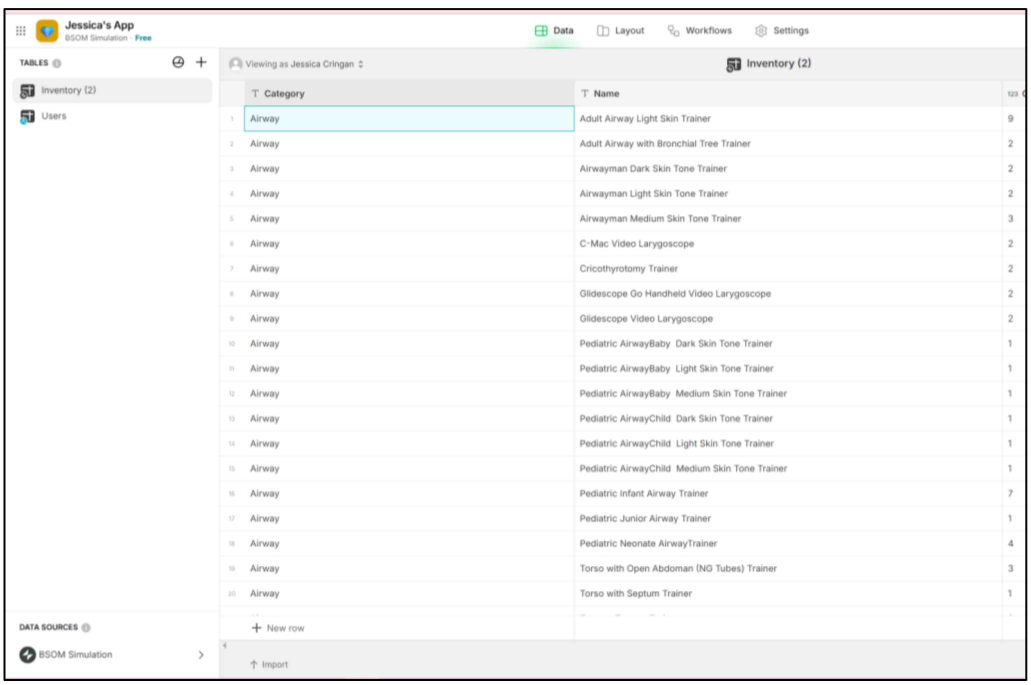


Figure 3

Editing data



Note. Data entry portion of the app. This information was imported from an Excel worksheet.

Figure 4

Layout customization

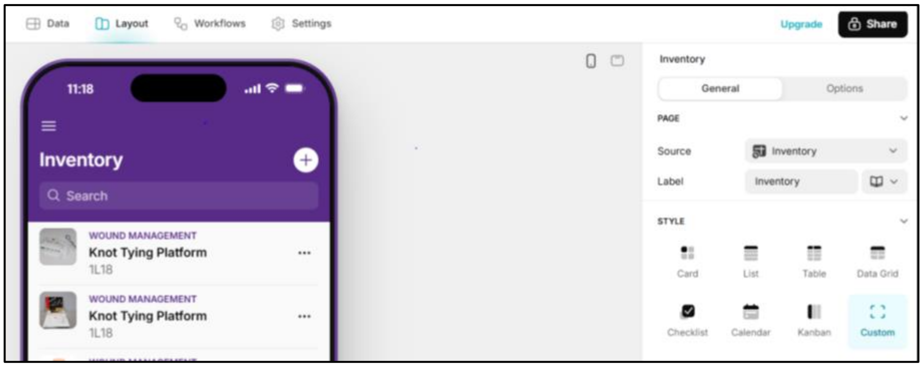
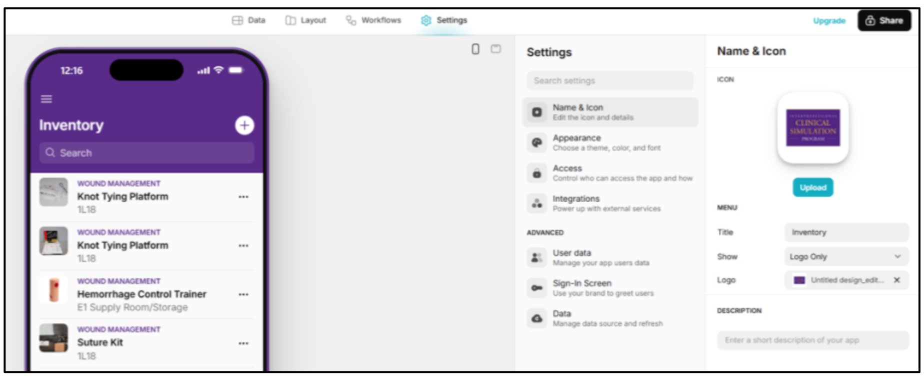


Figure 5

Settings options



Note. Options available within the app.

Figure 7

Final product

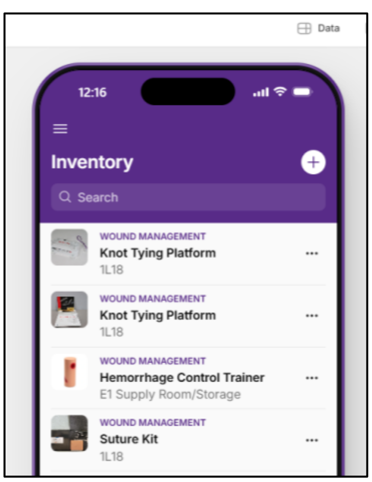
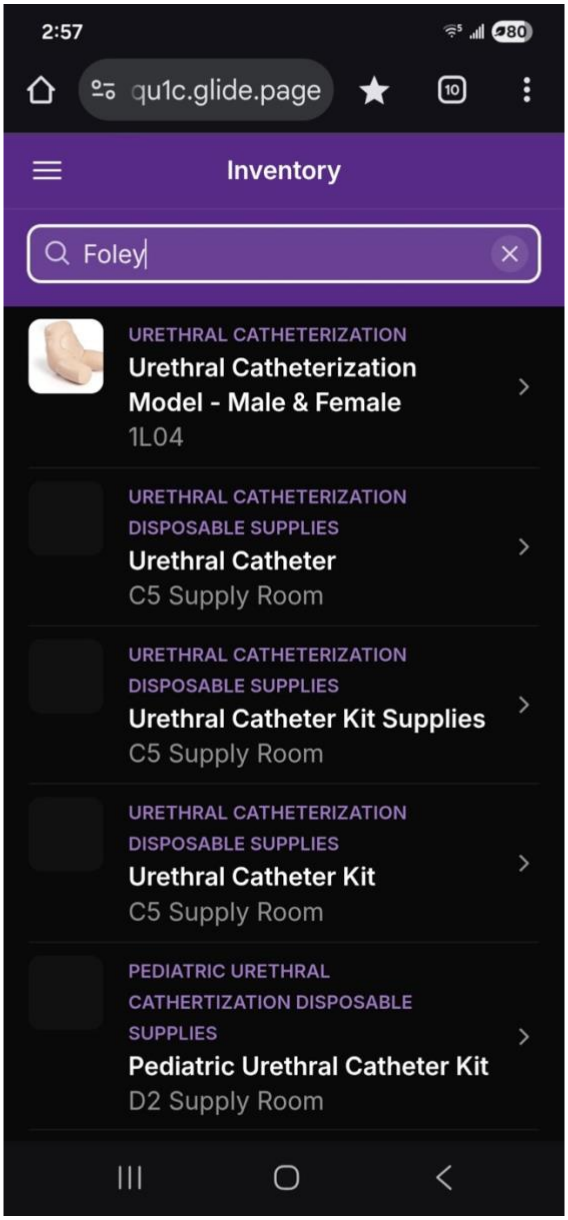


Figure 8

Locating inventory



Note. Example of inventory search, used to locate an item in the simulation center.

Conclusion

Glide app is an effective solution for inventory management in a simulation center. It is a user-friendly app which can be created by individuals without any prior knowledge of coding. Data can be customized and easily accessed by multiple users.

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Lower Extremity Edema Moulage Application for High-Fidelity Medical Simulation

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Conflict of Interest Statement
The authors of this manuscript declare no conflicts of interest.

