Disaster Medicine and Public Health Preparedness

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Review Article

Cite this article: Torres-Agüero D, Armijo-Rivera S, Vicencio-Clarke S, Norte G, Herrera E and Lagos Cordero A (2025). Enhancing Disaster Preparedness and Community Safety Through Virtual Simulation: A Scoping Review in Undergraduate Health Education. *Disaster Medicine and Public Health Preparedness*, **19**, e351, 1–11
https://doi.org/10.1017/dmp.2025.121

Received: 09 December 2024
Revised: 14 March 2025
Accepted: 11 April 2025

Keywords:
disaster medicine; virtual reality; undergraduate medical education; simulation training

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Enhancing Disaster Preparedness and Community Safety Through Virtual Simulation: A Scoping Review in Undergraduate Health Education

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Abstract

Objectives: Disaster medicine (DM) prepares health care professionals to manage emergencies caused by significant societal disruptions. Training recent graduates and final-year students is an essential element of disaster preparedness. This review aims to examine the use of Virtual Simulation (VS) in undergraduate students' DM training.
Methods: The research team searched Scopus, PubMed, WOS, and Scielo. The team followed the 6-step approach described by Mak to conduct Scoping Reviews. We identified 262 reports, and 17 articles met the inclusion criteria. We extracted and analyzed data, focusing on educational settings, professions involved, and intervention characteristics. The report followed PRISMA guidelines.
Results: The implementation of VS in DM training has been geographically concentrated, with most studies focused on nursing education. Most programs use virtual reality, with limited augmented or mixed reality integration, principally in nursing students. The training focused primarily on triage, disaster preparedness, evacuation, decontamination, improving knowledge retention, self-confidence, and decision-making.
Conclusions: Although VS has effectively enhanced technical skills and disaster preparedness, its use remains limited in undergraduate health education. Further research is needed to expand its application in interprofessional and non-nursing contexts, with deliberate practice principles to maximize efficiency. Integrating VS into community training can reduce costs and enhance large-scale emergency response.

Narrative Abstract

Disaster medicine (DM) prepares health care professionals to respond to emergencies that disrupt society. Training recent graduates and final-year students is crucial for preparedness, yet traditional methods often fail to provide hands-on experience. To bridge this gap, a scoping review explored the role of Virtual Simulation (VS) in DM training for undergraduate students. A team of 6 experts analyzed 262 studies, narrowing down to 17 relevant articles. Results revealed that VS is predominantly used in nursing education, focusing on triage, preparedness, evacuation, and decision-making key components in protecting both hospital resilience and community well-being. Programs largely relied on virtual reality, with minimal integration of augmented or mixed reality. Despite its potential to enhance skills and confidence, VS training seldom applied deliberate practice principles, limiting its effectiveness. Expanding VS adoption across health professions and incorporating deliberate practice could improve disaster preparedness, optimize resource use, and enhance community resilience, underscoring the need for further research and program development.

According to the World Health Organization (WHO), a disaster is "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with exposure, vulnerability, and capacity conditions, leading to 1 or more of the following: human, material, economic and environmental losses and impacts."[1] The Guidelines for Evaluation and Research in the "Stein Style" defines a disaster as "serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its resources; the result of a vast ecological breakdown in the relations between man and his environment, a serious and sudden event (or slow as in drought) on such a scale that the stricken community needs extraordinary efforts to cope with it, often with outside help or international aid."[2] Otherwise, DM is "a discipline consisting of a combination of studies in emergency health services, emergency medicine, disaster management, and public health."[3]

Improving communities' and countries' resilience and health security requires comprehensive disaster risk management, which involves the health workforce's preparedness, readiness, and response to disasters.[4]

Having a trained health care workforce is critical in countries at high risk of disasters, especially in rural areas where specialists may not be available. In these contexts, recent graduates and final-year students are often the first to respond to emergencies,[5] assisting health care teams in triage, basic life support, and initial stabilization of patients. Their preparedness directly contributes to both hospital readiness—by ensuring a pipeline of competent professionals who can integrate seamlessly into emergency response efforts—and community safety, by extending medical support to underserved populations during crises. Strengthening their disaster medicine training through simulation-based education enhances their ability to function effectively in high-pressure situations, ultimately improving overall emergency response capacity.

Health sciences education aims to improve the preparedness of professionals and the whole health workforce. Virtual Simulation (VS) in deliberate practice programs has proven to be an effective tool for preparing health professionals. It allows them to practice critical skills in a controlled and immersive environment, significantly improving their confidence, knowledge acquisition, and hospital preparedness for disasters.[6] Deliberate practice, a key principle in acquiring expert performance using simulation, is understood as "a structured, goal-oriented approach to skill development that emphasizes intentional habit modification, immediate feedback, and iterative refinement to enhance performance."[7]

In disaster preparedness, adopting a multidisciplinary approach that integrates organizational, human, and technological factors is vital to optimizing the training of health professionals in critical situations.[8]

These areas allow for a better understanding and management of the complexities present in emergencies, highlighting the importance of preparation and the development of response capacities.[9] Although undergraduate disaster preparedness training increases theoretical knowledge, it does not ensure adequate preparation to act in real scenarios. Hence, integrating clinical simulation into the curriculum becomes essential to provide students with the necessary skills and guarantee an effective response in disaster situations.[9]

VS has shown promising results in enhancing disaster preparedness, confidence, and performance among nursing students.[10,11] Additionally, VS improves disaster response by strengthening decision-making abilities, situational awareness, and coordination in high-stress scenarios, while also fostering interdisciplinary collaboration.[12] Evidence also suggests that VS positively impacts self-efficacy and preparedness of participants in handling mass casualty incidents after simulation-based training.[13] Still, more scientific evidence is needed to understand its long-term effectiveness in real-world disaster response, its role in fostering interdisciplinary collaboration, and its potential impact on improving community safety.[14]

The need to understand how VS in all these forms (augmented reality, mixed reality, or computing simulation) has been used to train undergraduate health students in DM led us to our research question: How has VS been implemented as a teaching method in the training of competencies in DM in undergraduate health sciences students?

Methods

The research team comprised 6 researchers from 3 countries (Portugal, The Netherlands, and Chile). Five had training as simulation educators and participated in simulation teaching undergraduate programs, 1 had been serving as part of *Médecins sans Frontières* and Red Cross in Africa and Middle East, and 1 had been responsible for training programs to prepare health care providers to respond in cases of radiation and chemical accidents. One has been in charge of firefighter preparedness for natural and chemical disasters. The team includes physicians, nurses, and firefighters. All the team members had content expertise related to the modalities of VS analyzed, and 4 had experience conducting scoping reviews. A librarian assisted the team in developing the definitive search strategy.

The research team conducted a preliminary search to identify reviews related to teaching DM in undergraduate settings in the literature. Using the general terms "disaster medicine," "virtual simulation," and "undergraduate student," we searched the Scopus database but found no existing reviews in the literature focused on this population. The existing literature justifies the need for a scoping review. The team followed the 6-step approach described by Mak to conduct Scoping Reviews,[15] aimed at analyzing various forms of VS used in the undergraduate education of health professionals.

Step 1: Identifying the Research Question

Based on the preliminary literature search, educating undergraduate students is crucial for enhancing health care systems' and countries' preparedness to respond effectively to disasters using available resources. Given the potential of VS as a tool for teaching and assessing knowledge and competencies in clinical decision-making within health professions, we formulated the research question: How has VS been implemented as a teaching or assessing method in training DM competencies in undergraduate health students?

Step 2: Identifying Relevant Studies

A librarian assisted in developing the search strategy. After 2 meetings dedicated to understanding the operational definition of disaster medicine,[3] virtual simulation modalities,[16] and the research team's suggestions and considering that the field has specific expressions not covered by Medical Subject Headings, we defined the search terms (Table 1) and the search strategy (Table 2). For the inclusion criteria, we included only articles that report curricular activities using virtual simulation in any of their modalities to teach disaster medicine to undergraduate students. The exclusion criteria considered using any other simulation modality (high fidelity, low fidelity simulation, and simulated patients). No language filter was applied. We searched SCOPUS, WOS, Scielo, and PubMed databases for articles published up to March 2024. This review was not registered with PROSPERO, as the platform does not accept reviews categorized as scoping, literature, or mapping reviews.[19]

Step 3: Selecting Studies to be Included

The search strategy led to the extraction of 262 abstracts (143 from Scopus, 64 from PubMed, 54 from WOS, and 1 from Scielo). One

Table 1. Operational definitions for terms used in the literature appraisal

Terms to analyze	Operational definitions
Undergraduate	Formal training processes in university and technical careers
Augmented reality	A type of virtual reality in which synthetic stimuli are superimposed on real-world objects, usually to make information otherwise invisible to human senses perceptible. A technology that overlays digital computer-generated information on objects or places in the real world to enhance the user experience. The combination of reality and overlay of digital information is designed to enhance the learning process. A spectrum of mixed-reality simulation that is part way between the real world and the virtual world. A form of virtual reality that includes head-mounted displays, overlays of computer screens, wearable computers, or displays projected onto humans and manikins[16].
Artificial intelligence	A system of computerized data-gathering and prediction that models human behavior and decision-making with minimal human intervention. In healthcare simulation, AI often refers to underlying programming that provides physiological or system-based algorithm changes based on inputs from users and learners. Often paired with *machine learning*, in which the software is programmed to alter algorithms and predictions based on observed data and results without human intervention. *Virtual patients* use artificial intelligence to react appropriately to the user or learner[16].
Computer-based simulation / Screen-based simulation	The modeling of real-life processes with inputs and outputs exclusively confined to a computer, usually associated with a monitor and a keyboard or other simple assistive device (Textbook of Simulation). Subsets of computer-based simulation include virtual patients, virtual reality task trainers, and immersive virtual reality simulation[16].
Live, virtual, and constructed (LVC) simulation	A broadly used taxonomy describing a mixture of simulation modalities; a live simulation involves real people operating real systems; a virtual simulation is where a real person operates simulated systems; and a constructed simulation does not involve real people or real systems but instead consists of computer programs that create an environment[16].
Mixed Reality (XR)	A category that encompasses the hybrid combination of virtual reality environments and reality (e.g., real environment, standardized patient, normal manikin simulator). Often encompasses the definition of Augmented Reality (AR) but has more virtual features than typical AR. The blend of what is physically present to what is 100% computer-generated is expressed in this continuum: Reality——— Augmented Reality——— Mixed Reality——— Virtual Reality. A simulator that combines virtual and physical components[16].
Serious games	A mental contest played with a computer in accordance with specific rules, which uses entertainment to further training, education, health, public policy, and strategic communication objectives. A game designed for a primary purpose other than pure entertainment. Serious games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. Serious games are simulations of real-world events or processes designed for the purpose of solving a problem. In the defense context, serious games are used to rehearse, train, or explore military options in a simulation of real-world events or processes. The "serious" adjective is generally appended to refer to products used by industries like defense, education, scientific exploration, healthcare, emergency management, city planning, engineering, religion, and politics[16].
Virtual reality	The use of computer technology to create an interactive 3-dimensional world in which the objects have a sense of spatial presence; virtual environment and virtual world are synonyms for virtual reality. A computer-generated 3-dimensional environment that gives an immersion effect. Often refers to the 3-dimensional (3D) Head-mounted Display VR (HMD VR) in which the Virtual World is projected using a head-mounted display. A shorthand of the HMD VR hardware, which always uses a Virtual World. In that way, it is not necessarily synonymous with Virtual Environment and Virtual World, but a synecdoche/metonymy[16].
Escape room	"Live-action team-based game where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to accomplish a specific goal (usually escaping from the room) in a limited amount of time"[17]. Escape rooms are interactive, problem-solving simulations that foster teamwork, decision-making, and knowledge retention in high-pressure scenarios, making them a valuable tool for disaster medicine education[18].
Disaster medicine	Disaster medicine is a discipline consisting of a combination of studies in emergency health services, emergency medicine, disaster management, and public health[3].

researcher (SA) removed duplicates (71), resulting in a corpus of 191 abstracts for the initial review. These titles and abstracts were reviewed and filtered by an expert (SA), eliminating proceeding papers, books, book chapters, commentaries, and articles written in languages not managed by the authors (Chinese and German). Through this process, 39 articles were excluded. A total of 152 abstracts were appraised independently by 2 reviewers (SA, DT) to determine if they met inclusion and exclusion criteria. The inclusion criteria considered articles reporting data from curricular simulation activities involving undergraduate health students and focused on VS training programs implemented until March 2024. Exclusion criteria included non-curricular simulation activities (such as experiences in congresses or workshops), experiences using high fidelity with mannikin, low fidelity or simulated patients, and programs focused on non-undergraduate students and other populations. Dissensus was discussed and agreed upon by both reviewers. Finally, a corpus of 17 articles was included in the analysis phase. The reasons for exclusion are summarized in the PRISMA flow diagram (Figure 1).