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Brief Description
Health professions education programs are increasingly incorporating manikin-based simulation (MBS) into their curriculum, and access to effective moulage is critical to providing realistic high-fidelity scenarios (Huang et al., 2012). Simulation effectiveness rests partly on maintaining a fiction contract with the learner (Issenberg et al., 2005). Poorly constructed moulage can break down the fiction contract, detract from the learning experience, and inadvertently demonstrate incorrect physical exam findings to clinically inexperienced learners (INACSL Standards Committee, 2016; Rudolph et al., 2014). Our curriculum contains several MBS cases that feature the exam finding of lower extremity edema. We experienced significant difficulty finding realistic lower extremity edema moulage applications. We collaborated with our institution's undergraduate engineering capstone program to design and manufacture a low-cost, highly realistic moulage application mimicking lower extremity pitting edema. Student and faculty survey findings were overwhelmingly positive. Survey participants highlighted the improved realism of the rebound and pitting effect, more accurate tactile response, and greater usability compared to the commercially available foam-based device previously used.

Introduction
Lower extremity edema is a critical physical exam finding associated with common conditions such as deep vein thrombosis, heart failure, and kidney disease. The ability to recognize and grade edema is an essential skill for healthcare providers, as it assists in timely diagnosis and the selection of appropriate treatments. As health professions students are increasingly exposed to patient care experiences through standardized patients (SP) and manikin-based simulation (MBS) cases during preclinical training, it is imperative that these experiences mimic real-life patient presentations as closely as possible to ensure adequate preparation for actual patient encounters. Poorly constructed moulage can lead to a breakdown of the fiction contract, confusion among experienced learners who expect specific physical exam findings, and demonstration of incorrect findings to inexperienced learners.

An online search for wearable edema moulage accessories revealed models with significant limitations in realism. These limitations include short length (ankle edema only), poor facsimiles of skin appearance and texture, and use of memory foam, creating an unusual tubular appearance to the extremity. The tactile experience of the models we tested did not simulate that of human skin, and the pitting of the material rebounded too quickly in a non-physiologic manner. Additionally, available skin tone options were limited in wearable commercially available products. Driven by these limitations, we endeavored to develop a device that looks, feels, and acts like edematous human tissue to provide realistic exam findings for both inexperienced and advanced clinical learners.

Our objective was to create a model that was durable, easily reproducible without a need for specialized equipment, and cost-effective. The resulting device is a layered application utilizing tattoo skin, silicone, nanotape, and maltose gel. The tattoo skin serves as the visible outer layer, selected to match the desired skin tone. The nanotape forms a sealed, leak-proof pocket that contains the maltose gel. A thin silicone sheet backing prevents adhesion to the leg when applied. All layers are stitched together, and elastic bandages are affixed to the sides. These are secured around the leg with hook-and-loop fasteners, allowing the device to be firmly attached to the limb with even pressure and no distortion. Our device fills a critical gap in medical education by realistically simulating pitting edema with a range of skin pigmentations.

Materials and Cost

This device can be created without need for specialized equipment and utilizes easily obtainable materials sourced online. The final material cost is approximately 83 USD per device (Table 1). The estimated time for one person to create one device is 4 hours, assuming all materials are readily available (Table 1).

Table 1

Cost of materials per device

Component	Material used	Quantity per device	Unit cost (USD)	Total cost per device (USD)
Skin layer	11” x 7” tattoo skin	1 sheet	$34.99	$34.99
Gel layer	Stress ball maltose gel	4 balls	$2.83	$11.33
Gel enclosure	0.04” x 2” nanotape	3 rolls	$3.59	$10.77
Interface layer	15.7” x 11.8” silicone sheet	1 sheet	$2.66	$2.66
Leg straps	2” elastic bandage wrap	500” strip	$4.50 per 65” roll	$8.99
Strap securing material	1” x 4” hook-and-loop tape with adhesive back	5 sets	$4.99 per 16 sets	$4.99
Stitching	Sewing needle and thread	1 spool	$9.49	$9.49
Estimated total cost (per device)				**$83.22**

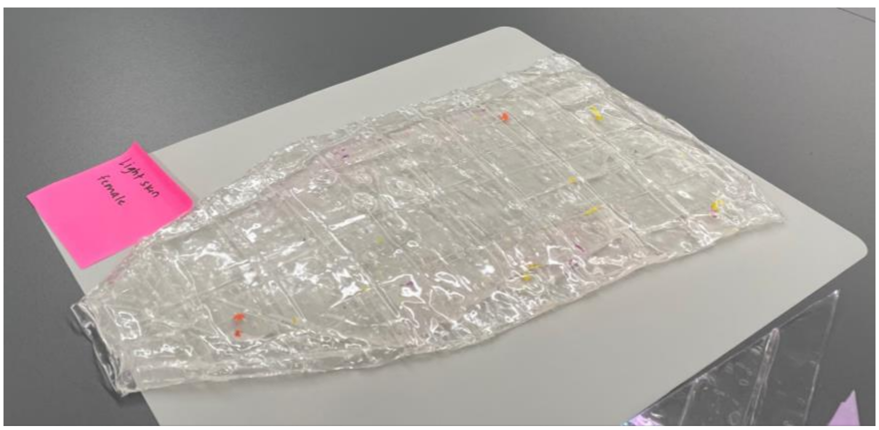
Note. Prices are reflective of USD as of April 2025. Items are typically bought in bulk and individual units are used to create the model.

Device design and construction

Five devices were created, three to fit Laerdal SimMan 3G/3G+ (Laerdal SimMan 3G, Laerdal Medical, Wappingers Falls, NY) and two to fit Gaumard Victoria (S2200 birthing simulator, Gaumard Scientific, Miami, FL). The outer “skin” layer is achieved using a 3mm thickness tattoo skin sheet in the desired skin tone. The 11” x 17” sheet is trimmed on one end to create a tapering effect that matches the narrowing contour of a human leg from the calf to the ankle. The second layer is an enclosure made from double-sided nanotape. This enclosure contains the maltose gel which forms the innermost layer of the device (Figure 1). The amount of maltose hydrogel used during production determines the simulated level of edema. The current model is designed to simulate Grade 2+ to 3+ edema, with an objective indentation depth of between 3 to 6 mm and a rebound time of between 15 and 30 s. A thin silicone sheet is used as the bottom layer, interfacing with the leg (Figure 2). Ten securing straps, five on each side, are sewn in place along the left and right edges of the device (Figure 3). These straps consist of 2” wide elastic bandage wrap cut-to-size, with opposing sections of hook-and-loop fasteners affixed to them. The fasteners allow the device to be securely attached around the manikin's leg with even pressure, avoiding bulging or raised edges. See Figures 4 and 5 for the finished appearance. See Supplemental Material for detailed instructions and material purchasing information.

Figure 1

Nanotape and gel enclosure



Note. Nanotape and gel are laying on a silicone mat to prevent adhesion to table.

(continued on next page)

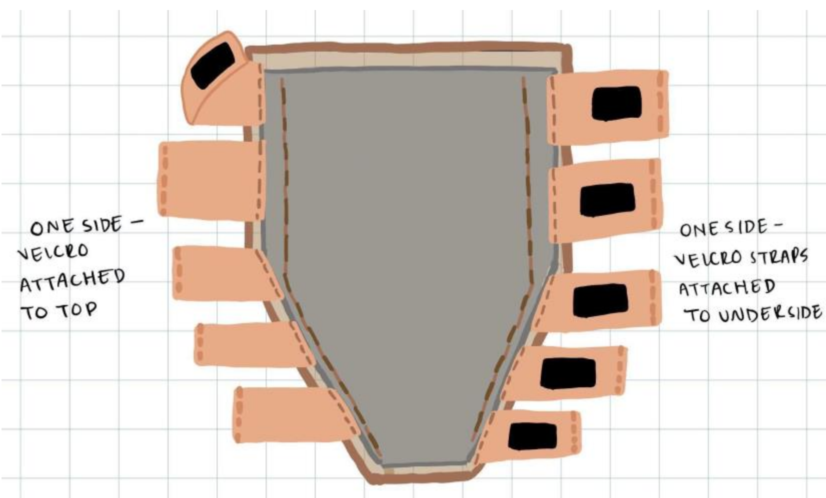
Figure 2

Sealed, gel-filled nanotape enclosure positioned on thin silicone sheet backing with tattoo skin folded back

Note. Matte side of tattoo skin outward facing.