Step 4: Charting the Data

The team collaboratively developed the data extraction form (SA, DT, GN, SV) and defined the extraction categories. The automatic bibliometric elements extracted from the databases and included in the analysis were keywords and years. The manually generated extraction categories included the type of institution (university or technical), the career field in which the program was implemented, the course or program level (ranging from 1-7), the number of locations where the program was implemented (within the same or across different institutions), the year, type, and the duration of the intervention (total hours and general timeline), the

Table 2. Search strategy

Search strategy	Data Base	N° of articles 2008 - 2024
TITLE-ABS-KEY (learning AND ("undergraduate education" OR "Undergraduate Medical Education" OR "Health Area Students" OR "Health Occupations Students" OR students) AND ("Virtual Reality" OR "Simulation Training" OR "Computer Simulation" OR "Augmented Reality" OR "Mixed Reality") AND (disasters OR "Natural Disasters" OR "Man-Made Disasters" OR "human disaster*" OR avalanches OR droughts OR "Cyclonic Storms" OR earthquakes OR floods OR landslides OR tornadoes OR wildfires OR "Tidal Waves"))	SCOPUS	143
("learning"[MeSH Terms] OR "learning"[All Fields] OR "learn"[All Fields] OR "learned"[All Fields] OR "learning s"[All Fields] OR "learnings"[All Fields] OR "learns"[All Fields]) AND ("undergraduate education"[All Fields] OR "Undergraduate Medical Education"[All Fields] OR (("health"[MeSH Terms] OR "health"[All Fields] OR "health s"[All Fields] OR "healthful"[All Fields] OR "healthfulness"[All Fields] OR "healths"[All Fields]) AND ("students"[All Fields] OR "students"[MeSH Terms] OR "students"[All Fields] OR "student"[All Fields] OR "students"[All Fields])) OR "Health Occupations Students"[All Fields] OR ("student"[All Fields] OR "students"[MeSH Terms] OR "students"[All Fields] OR "student"[All Fields] OR "students"[All Fields])) AND ("Virtual Reality"[All Fields] OR "Simulation Training"[All Fields] OR "Computer Simulation"[All Fields] OR "Augmented Reality"[All Fields]) AND ("disasters"[All Fields] OR "disasters"[MeSH Terms] OR "disasters"[All Fields] OR "disaster"[All Fields] OR "Natural Disasters"[All Fields] OR "Man-Made Disasters"[All Fields] OR "human disaster*"[All Fields] OR ("avalanches"[MeSH Terms] OR "avalanches"[All Fields] OR "avalanche"[All Fields] OR "avalanching"[All Fields]) OR ("droughted"[All Fields] OR "droughting"[All Fields] OR "droughts"[MeSH Terms] OR "droughts"[All Fields] OR "drought"[All Fields]) OR "Cyclonic Storms"[All Fields] OR ("earthquakes"[All Fields] OR "earthquakes"[MeSH Terms] OR "earthquakes"[All Fields] OR "earthquake"[All Fields]) OR ("floodings"[All Fields] OR "floods"[MeSH Terms] OR "floods"[All Fields] OR "flood"[All Fields] OR "flooded"[All Fields] OR "flooding"[All Fields]) OR ("landslides"[MeSH Terms] OR "landslides"[All Fields] OR "landslide"[All Fields] OR "landsliding"[All Fields]) OR ("tornadoes"[MeSH Terms] OR "tornadoes"[All Fields] OR "tornado"[All Fields] OR "tornados"[All Fields]) OR ("wildfires"[MeSH Terms] OR "wildfires"[All Fields] OR "wildfire"[All Fields]) OR "Tidal Waves"[All Fields])	PubMed	64
learning AND ("undergraduate education" OR "Undergraduate Medical Education" OR "Health Area Students" OR "Health Occupations Students" OR students) AND ("Virtual Reality" OR "Simulation Training" OR "Computer Simulation" OR "Augmented Reality") AND (disasters OR "Natural Disasters" OR "Man-Made Disasters" OR "human disaster*" OR avalanches OR droughts OR "Cyclonic Storms" OR earthquakes OR floods OR landslides OR tornadoes OR wildfires OR "Tidal Waves")	Wos	54
learning AND ("undergraduate education" OR "Undergraduate Medical Education" OR "Health Area Students" OR "Health Occupations Students" OR students) AND ("Virtual Reality" OR "Simulation Training" OR "Computer Simulation" OR "Augmented Reality") AND (disasters OR "Natural Disasters" OR "Man-Made Disasters" OR "human disaster*" OR avalanches OR droughts OR "Cyclonic Storms" OR earthquakes OR floods OR landslides OR tornadoes OR wildfires OR "Tidal Waves")	Scielo	1

simulation modality, the organization of the participants, the format of intervention (on-site or remote), the profession of the instructors, and their simulation training and experience.

Given the final sample size, the 17 selected articles were analyzed by 1 expert in the specific field (firefighter, emergency medicine, or nuclear/chemical disasters) and 2 researchers with expertise in simulation. Discrepancies were resolved through a consensus agreement between 2 researchers (SA, DT).

Step 5: Collating, Summarizing, and Reporting the Results

The research team conducted numerical and thematic analyses using the data extracted from all papers. At each step, at least 2 independent researchers performed the analysis. Through a reflective and collaborative process, they refined the initial coding based on predefined operational definitions and discussed the relations between the identified themes. The report was prepared following the PRISMA-ScR checklist.[20]

Step 6: Consulting Stakeholder

To enhance the rigor and relevance of the discussion, the research team consulted a stakeholder expert in critical patient care and simulation training. This expert provided an independent critical review of the findings, offering insights on key discussion points and helping to identify potential gaps in the literature based on their professional experience. Their role was advisory and did not involve direct participation in data collection or analysis. Instead, their input contributed to refining the interpretation of results and ensuring that relevant perspectives from the field were considered.

Results

Bibliometric Characterization

The studies range from 2008-2024, with peak publication years in 2015 and 2022 (17.65% each) and consistent reporting over the last 5 years. Across the 17 articles, 56 different keywords were used, with only 5 appearing in 4-5 articles (Figure 2).

Descriptive characteristics of programs

A significant portion of the studies (47.06%) did not report the year of intervention, limiting the ability to analyze temporal trends on implementation. Among the studies that did report the year, an increase in implementation was observed starting in 2015. However, the limited reporting of intervention years restricts the ability to analyze temporal trends. Most interventions were conducted at universities (88.24%), with the majority focusing on nursing programs (58.82%), followed by medical programs (17.65%). Notably, a single institution in the US accounted for 6 reports (35.29%) on decontamination training for nursing students. The remaining studies concentrated on other training areas, including triage (23.53%), disaster preparedness (23.53%), and evacuation (17.65%). The programs were implemented across the US, Europe, and Asia (Figure 3).

Most of the interventions (70.59%) were conducted at a single location and delivered face-to-face, with 94.12% of the reports describing 1-time events (single interventions). Various instructional approaches were employed, with 47.06% of the studies incorporating multiple simulation methodologies and 17.65% using Problem-Based Learning, including VS as a teaching tool. Regarding the modality of VS, 82.35% of the reports focused on

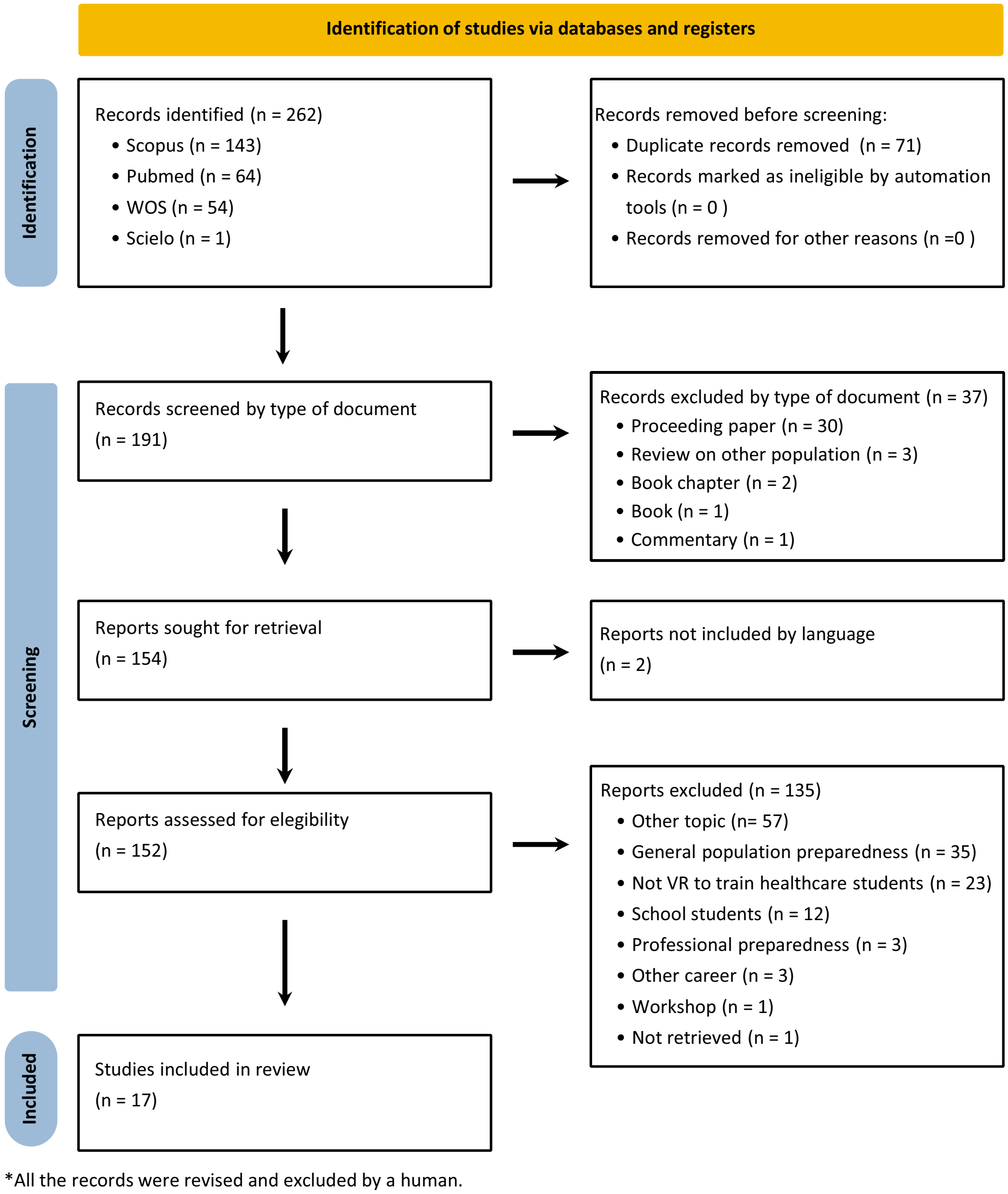

Figure 1. Prisma Flow Chart.

virtual reality (VR), without components of augmented reality (AR) or mixed reality (MR). However, only 47.06% of the instructors had formal simulation training (Table 3). Four key training areas were identified, and the analysis of these areas is detailed in the following section (Figure 3).

Triage. In 4 studies focused on triage training (23.53%), VR was used as an innovative educational tool, with different approaches to its implementation. These included pre-selected scenarios,[21] collaborative creation of simulations,[22] and comparisons between triage systems.[23] The target population was medical,[21] nursing,[22] and paramedic students,[23,24] but none of the studies involved interprofessional training. The number of participants reported ranged from 20-[21]70,[24] and the interventions involved triaging between 5-[21]25 victims simultaneously.[23] All the courses were conducted in person.