Figure 3

Straps with hook-and-loop attachments



Note. Illustration created by author.

Figure 4

Final appearance of lower extremity edema moulage application

Figure 5

Devices applied to right leg of manikin

Note. Device applied to right lower extremity with demonstration of pitting edema.

Data Collection and Analysis

Objective testing

To establish objective performance metrics, we first determined pitting edema specifications based on established clinical guidelines (Calzon et al., 2023). We defined the target simulation parameters as follows: Grade 2+ edema was characterized by a 3–4 mm indentation with an approximate rebound time of 5–15 seconds. Grade 3+ edema was characterized by a 5–6 mm indentation with an approximate rebound time of 15–60 seconds.

We conducted 10 indentation trials across different areas of the lower leg for each device. Each indentation was pressed fully, and the resulting depth was recorded. Upon release, the rebound time was measured from the moment of release to full surface recovery. We also tested the commercially available foam-based leggings currently in use at our facility. All five of our manufactured devices performed within the target metrics, successfully mimicking Grade 3+ pitting edema, whereas the foam-based device displayed non-physiologic, near instantaneous rebound and demonstrated excessive depth of indentation. The results are summarized in Table 2.

Table 2

Pitting edema indentation trial results of five individual devices

Device	Average indentation depth (mm)	Average rebound time (s)
Male 1	6.1	15.73
Male 2	5.9	20.19
Male 3	6.0	26.34
Female 1	6.0	22.96
Female 2	5.9	21.58
Foam-based model	20.5	1.35

Durability testing

Durability was assessed through two standardized protocols: palpation testing and attachment/removal testing. For palpation testing, we performed 100 repeated palpation cycles on each device to simulate frequent use during clinical training. All devices maintained structural integrity and continued to function as intended throughout the testing. For attachment/removal testing, each device was attached and removed from a manikin leg 30 times. We monitored the fit, material wear, and fastening strength throughout the process. While there was some minor loosening over time, the overall performance remained within acceptable limits given the expected frequency of use in the simulation center. The device maintained structural integrity and continued to function as intended over a period of six months when stored flat at room temperature (68°). They have not yet been tested beyond that time.

End-user survey

To assess realism and usability, we surveyed 15 participants, including 12 medical students, 2 physician faculty members, and 1 non-physician faculty member. The survey collected feedback on the visual realism, tactile feel, ease of use, and immersion provided by the new device compared to the current foam-based device. A 5-point Likert scale (1 = Not Effective, 2 = Somewhat Effective, 3 = Effective, 4 = Very Effective, 5 = Highly Effective) was used to assess feedback on both devices (Table 3).

Table 3

End-user survey results

	New device (mean score)	Commercial foam model (mean score)
Visual realism	4.3	2.3
Tactile feel	4.4	3.2
Ease of use	4.7	2.8
Immersion	4.5	2.7

Note. Mean score rated on a 5-point Likert scale (1 = Not effective, 5 = highly effective).

Feedback was overwhelmingly positive. Participants highlighted the improved realism of the rebound and pitting effect, a more accurate tactile response, and greater usability compared to the commercial foam model. Many noted that the device better represented actual pitting edema and offered a more immersive training experience. The simplicity of the attachment and improved durability were also favorably mentioned, further validating the design in meeting user needs. Representative comments included:

- "Rebound time, pitting, and texture feels really good and much better than the foam one."
- "Bulkiness is pretty accurate and the increase in realism is really good."
- "Original just compresses, but the new device has an actual pit and rebounds too."
- "I like how it leaves a pit and rebounds pretty similar to actual pitting edema."
- "It is much easier to use than the current device."
- "This will be really useful for future simulations considering the improvements made."

Discussion

This lower extremity edema moulage application is a simply applied manikin leg overlay designed to maximize fidelity. It provides realistic pitting edema, both visual and tactile, for healthcare learners in simulated patient care settings. This model has several advantages over currently commercially available edema applications. It covers the entire lower leg and tapers at the ankle, which facilitates the fitting a sock over the foot and ankle, thereby concealing the lower seam. Furthermore, it allows for edema measurements along the entire lower leg. The maltose core provides a realistic tactile sensation when pressure is applied and rebounds slowly, accurately mimicking the characteristics of real pitting edema. The design is easily modifiable to fit most simulators, is available in various skin tones, and can be adapted to increase or decrease the level of edema demonstrated. Additionally, it is durable, holding up well to repeated application and removal, which makes the initial time investment worthwhile. While we did not test this design on human actors, it has the potential to be applied to the leg of an SP to demonstrate pitting edema during SP encounters.

This model is highly cost effective, with an estimated material cost of 83 USD per device (166 USD per pair). Our research revealed that commercially available wearable extremity edema applications cost anywhere between 410 and 849 USD, with many of these models not covering the entire lower extremity. For comparison, the commercially available foam model used in our comparison testing cost 650 USD per pair.

Limitations of device

A primary limitation of this device is the time required for manufacturing (estimated to be 4 h). However, the durability testing demonstrated the device can be reused many times, mitigating the impact of the initial time investment over the product's lifespan.

The fabric elastic straps are susceptible to stretching or tearing with multiple uses. Since they are not stitched into the nanotape layer, they can be replaced independently without compromising the main structure of the device. Alternatively, a continuous loop elastic system could be implemented instead of the hook-and-loop system, allowing users to pull the device over the foot onto the leg where it would be held in place by tension.

These devices need to be stored lying flat, as stacking them upright can cause the maltose gel to migrate to the dependent end, leading to an uneven appearance of edema. This can be rectified by laying the device flat and gently massaging the gel enclosure to maneuver the gel to a uniform thickness. Stacking the devices without a protective layer between them can lead to damage to the elastic straps from the exposed hook-and-loop fasteners, as well as adherence of the skin layers to each other. We recommend a layer of wax paper be placed between the devices if they are stacked. These devices should be protected from sunlight.

Finally, these devices can only display one grade of pitting edema per unit. To simulate more or less severe grades, additional devices would need to be manufactured with differing volumes of maltose gel in the enclosure.

Conclusion

The lower extremity edema moulage application successfully met the goals of tactile and visual realism and demonstrated excellent durability and usability. Through careful material selection, iterative prototyping, and initial testing, we created a functional and cost-effective training tool that accurately simulates Grade 2+ to 3+ pitting edema. Our device demonstrates appropriate rebound characteristics, passed durability testing, and received overwhelmingly positive feedback from medical students and faculty, highlighting significant improvements over the commercially available foam-based device. The final design integrates multiple strategically integrated components – including a hydrogel core, nanotape sealing, silicone interface, tattoo skin outer layer, and elastic securing straps – to deliver a cohesive, realistic simulation experience. Our solution balances realism and functionality while staying within budget and remaining easy to independently manufacture and maintain.

Supplemental Digital Content Legend

Supplemental Digital Content 1: Online document, "Lower Extremity Edema Moulage Application: Fabrication Protocol" is included with step-by-step instructions and images to assist in replication of this item.
https://docs.google.com/document/d/1hB4rcxi5TOZtDRFOZjDhqj78VeFVRIgE/edit?usp=drive_link&ouid=117198032973870209376&rtpof=true&sd=true

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Wired for Performance: Using Wearable Physiological Sensors to Decode Cognitive Load in Healthcare Simulation

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Conflict of Interest Statement
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Brief Description

This article explores the feasibility of integrating wearable physiological sensors into high-fidelity healthcare simulation to monitor cognitive load and fatigue. Using electrocardiogram (ECG) and galvanic skin response (GSR) sensors, we captured real-time physiological data from nursing students engaged in both virtual and manikin-based simulation scenarios. Signal processing confirmed data quality, and preliminary findings demonstrated that wearable physiological sensors can detect fluctuations in sympathetic nervous system activity related to task complexity and simulation demands. The results affirm the practicality of using wearable sensors in simulation operations and support their potential to enhance learner assessment, optimize scenario design, and advance research on stress and performance in healthcare education. This pilot project underscores wearable physiological sensors as a feasible and valuable tool for decoding human responses in complex training environments.

Introduction

Wearable physiological sensors, also known as biosensors, sense, detect, and transmit real-time physiological responses such as heart rate, blood pressure, body temperature, movement, and cognitive load. This data can be used to diagnose, monitor, and manage health conditions (Zhang et al., 2025; Wang, 2024). Early research of wearable physiological sensors has predominantly focused on the clinical uses for patient monitoring, disease detection, and chronic disease management. Advances in wearable physiological sensors, such as smart contact lenses and sensor-embedded fabrics, will expand their capabilities, supporting new applications in educational settings and workforce monitoring (Risling, 2017).

Cognitive load, which is the mental effort required to process information, significantly affects a learner's ability to acquire and apply knowledge in complex clinical scenarios (van Merriënboer & Sweller, 2005). The relationship between both subjective self-reported and objective measures of cognitive load, as well as the effects on clinical performance, remains inadequately explored in nursing education. Simulation-based learning is essential in nursing education, providing a safe environment for student development of clinical and decision-making skills without compromising patient safety (Lioce et al., 2020). However, during simulation-based learning experiences, the cognitive load for nurses can be overwhelming due to the complexity of the scenario, assigned tasks, and necessary clinical judgment (Rogers & Franklin, 2021). In the practice setting, mentally fatigued healthcare professionals experience cognitive overload, resulting in reduced attention, impaired decision-making, slower information processing, and increased distractibility (Karim et al., 2024). Furthermore, repeated and continuous exposure to mental fatigue increases the risk of medical errors and reduces overall quality of care (Dall'Ora et al., 2020; LeGal et al., 2019).

Cognitive load can be measured by assuming that changes in human cognitive functioning cause corresponding changes in human physiology, including heart rate and skin temperature (Larmuseau et al., 2019). Heart rate, as measured via an electrocardiogram (ECG or EKG), can provide information about the overall function of the autonomic nervous system, specifically the effect of the sympathetic and parasympathetic nervous system on heart rate (Tiwari, et al., 2021). As cognitive demand increases in individuals, heart rate increases (Grassman et al., 2017).

The Galvanic Skin Response (GSR) measures skin conductance using sensor electrodes placed on the skin. Changes in conductance reflect variations in skin moisture, which are influenced by fluctuations in sympathetic nervous system activity (Larmuseau, et al., 2019). As an individual experiences more or less stress, the GSR increases or decreases, respectively (Hoogerheide, et al., 2018; Smets et al., 2018). Additionally, previous research indicates that increased cognitive load is associated with heightened GSR responses (Nourbakhs et al., 2012; Yousoof & Sapiyan, 2013).

Recent research has explored the physiological signs of distress in healthcare professionals, offering insights into the causes of burnout and other issues affecting well-being (Barac et al., 2024). Despite mitigation efforts by healthcare organizations, over half of U.S. nurses reported burnout symptoms in a 2023 survey (Berlin et al., 2023). A significant opportunity exists to explore how wearable physiological sensor technology can specifically benefit healthcare professional students. By deepening the understanding of student well-being throughout their educational programs, assessments can be enhanced, clinical performance improved, and awareness of physiological and psychological stress responses increased. Furthermore, by quantifying and analyzing stress levels among healthcare students during their training, effective strategies to alleviate stress can be developed and implemented. This proactive approach not only protects students' well-being but also prepares them to provide safe, high-quality care in the healthcare field.

Methods

This pilot study explores the implementation of wearable physiological sensors to assess and enhance participant performance in simulation-based training environments, with a primary focus on fatigue and cognitive load. By monitoring real-time physiological indicators such as heart rate variability and electrodermal activity, we evaluated the feasibility and value of wearable physiological sensors in understanding human responses during complex, high-stakes simulation scenarios.

Sample and Setting

The study participants (n=6) were full-time senior level nursing students at a Midwestern undergraduate baccalaureate program in the United States. The setting was a Society for Simulation in Healthcare (SSH) accredited simulation center that runs high-fidelity, simulation-based learning. The center is staffed by experienced Certified Healthcare Simulation Educators (CHSE) and follows the Healthcare Simulation Standards of Best Practice®, ensuring realistic scenarios and a safe learning environment.

Data Collection

The participants were equipped with both GSR and ECG sensors during the simulation activities. The Shimmer3 GSR and Shimmer3 ECG units provided a configurable digital frontend, optimized for measuring physiological signals related to skin temperature and heart rate, respectively.

All six participants attended a pre-briefing, followed by time to connect the wearable physiological sensors before participating in the simulation-based learning scenario with standard debriefing utilizing the PEARLS Debriefing Framework. Two of the participants were completed an immersive virtual reality (VR) simulation learning scenario. In this scenario, learners assumed the role of a primary nurse caring for a 9-year-old client presenting to the emergency department (ED) with new-onset type 1 diabetes mellitus, requiring assessment, communication, and clinical decision-making. The remaining four participants completed a high-fidelity manikin-based complex scenario, which cared for a 64-year-old client in the ED suffering from cardiac arrest. Primary and secondary nurses are required to work within the interprofessional team completing quick assessments, interventions of high-quality CPR and emergency medication, and effective team communication.

Data Processing and Analysis

The raw sensing signals often contain noise and artifacts from movement, electrode displacement, and external electrical interference. The collected ECG and GSR signals were processed, which included filtering techniques such as low-pass and high-pass filters to eliminate irrelevant frequencies to remove noise and artifacts. Additionally, notch filters were used to eliminate power line interference at 50 Hz for each sensing signal region. The data analysis was performed using iMotions Lab, a modular software for capturing, processing, and analyzing physiological sensors with built-in R Notebooks.

The physiological responses of the participant during the VR simulation were also measured using the HRV measured using the Standard Deviation of NN Intervals (SDNN) and inter-beat interval (IBI) distributions. SDNN is a measure of HRV that calculates the average value of HRV in milliseconds, reflecting the time between heartbeats. IBI is a measure of heart rate signals, which is used to assess the health of the participant's autonomous nervous system during the simulation process.

For example, increases in heart rate (shorter inter-beat intervals) coupled with decreases in heart rate variability, particularly lower SDNN, indicate a shift toward sympathetic dominance and reduced vagal modulation as the autonomic nervous system mobilizes resources for demanding mental activity. In parallel, increases in skin conductance level and the frequency/amplitude of phasic responses reflect activation of eccrine sweat glands under purely sympathetic control, providing a direct index of arousal and attentional engagement. Taken together, the pattern of higher heart rate, lower HRV, and higher skin conductance during task periods is a signature of elevated cognitive load. When sustained, these sympathetic-based responses can be interpreted as accumulated cognitive fatigue, with the prolonged effort leading to delayed parasympathetic recovery and reduced variability during and after task blocks.

Results

The signal processing results show that the signal-to-noise ratio (SNR) of the collected sensing data was above 28.48 dB, indicating excellent quality of the signal, with less than 1% noise. The following preliminary results suggest that GSR and ECG measurements reflect the participants' fatigue levels and the patterns of their cognitive load during simulation.

Heart Rate and Skin Conductance during Simulation Scenarios

The ECG and GSR data from the two simulations is shown in Figure 1. For the high-fidelity manikin-based scenario, participants completed two tasks (airway and chest compressions) over 10 minutes (Figure 1A). For the immersive VR simulation, participants completed 14 tasks over 20 minutes (Figure 1B).