The main findings of these studies indicated that VR training improves participants' speed, accuracy, and self-efficacy[21,23] and enhances interprofessional communication[22] through iterative exposure, structured feedback, and enhanced decision-making opportunities.[21,23,24] However, the outcomes varied depending on the study design (number of cases included and repetitions) and the VR platform used. Specifically, repeated VR scenarios led to significant reductions in triage completion time,[21] while structured, algorithm-based training improved triage accuracy and reduced undertriage errors.[23] Moreover, platform design and study methodology influenced learning outcomes, with interactive and immersive VR environments fostering greater engagement and skill acquisition.[24] Overall, the studies demonstrate that VR, with lectures and high-fidelity simulation, provides an excellent opportunity to develop triage decision-making skills. However, the effectiveness of

https://doi.org/10.1017/dmp.2025.121 Published online by Cambridge University Press

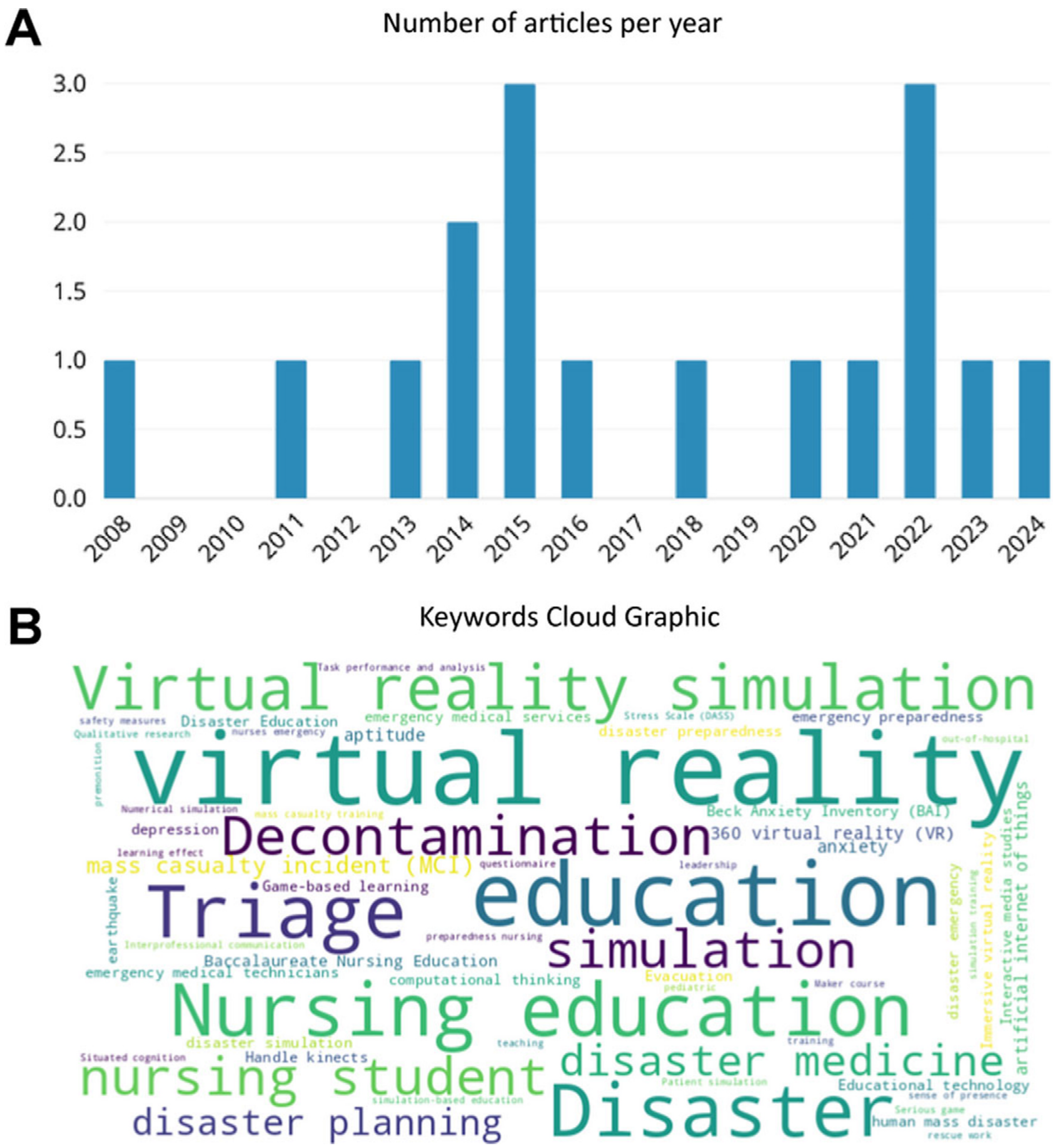

Figure 2. Bibliometric characteristics of the selected articles.
A: Number of articles per year.
B: Keywords Cloud graphic.

VR training depends on factors such as scenario repetition, feedback mechanisms, and the level of immersion provided by the platform.[21,24]

Disaster preparedness. Four studies used VR simulation to train disaster preparedness (defined by United Nations as "The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters"[26]) but employed different methods. Two studies focused on mass disasters: 1 used full immersive simulation based on a bus accident to assess sense of presence with virtual simulation and correlates that with decision-making and stress during massive disaster,[25] and another utilized 3D simulation in a longitudinal comparative design, focused on assessing changes in knowledge after disaster simulation were the participant's trained triage, and first aid to victims of radioactive and explosive events.[12] The remaining studies explored non-technical performance (decision-making styles assessed using the Rational-Experiential Inventory) in controlled environments[27] and hybrid simulation using web resources.[28] The target populations included only nursing students[12,28] and interprofessional groups of medical, nursing, and paramedic students.[25,27] Participants ranged from 40-[12]83.[25,27] The augmented reality interventions featured a single scenario with multiple victims.[25,27,28] Overall, VR training improved disaster preparedness performance and non-technical performance, as measured through pre- and post-tests,[12] performance metrics,[12] and evaluations of decision-making and teamwork.[27] Self-reported confidence and perceived readiness further supported its effectiveness in enhancing both technical and non-technical competencies.[28] However, immersion in the scenario was not always a decisive factor for performance. On the contrary, perception of the environment and familiarity with the technology significantly influenced the results.[25,27] Studies using

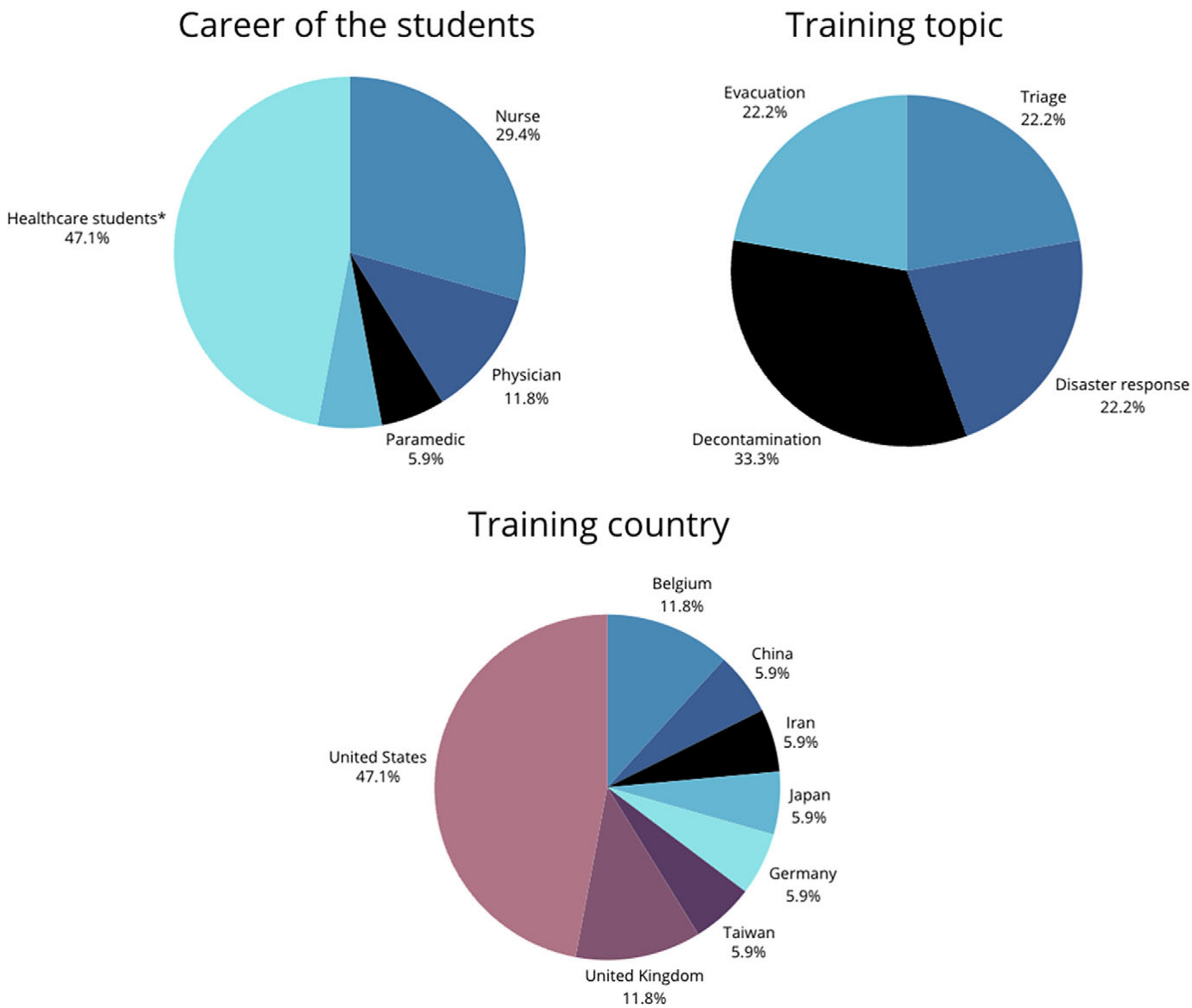

Figure 3. Characteristics of the programs implemented.

3D VR demonstrated superior knowledge retention compared to traditional methods.[12]

Evacuation. Three studies focused on the health students' preparedness to respond to earthquakes and evacuations, with 1 study specifically addressing participants' psychological responses, measuring anxiety control using the Depression, Anxiety, and Stress Scale (DASS) and Beck Anxiety Inventory (BAI) in a pre-post VS earthquake training.[29] The other 2 studies focused on practical learning, such as evacuation management and computational thinking, and assessed knowledge retention using theoretical pre- and post-intervention tests, as well as CPR practical skills.[30,31] The target populations were medical[29,30] and nursing students.[31] Participant numbers ranged between20-[29]167.[31] These studies compared VR with traditional training methods and found that VR enhanced knowledge retention and practical skills. Topics covered included fire extinguishing, earthquake debris protection and evacuation, and cardiopulmonary resuscitation during evacuations.[31] Participants consistently reported higher satisfaction with VR training, with significant improvements in decision-making in CPR management and self-confidence in their abilities in disaster scenarios, compared with traditional teaching methods.[29–31] VR simulations also improved anxiety control in disaster situations, particularly earthquake training contexts.[29]

Decontamination. The most represented topic was the task of decontamination, with 6 articles from the same research group focusing on preparing nursing students to select and use appropriate personal protective equipment when caring for patients exposed to biological, chemical, or radiological hazards that pose risks to health care workers.[32–37] All studies used VR as an educational tool, with immersion and teaching method variations. Some studies compared VR to traditional methods[35] or other simulations,[37] while others explored how different levels of VR immersion affect learning outcomes.[36] One study assessed movements in specific tasks, registering motions and self-efficacy in emergency preparedness competency dimensions using the Emergency Preparedness Information Questionnaire (EPIQ). This tool includes items related to leadership, belonging to the dimension of the Incident Command System, which is considered disaster leadership training.[34] The studies that reported participants ranged between 76-[34]197.[36]