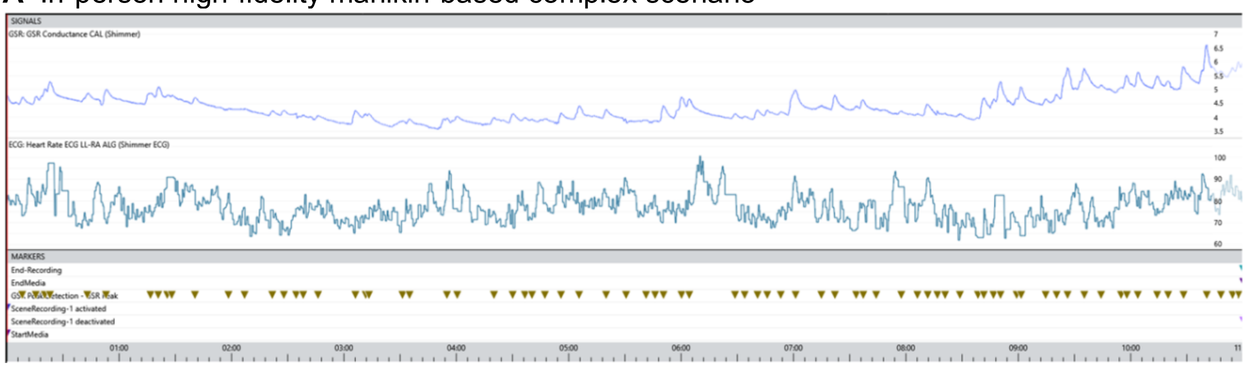
The GSR conductance fluctuates significantly over the course of the immersive VR scenario (Figure 1B), ranging approximately from 0.1 to 0.7 micro siemens (μS), representing the sympathetic nervous system activation associated with the participant's cognitive load during the simulation process. A particularly noticeable increase in variability is observed in the second half of the scenario, corresponding to elevated physiological fatigue of the participant. The ECG data demonstrates a similar variation in heart rate, indicating changes in the participant's physiological state, including arousal, fatigue, and relaxation. There are several periods of increased heart rate when changing tasks within the simulation, suggesting an increased cognitive load. GSR peaks frequently coincide with increases in heart rate because both are markers of sympathetic activation during cognitively demanding tasks, but their relationship is not one-to-one. Unlike GSR, which reflects purely sympathetic input, heart rate is jointly regulated by sympathetic and parasympathetic influences; as a result, heart rate may not consistently increase even when a GSR peak occurs.

Figure 1 also shows the recovery periods where both signals stabilize, reflecting a return to baseline arousal levels when the simulation was completed. As a result, both the ECG and GSR signals demonstrate prominent peaks and high variability in two phases: (1) at the start of the simulation associated with an increased cognitive load and (2) towards the end of the simulation associated with an increased fatigue level.

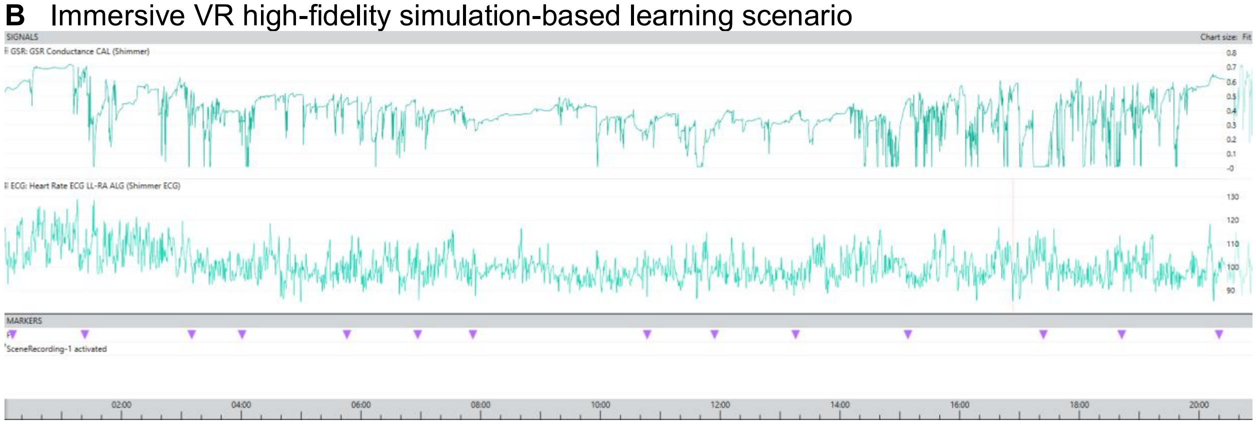
Figure 1

Collected GSR and ECG signals corresponding to simulation tasks

A In-person high-fidelity manikin-based complex scenario



B Immersive VR high-fidelity simulation-based learning scenario



Note. GSR and ECG signals during the (A) in-person high-fidelity manikin-based complex scenario with two tasks (airway and chest compression) and the (B) immersive VR high-fidelity scenario with fourteen VR-based simulation tasks, identified by purple markers on the graph.

Figure 2 also shows patterns of heart rate and skin conductance during both the simulation scenarios. Figure 2B shows the participant's heart rates are on a fast-pace and more intense during the immersive VR cardiac arrest activity, oscillating frequently between 60 and 90 beats per minute. This suggests a dynamic physiological process linked to the physical activities during the VR-based simulation. In the first part of the VR session, around the first 100 seconds, the heart appears more erratic as the participant started the simulation. High HRV often indicates adaptability and a healthy stress-response system when it correlates with mindfulness activities. A few sharp peaks and dips indicate several simulation tasks (e.g., during the 350-390s) affecting the heart rate. The graph's lowest values hover around 60 bpm, indicating the participant's resting heart rate after a high cognitive load period.

Figure 2B shows the GSR data during the immersive VR cardiac arrest simulation activity. The GSR values range from 3.6 μS to 6.6 μS, indicating significant changes in skin conductance, driven by the participant's physiological responses to the VR simulation tasks. In the initial phase (0–200s), a declining trend in GSR was observed, indicating a reduction in stress levels as the participant was going through the VR-simulation tasks. In the middle phase (200–400s), the GSR showed frequently moderate fluctuations with small peaks, suggesting short-term changes during the simulation tasks. In the final phase (400–600s), a steady increase in baseline GSR occurred with larger and more frequent peaks, indicative of heightened engagement of the participant due to increasing task demands. This suggests a sustained increase in sympathetic nervous system activation due to the participant's prolonged focus on the simulation tasks. Also in this phase, responses appeared longer and more sustained, reflecting a shift in the participant's emotional state. Peaks in the later phase were more frequent and larger in amplitude, indicating increased physiological response to the simulation tasks.

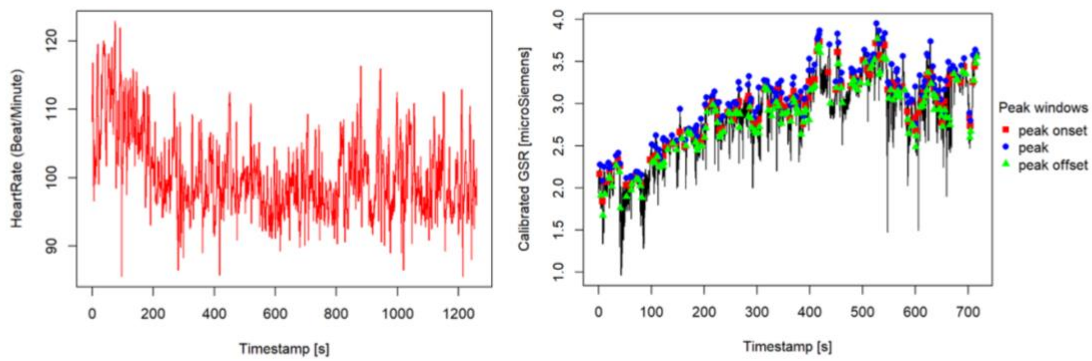
Figure 2B also demonstrates the relationship between heart rate and GSR. During periods of rising heart rate corresponded to increase in GSR peaks, suggesting synchronized physiological responses of the participant to changes in the simulation tasks. After 200 seconds, both metrics show an upward trend, suggesting the increase in task complexity was leading to higher fatigue levels of the participant. Also in the first half, there were frequent heart and GSR fluctuations, indicating periods of heightened cognitive demand. Eventually, around the midpoint of the simulation, heart rate stabilized and GSR baseline decreased, suggesting reduced cognitive engagement.

(continued on next page)

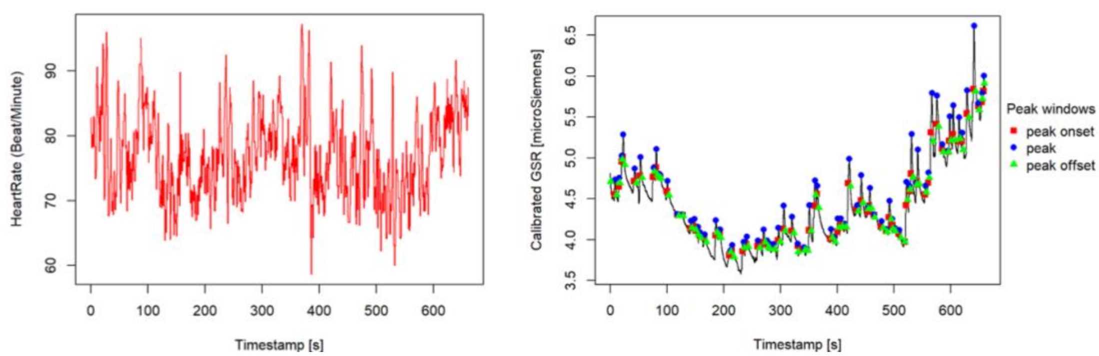
Figure 2

Patterns of heart rate and skin response during simulation scenarios

A In-person high-fidelity manikin-based complex scenario



B Immersive VR high-fidelity simulation-based learning scenario



Heart Rate Variability during Simulation Scenarios

The physiological responses of the participant during the VR simulation were also measured with HRV, specifically, using the Standard Deviation of NN Intervals (SDNN) and inter-beat interval (IBI) distributions. SDNN is a measure of HRV that calculates the average value of HRV in milliseconds, reflecting the time between heartbeats. IBI is a measure of heart rate signals, which is used to assess the health of the participant's autonomous nervous system during the simulation process.

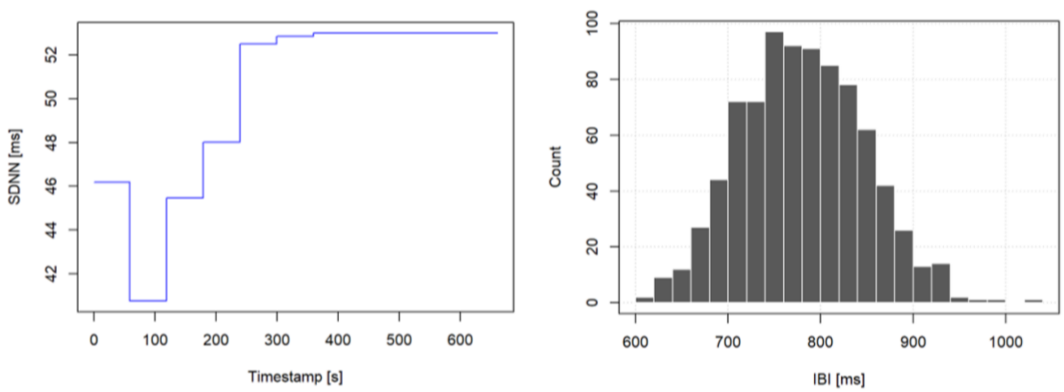
Figure 3 shows two aspects of HRV analysis, SDNN over time (left) and IBI distribution (right). During the manikin-based complex scenario (Figure 3A), the SDNN immediately declines, reflecting an increased cognitive load at the beginning of the simulation. In contrast, during the immersive VR scenario (Figure 3B), SDNN declines more gradually from 25ms to a low of 19ms by approximately 400 seconds. This decrease in SDNN at the beginning of the simulation indicates heightened sympathetic activity as a result of the increased task demand and cognitive load. After this midpoint, SDNN steadily rises, returning near its initial value (24ms) by 1200 seconds. This suggests physiological recovery and relaxation as the scenario progresses. Both scenarios demonstrated this overall U-shaped pattern, reflecting an early increase in cognitive load, followed by mid-task fatigue, and subsequent recovery at the end of the simulation.

For the manikin-based activity, Figure 3A also shows that the most frequent IBI value is around 750 – 800 ms, with a high concentration of beats in this interval. Figure 3B, which represents the immersive VR scenario, shows the most common IBI value is around 600 ms. Overall, for the VR scenario, the histogram demonstrates a relatively consistent heart rhythm with only minor variations between beats. The standard deviation of the IBI data (20.27 ms) indicates relatively stable beat-to-beat variability, consistent with a moderate workload throughout the simulation for the participant. The total IBI range of 116.14 ms reflects some variability in heart rate, suggesting brief transitions between cognitive load and fatigue. Taken together, the distribution reflects overall low-to-moderate HRV, indicating (1) a generally steady rhythm during the activity and (2) reduced physiological adaptability as the participant engages in various, changing simulation tasks.

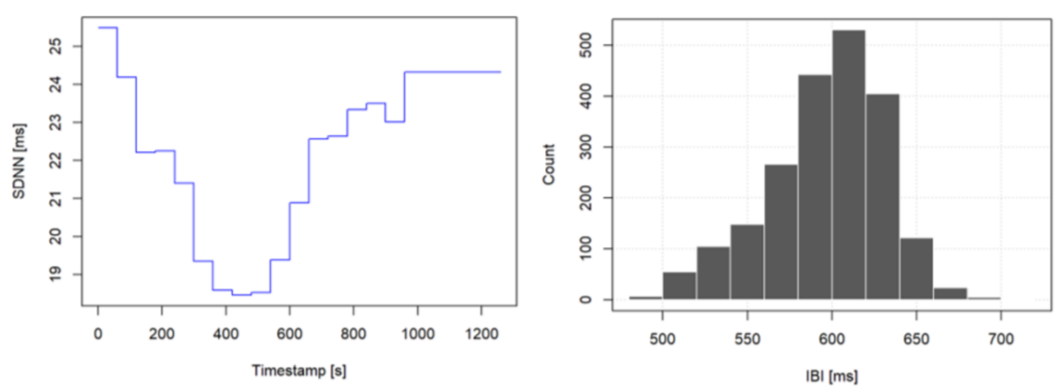
Figure 3

Momentary HRV (left) and IBI time series (right) during the simulation scenarios

A In-person high-fidelity manikin-based complex scenario



B Immersive VR high-fidelity simulation-based learning scenario



Discussion

Understanding how nurses and other healthcare professionals react during stressful patient care situations where a high cognitive load can lead to fatigue, may help explain the healthcare professionals' burnout and cognitive overload. Physiological indicators of distress in healthcare professionals may offer insights into the causes of burnout and other issues affecting well-being and patient safety risks.

Reviewing wearable physiological sensors data, we identified several periods of higher heart rate correlating with changing simulation tasks, indicating an increased cognitive load. Similarly, increased GSR peaks corresponded with higher heart rate activity, suggesting a synchronized response to the participant’s task demands. Both the heart rate and GSR data demonstrate prominent peaks at the start of the simulation scenario and toward the end of the scenario. This can be associated with an increase in cognitive load and changes in physiological states, leading to higher fatigue levels.

These results suggest wearable physiological sensors are feasible and valuable in healthcare settings, as they were able to capture meaningful physiological responses, including increased sympathetic activity associated with higher task demand and cognitive load during the simulation. Future healthcare simulation studies with larger sample sizes are needed to better understand the correlation to specific patient care situations. Additional research may compare virtual reality and manikin-based modalities to determine whether one modality better captures patterns of cognitive load and fatigue, as well as extend monitoring into the debriefing phase where much of the learning occurs. Future investigations should also continue to integrate and compare biosensor data with participants’ self-reported cognitive load and fatigue, an area our team is already actively examining. Table 1 shows future research directions of this study by implementing a multi-sensory system with ECG, GSR, eye-trackers, EMG, EEG, and IMU.

Table 1

Future research on measurement of human-related factors affecting nursing simulation

Wearable physiological sensor	**Measurement metric**	**Human factor**	**Simulation application**
Cardiac activity – ECG	Heart rate and heart rate variability	Fatigue, physical and mental state	Detect stress/fatigue during scenarios; guide pacing
Skin response – GSR	Nervous system activity	Mental state/condition	Monitor stress and engagement in high-stakes simulations
Eye movement – Eye trackers and glasses	Eye movements, head position	Situational awareness	Evaluate hazard recognition skills in simulation
Muscle engagement – electromyography	Muscle load/response, body posture, body speed, body rotation and orientation	Musculoskeletal disorders, work intensity, physical fatigue	Assess psychomotor skill performance and ergonomics
Brain activity – electroencephalography	Brain waves and nervous system activity	Mental state/condition, heat stress	Detect cognitive overload and workload during scenarios
Kinematic – Inertial measurement unit	Kinematic motion, movement patterns of nurses	Ergonomic evaluation, assess risks of trips, falls and slips	Track movement/team dynamics and identify unsafe patterns

Limitations of Design

The limitations of this pilot study include a small sample size and no direct comparison between the two modalities of simulation-based education (manikin-based and immersive VR). The study results also lack a comparison of biosensor data with participants' self-reported perceptions of fatigue and cognitive load, which would bring an important step towards advancing this research. Integrating self-report measures alongside sensor data could examine alignment and discrepancies between subjective and objective measures, providing a more comprehensive understanding of the learner experience.