Table 3. Descriptive characteristics of the programs implemented

Variables	Categories	n	%
Type of institution	Professional	15	88.24
	Technician	1	5.88
	Both	1	5.88
Career where the program takes place	Nursing	10	58.82
	Medicine	3	17.65
	Nursing Medicine Paramedic	2	11.76
	Paramedic	2	11.76
Course or program level (years)	Not reported	9	52.94
	1	1	5.88
	2	1	5.88
	4	3	17.65
	5	1	5.88
	7	2	11.76
Number of locations in which it is implemented	1	12	70.59
	2	4	23.53
	3	1	5.88
Intervention format	In-person	12	70.59
	Blended	4	23.53
	Online	1	5.88
Organization of the participants	Small group (up to 12)	9	52.94
	Individual	4	23.53
	Full class	4	23.53
Teacher profession	Nurse	5	29.41
	Physician	2	11.76
	Nurse and physician	2	11.76
	Paramedic	1	5.88
	No register	7	41.18

The studies generally agree that VR enhances student satisfaction and provides an immersive experience. However, results on its effectiveness for long-term performance and retention are mixed. Some studies suggest that VR is superior for retention,[35] while others indicate that traditional methods may still outperform VR regarding immediate post-intervention accuracy.[34] VR simulations also effectively taught leadership skills related to emergency preparedness. Leadership aspects include assessing site safety for oneself, co-workers, and victims during large-scale emergency events (Item 6) and recognizing tasks that should not be delegated to volunteers (Item 8). VR simulation training improves students' self-confidence in disaster environments.[34]

Limitations

Although the research team had content expertise and relevant experience in disaster medicine and simulation, including only 1 reviewer for the initial exclusion of abstracts may have introduced selection bias. Additionally, while the final thematic analysis involved field experts and simulation experts, discrepancies were resolved through consensus rather than blind assessment by multiple reviewers. This approach could have affected the objectivity of the findings. Furthermore, the review excluded non-English studies due to the language limitations of the team, potentially missing insights from non-English-speaking regions, thus limiting the generalizability of the results to these regions. None of the studies analyzed in this review declare that they adhere to deliberate practice principles, which could be considered a limitation. This gap presents an opportunity for future implementations and research.

Discussion

This scoping review has identified a limited number of publications on the use of VS for teaching disaster medicine to undergraduate health sciences students, despite a growing interest in recent years driven by technological advancements and the global shift toward virtual learning due to the COVID-19 pandemic.[38]

The findings suggest that, while VS shows promise, its implementation has been largely isolated and concentrated in specific regions, mainly focusing on nursing education. Songwathana and Timalsina highlighted the urgent need for training nurses in developing countries, emphasizing the importance of education and training in improving readiness for disaster situations.[39] Some institutions have acknowledged that technological innovations like VS offer significant potential for advancing nursing education, particularly in disaster preparedness.[32–37] VS facilitates experiential learning by immersing learners in high-pressure disaster scenarios, allowing for scenario repetition, structured assessments, and immediate feedback, which enhances skill acquisition and decision-making under stress.[6,14] The ability to measure performance through data analytics enables personalized learning pathways and targeted skill reinforcement.[5] Incorporating these tools into nursing training programs is essential for equipping nurses with the skills and competencies to respond effectively to emergencies and disasters.[40]

All the studies on triage training suggest that VR can be an effective tool for increasing triage completion speed, accuracy, and self-confidence among participants through scenario repetition and structured feedback.[21,23,24] Additionally, VR enhances interprofessional communication by improving coordination, role distribution, and information sharing among health care teams during triage scenarios.[22] VR has proven effective in teaching various skills to both medical[41] and nursing students,[42] particularly by fostering engagement, reinforcing decision-making under pressure, and improving emotional control through immersive, high-stress simulations.

VS has demonstrated benefits in knowledge retention and emotional control under pressure during earthquake evacuation exercises.[29,30,31] These positive results are consistent across various types of training, from evacuation management to developing computational thinking skills in emergency contexts. Globally, Emergency Medical Systems are often unprepared for effective responses to major emergencies and disasters.[43] Key strategies for improving hospital disaster response include staff training and collaboration with external partners.[44] Because students are part of the hospital community, their training should also be integrated into these preparedness strategies.

Decontamination skills were the focus of 6 training programs developed between 2014 and 2022 at a single US institution.[32–37] Over time, the program has evolved and increased its training capacity, becoming more comprehensive. Managing trauma patients exposed to biological, chemical, or radiological agents is a low-frequency, high-risk scenario requiring specific skills, and VS has emerged as one of the most effective training options for this purpose.[45] However, nurse experiences in this area indicate that further efforts are needed to improve training and preparedness.[46]

Studies generally agree that VR enhances student satisfaction and offers an immersive learning experience. However, the evidence on its long-term effectiveness and retention is mixed. Some research suggests that VR leads to better retention,[35] while other studies indicate that traditional methods may still outperform VR regarding immediate post-intervention accuracy.[34] Additionally, VR simulations have proven effective in teaching leadership skills, boosting students' confidence in managing disaster scenarios.[34]

Some of the early studies in this review emphasize the positive impact of VR on critical skills training and knowledge retention while also noting the technological limitations and high cost of large-scale implementation.[12] Although these initial studies suggest that VR may not be superior to other methods unless it is well integrated with experiential learning theory,[12,28] this perspective evolves. One of the later studies on general disaster preparedness concludes that the perception of the learning environment, including realism and control, is a key factor in the effectiveness of simulation.[12] While VR has shown promise as an educational tool for disaster preparedness, its superiority over traditional methods depends on several factors. Studies on triage training indicate that VR improves speed, accuracy, and self-efficacy, but its effectiveness varies based on scenario repetition, structured feedback, and platform design.[21,23,24] For disaster preparedness, 3D VR simulations demonstrated superior knowledge retention, while familiarity with technology and environmental perception significantly influenced outcomes.[12,25,27] Evacuation training studies highlighted VR's role in improving anxiety control and decision-making, but practical skill acquisition depended on the training structure.[29,30,31] In decontamination training, VR effectively taught leadership and emergency preparedness skills, although traditional methods outperformed VR in immediate post-intervention accuracy.[34-36]

Recent studies show an increase in the number of VS interventions,[24,25,27,29] participants,[36] and the adoption of interprofessional formats in disaster education.[25,27] This suggests an expanding interest in VS applications, likely driven by technological advancements. However, the literature remains limited and lacks longitudinal studies assessing long-term effectiveness and standardized implementation. While VS presents an opportunity to enhance disaster preparedness training, further research is needed to confirm its impact and scalability across educational settings.