Conclusion

This study explores the implementation of wearable physiological sensor technologies to assess participant performance in high-fidelity simulation-based training environments, with a primary focus on fatigue and cognitive load. From a successful pilot using GSR and ECG sensors to monitor real-time physiological indicators of cognitive load, we found that wearable sensors are both feasible and valuable for assessing human responses during simulation-based learning activities. Our research suggests increased sympathetic nervous system activity associated with elevated task demand and cognitive load can be reliably captured through these wearable sensors. We further highlight the applicability of physiological sensors use, drawing parallels between healthcare simulation and the patient care setting where situational awareness and cognitive load are equally critical. These findings support using wearable physiological sensors as a practical tool for providing insight into participants' cognitive load and fatigue during training, which can enable more effective assessment, feedback and learning in healthcare simulations, with the goal to improve patient safety.

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Simulated Task Trainer for Diabetic Foot Ulceration Dressing and Debridement: A Preliminary Design

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Conflict of Interest Statement
The authors of this manuscript declare no conflicts of interest. Innovations were designed at the STRATUS Center for Medical Simulation when author BFQ was employed there.

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Brief Description
Type I and type II diabetes are major metabolic disorders that affect over 500 million adults worldwide and are responsible for 3.4 million deaths worldwide (IDF Diabetes Atlas, 2025). Diabetic emergencies related to poor glycemic control constitute a significant proportion of annual emergency room visits, with no indication of a decline in frequency in the near future (McDermott et al., 2022; Uppal et al., 2022). Neuropathy and vasculopathy place patients with diabetes at increased risk for foot ulcers and wound infections. When present, these infections can cause significant morbidity such as chronic non-healing wounds, osteomyelitis, amputations and systemic infections (Frazee, 2024; Jeyaraman et al., 2019; Jupiter et al., 2015). Wound debridement and comprehensive wound care can be utilized to minimize the risk of infection. Medical simulation provides an opportunity to teach clinicians how to properly care for diabetic foot ulcers (DFUs) in addition to developing the psychomotor skills required for wound debridement. To help address current limitations surrounding accessibility to DFU simulators, we propose a preliminary design for a DFU trainer that is easily made, reproducible, dynamic, and cost-effective.

Introduction
Diabetes is a chronic illness that occurs when the body is unable to regulate blood glucose levels appropriately. This condition manifests in two variations, when the body does not produce enough insulin (Type I) or is unresponsive to the secretion of insulin (Type II) (Ozougwu et al., 2013; Rawshani et al., 2017). Diabetes and prediabetic risk factors have been deemed a rising public health issue worldwide (Management-Screening, Diagnosis and Treatment, 2016; Diabetes Statistics, 2025). Diabetic neuropathy, a complication of uncontrolled diabetes, refers to nerve damage that commonly causes loss of sensation in the feet (Bansal et al., 2006; Feldman et al., 2019). Diabetic neuropathy contributes to the development of foot ulcers, chronic wounds, and acute infections that can significantly alter a patient's quality of life if not cared for properly (Bader, 2008; Jeffcoate & Harding, 2003; Snyder & Hanft, 2009). Up to one-third of individuals with diabetes worldwide will develop a foot ulcer, with a lifetime risk

estimated between 19% and 34%. After healing of an initial ulcer, the risk of recurrence is even higher (Edmonds et al., 2021).

Proper wound dressing and surgical debridement are treatment modalities which minimize the risk of further tissue infection and damage (Lebrun et al., 2010; Moura et al., 2013). However, developing the proper technique for these modalities may be difficult for novice clinicians. Medical simulation training offers a psychologically safe and educationally enriching experience for clinicians and students to practice psychomotor skills under the guidance of senior practitioners. As of August 2024, there are a limited number of commercial wound debridement simulators that are surgically interactive and available for purchase. This prompted the creation of a preliminary design for a simulated foot trainer with diabetic skin ulcers using repurposed materials available in our simulation lab. The following model design methods will provide basic and reproducible instruction on how to design a simulator that can be customized for foot wound dressing and debridement training. As DFU wound debridement is often performed using sharp instruments like a scalpel or a curette, we prioritized operator safety when conceptualizing the design for this trainer to minimize the risk of unintentional injuries. This necessitated utilizing a rigid material for structural integrity of the foot and strategic placement of ulcerated skin pads to prevent hand crossover during debridement. In our case, a silicone foot was used for the construction of our simulator.

Objective

As diabetes is becoming more prevalent, podiatric interventions may become an increasingly important component in caring for patients with diabetes (Saeedi et al., 2019). However, as there is a limitation in the number of surgically interactive DFU trainers available for purchase, the introduction of more interactive simulators could enrich podiatric training opportunities. Our objective was to create a low-cost, dynamic, and easily made task trainer for high quality diabetic podiatric care. As this is a preliminary design, we hope the methods used to create this model can serve as a foundation for the development of more advanced task trainers in the improvement of podiatric care (Grollo et al., 2018).

Methods

The cost and materials to create the simulated diabetic foot ulcer are presented below (Table 1).

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Table 1

Total Cost of Materials

Model Components	Cost per unit (In USD)	Vendor (Vendor identification numbers)	Cost in bulk (brand)
Simulated mannequin foot (right side)	$16.26	Amazon (B0CCXCJL2D)	$16.26 (YangShine)*
Suture pad	$47.50	Limbs & Things (00092)	$95.00 for 2 pads (Limbs & Things)
Upholstery foam cushion	$3.80**	Amazon (B08NWPJG59)	$9.56 for 1”x12”x36” (QOMFY)
All purpose super glue	$1.12	Amazon (B0BCL2KT5Y)	$8.99 for 8 super glue sticks (GH1200)
VELCRO brand – 1 foot sticky back hook and loop fasteners	$0.62	Amazon (B000GRBEK2)	$18.89 for 30 feet (VELCRO)
Disposable plastic eye shield	$1.10	Amazon (B079MK3V6Z)	$21.99 for 20 eye shields (STARRYSHINE)
Black acrylic paint 0.25 oz	$0.37	Amazon (B000RDP7UI)	$5.99 for 4 oz (Chef Master)
Red food coloring 0.5 oz	$0.51	Amazon (B0025U73E4)	$10.70 for 10.5 oz (Chef Master)
Cost per foot model	**$71.28**	**Total cost**	**$187.38**

Note. The dollar cost per foot refers to the expenses required for constructing a single foot model using individual components. The total cost represents the overall expense which includes bulk pricing of all required materials. The vendors listed are those from which materials were purchased for this project; their inclusion is for reference only and not a requirement for model replication. Prices are reflective of USD as of June 2025. *As the original model was constructed in June 2023, the manikin foot used at that time is no longer available for purchase. To address this, Table 1 includes the most comparable alternative sourced from the same vendors as the original. **Approximately 4/10 of the original size of the upholstery foam was used in the construction of this simulator. The calculated price was obtained by dividing the cost in bulk by 40. This ratio would equate to a 0.4”x4.8”x14.4” size.

The anatomical location and size of DFUs vary widely between individuals. This preliminary model includes plantar ulcerations in weightbearing areas such as the heel and medial first metatarsal, along with dorsal wounds over the fourth and fifth metatarsals (LeMaster et al., 2008; Ünlü et al., 2007). Simulated ulcerations and wound beds, which served as the debridable regions of the task trainer, were created using commercially available suture pads (Limbs & Things, Bristol, England, United Kingdom). We developed a podiatric task trainer for the management of diabetic foot ulceration (Appendices A – D). The stepwise methods below illustrate the design process behind the model, starting with the construction of simulated ulcerations then progressing to the construction of the foot.

1. Select and mark locations for ulcer placement on foot.
2. Use a #1 blade scalpel, excise skin from foot. Ensure the area being cut is sized appropriately for the introduction of simulated ulcerations.

3. Cut suture pads to match section removed from the foot.
4. Make incisions 2 cm deep into the suture pads on the skin side and expand circumferentially to create an adequately sized wound bed.
5. Stain the subcutaneous fat layer with red food coloring to simulate the appearance of healthy wound bed tissue.
6. Apply super glue and dirt over the healthy wound bed to simulate a necrotic ulcer for debridement.
7. Apply hook and loop fastener to the bottom of the suture pad for insertion into foot model.
8. Place upholstery foam into the section removed the foot. If the simulated foot is hollow, add upholstery foam to provide structural integrity and resistance. Alternative materials include silicone rubber, plastic inserts, and memory foam. For solid models, this step may not be required.
9. Cut a single pair of disposable plastic eye shields into rectangular segments and size appropriately to fit within the resected regions. Alternative materials include any durable plastic such as acrylic or polyethylene terephthalate from plastic water bottles. The addition of this plastic layer is essential for the mounting of the simulated ulcerations.
10. Apply super glue between the upholstery foam and the plastic pieces until adequately adhered.
11. Place strips of hook and loop fastener onto the exterior aspect of the plastic pieces for ulceration pad mounting.
12. Fasten ulceration pads onto the simulated foot using the plastic pieces. Add hot glue around the border of the opening for increased adherence (Appendices A-C).
13. Add black acrylic paint to the hallux to simulate the appearance of gangrenous and necrotizing tissue (Appendix C).
14. After debridement of necrotized tissue, replace the tissue with the addition of more super glue and dirt. Alternatively, remove the simulated ulceration entirely for replacement with another ulceration pad. Appendix A shows a fully debrided foot ulceration revealing healthy soft tissue.

Results

Using the above materials available in our simulation center, we created a simulator representative of a diabetic foot with debridable ulcers for an estimated cost of $71.28 USD. DFUs were made using suture pads, dirt, and super glue. For this model, wounds were localized on the dorsal aspect of the fourth and fifth metatarsals. On the plantar aspect of the foot, wounds were placed on the first metatarsal and calcaneus. This model design allows learners to practice the psychomotor skills associated with DFU wound debridement and wound dressing application. A photograph illustrating the use of the trainer for wound dressing can be seen in Appendix D.

Discussion

With the global prevalence of diabetes increasing at an alarming rate, diabetic neuropathy and foot ulcerations will likely increase (McDermott et al., 2022; Saeedi et al., 2019), underscoring the need for high-quality hands-on training. This task trainer was developed to support the goal of making more accessible training for managing DFUs. In addition to supporting the development of debridement and dressing techniques, the trainer can be modified to allow practice of other podiatric clinical skills. Because the resected regions are made from suture pads, they can be exchanged with pads containing premade lacerations and simulated debris for users to irrigate and suture. Incision and drainage of cutaneous abscesses on the foot can also be effectively simulated by incorporating lotion-filled balloons beneath suture pads (Adams et al., 2018; Freeman et al., 2014). Additionally, punch biopsies can also be performed by discoloring a small part of the suture pad with a marker to simulate an abnormal skin lesion. This model can also be used to train novice clinicians on wound assessment, classification, and sterile technique.

The net cost of the model components was $71.28 USD for one simulator. While the construction of the trainer is moderately priced, it was made utilizing resources that were readily available in our simulation lab. This cost can be mitigated by substituting comparable products from other manufacturers that offer lower-cost alternatives. Given the suture pads are one of the most costly components, we recommend reusing suture pads by creating new ulcerations each time. Plastic mannequin foot models can also be used as a substitute for more costly silicone foot models.

The hook-and-loop fastening mechanism allows for easy and rapid replacement of simulated DFUs for new users. Although this simulator was created for practicing DFU debridement and dressing application, the customizability of the design permits expansion to other procedural interventions. The detachable foot offers a customized experience, as it can be mounted and used independently or implemented into full-body manikin models for higher-fidelity simulation. Full body manikins may allow for a hybrid simulation for learners to develop interpersonal skills while performing the desired clinical procedures. This feature can be used to promote emotional engagement by allowing learners to respond to verbal expressions of pain from a simulated patient and to practice communication skills such as delivering bad news, including discussions about possible amputations (Ahmed et al., 2018; Brown & Reid, 2022; Brown & Tortorella, 2020). One limitation of implementing this design with full body mannequins is irreversible damage to the foot.

During the construction of this model, we encountered a logistical challenge. The original foot model was made of a stiff rubber material, which made it difficult to manually create wound beds suitable for debridement. As a result, the design team decided to completely resect parts of the rubber foot with a scalpel and to replace those parts with a softer suture pad. This was chosen over layering the pad on top of the original model because we believe filling the gap better simulates the level surface of a foot. Although layering the suture pad over the foot may not affect skill practice, the added elevation may compromise ergonomic and anatomic fidelity. Furthermore, the inserted pad provides a realistic simulation of a wound becoming progressively healthier as more necrotized tissue is debrided. For a more realistic and seamless experience, future upgrades to the current design may include using a foot model with a solid interior to limit cushioning when actively debriding.

Limitations of Design

Upon completion, we acknowledge several limitations present in the initial design of this simulator. First, based on the measured dimensions of our simulated task trainer the approximate shoe size for this trainer is a US men’s size 8. Mannequin models are generally limited to one size and cannot accurately reflect the varied shoe size and foot measurements amongst the general population. Implementing the DFU design methods into pediatric sized mannequins can allow specialists to practice debridement on a model foot with a much smaller surface area.

Next, because our model was hollow, we were required to pad the inside with foam for structural integrity and ulceration pad adherence. This mechanism of attachment may affect stability for steady debridement as there is no hard surface beneath the ulceration pad to secure the model in place effectively. Because of this, solid mannequin foot models may be recommended as a base for future designs. As the constructed DFU trainer is detached from a full body structure, it must be mounted to stabilize the model for practical use. This can be addressed by suspending the trainer to a comfortable height with the plantar side facing the user and utilizing clamps or ropes tied around the ankle joint to secure the model.

Lastly, subject matter expert opinions are vital to assess this model's utility and efficiency. At the time of writing, we have not conducted any simulation sessions that incorporate this model into the educational curriculum. Usability testing of the model was conducted by simulation specialists at our academic institution. Although the simulator was not subjected to pilot testing following its development, its design and practical implementation were informed by the expertise of a board-certified physician with substantial experience in the clinical management of DFUs within emergency care settings. This physician provided guidance based on their knowledge of the clinical protocols and procedural nuances associated with debridement in patients presenting with ulcerations. Feedback regarding the practicality of using this simulator for debridement and other clinical skills should be gathered from podiatrists, orthopedic surgeons, physical therapists, and other wound care specialists who perform DFU debridement and podiatric care in routine clinical practice. In summary, given the numerous indications highlighting the potential of this design approach across various areas of simulation-based education, innovations in the present design and practical implementation of the model is essential to assess the usability of this simulator.

Conclusion

Using readily available items available in our simulation center, we created a task trainer that can serve as an efficient training modality for clinicians involved in providing podiatric care. Our model making methods allow for customizability in wound creation and distribution in trainers produced using these methods. As interactive podiatric simulators are expensive and can be difficult to acquire, we hope this conceptual design can contribute to increasing access to podiatry training and the development of more advanced simulators that can improve the management of patients with diabetic foot ulcers or other podiatric complications.

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Appendix A

Appearance of Healthy Tissue in a Fully Debrided Wound Bed

Note. Healthy tissue appearance was created with red food coloring. An #11 blade scalpel was used by a simulation specialist to clean the wound bed.

Appendix B

Ulceration Attached to the Dorsal Aspect of The Foot

Note. Ulceration pad was attached using a hook-and-loop fastening mechanism. This mechanism of attachment allows for rapid exchange of ulceration pads once a wound has been fully debrided.

Appendix C

Simulated Foot Ulcers on Plantar Side

Note. Although dirt and trace amounts of glue residue were used as simulated substitutes for dead and necrotizing skin cells, simulation specialists may choose alternative materials such as caulk when replicating the design of our debridement model, if available.

Appendix D

Wound Dressing Application on Task Trainer

Note. The photo demonstrates a basic wound dressing for foot wounds located at the anatomical landmarks listed above.