Our results underscore the importance of expanding the scope and consistency of these educational interventions. Previous studies have shown that the effectiveness of simulation in improving technical and decision-making skills depends on the use of deliberate practice programs.[47] However, none of the studies analyzed in this review implemented these principles, which could be considered a limitation. This gap presents an opportunity for future implementations and research.

A recent review found that in disaster-prone countries, nurses often lack adequate knowledge and skills to respond to critical situations, including emotional relief during disasters.[48] Despite this, there is still a significant gap in integrating disaster medicine training at the undergraduate level, particularly in disaster-prone countries. Strengthening preparedness among professionals, health care students, first responders—including firefighters—and civilian volunteers is crucial for improving coordinated disaster response and emergency medical care to improve community safety. Virtual simulation (VS) has emerged as an effective tool to bridge this gap by providing immersive, risk-free training environments that enhance decision-making, communication, and teamwork,[22,34] and specific skills[21,23,24] in undergraduate students, and it could be extensive for other civilians. This review focuses exclusively on undergraduate health care students' training for disaster response, with no data on firefighters, volunteers, or civilians. However, health care students often serve as volunteers in emergencies, playing a critical role in disaster response efforts. Their training is not only essential for professional readiness but also for strengthening the broader response ecosystem, as they act as a vital link between medical teams and civil society. Large-scale mass casualty simulations have demonstrated valuable lessons in disaster response, reinforcing the role of simulation-based training in strengthening community preparedness.[49]

The Organization of American Firefighters, which represents 13 countries and, through them, more than 1.5 million volunteers, paid, military, and police firefighters, is actively working on implementing and updating its training curriculum for firefighters' training by incorporating VR technology for specific tasks such as victim search and rescue.[50] One opportunity to expand the use of VS is to use the same resources to train firefighters and students in high-pressure situations,[12] or to practice complex scenarios repeatedly, improving their performance and response capabilities during large-scale emergencies.[27] Civil society plays a crucial role in disaster response, and VS has the potential to enhance community-based training by providing scalable, immersive learning experiences, to respond effectively.[28] The Community Emergency Response Teams (CERT) program, developed by the Los Angeles Fire Department, analyzed the participation of untrained volunteers in the 1985 Mexico earthquake, where untrained volunteers rescued 700 people but tragically lost 100 of their own during the rescue efforts.[51] In collaboration with the Emergency Management Institute of the Federal Emergency Management Agency of the United States, CERT designed a training program for civilians focused on disaster-first responses, including the training of CERT instructors. The program includes mass casualty events and rescue simulations, though it has not yet incorporated VS as a training tool.[17] Given its scalability and accessibility, VS could be a valuable complement to CERT training, enabling broader participation and standardized disaster preparedness experiences. By immersing students in realistic, high-pressure scenarios, VS helps cultivate critical thinking and decision-making - key skills for health care professionals in stressful situations. Integrating VS into community disaster training could optimize costs, enhance engagement, and improve overall emergency response capabilities on a larger scale.

As health care systems face growing challenges, particularly in natural disasters and public health emergencies, the need for effective training solutions like VS becomes even more apparent. This approach underscores the importance of a multidisciplinary framework in disaster preparedness. Ultimately, incorporating VS into training not only strengthens health care teams but also enhances disaster response capacity by integrating undergraduate students into high-pressure realistic scenarios.[6] In many countries, final-year nursing and medical students actively engage in emergency care, playing crucial roles in triage and basic life support.[9] Moreover, comparisons with the training of professional nurses and physician residents suggest that VS facilitates the early acquisition of critical competencies, supporting a smoother transition into effective clinical practice.[14]

Technological advancements, particularly VS, offer significant potential for improving the preparedness of health care professionals

https://doi.org/10.1017/dmp.2025.121 Published online by Cambridge University Press

for disaster scenarios. Integrating such innovative tools into disaster response training frameworks is essential to enhance the capacity of health care workers to manage emergencies more effectively.

Conclusion

In conclusion, this scoping review highlights the increasing use of VS in disaster medicine education for undergraduate health sciences students, as reflected in the rising number of interventions, participants, and adoption of online or blended training formats. Despite its promise, VS adoption is still limited to certain regions and mainly focuses on nursing education. Integrating VS into disaster preparedness training is particularly crucial for developing countries, where health care professionals are often underprepared for emergency response. While studies demonstrate the effectiveness of VS in improving triage decision-making, anxiety control, and practical disaster response skills, its effectiveness depends on factors such as scenario repetition, structured feedback, and platform design, and challenges such as high implementation costs and the absence of deliberate practice-based programs remain.

The authors suggest that expanding VS to include a broader range of health profession students and interdisciplinary settings could improve preparedness and optimize resource usage. Virtual simulations offer a valuable opportunity to develop technical skills, critical thinking, and resilience in health care teams by immersing students in realistic, high-pressure scenarios. While resilience is a broad concept, our findings suggest that VS contributes to psychological preparedness by improving anxiety control, self-confidence, and performance under pressure, as evidenced by studies assessing anxiety management in earthquake training scenarios. Future implementations should incorporate deliberate practice principles and extend to non-health care first responders to fully harness its potential, creating a comprehensive and cost-effective disaster preparedness strategy.

Author contribution. D.T. and S.A. developed the study ideas and formulated research goals. D.T., S.A., G.N. S.V., E.H. designed the methodology and created models. S.A. handled programming, software development, implementation, and testing of code components. All authors contributed to performing experiments and data collection. D.T., S.V., and S.A. provided study materials, reagents, samples, and analysis tools. D.T., S.A., S.V. managed data annotation, cleaning, and maintenance. All authors were involved in drafting the initial manuscript and in critical review and revision. S.A. was responsible for data visualization. D.T. and S.A. oversaw research planning and execution, including mentoring and coordination.

Acknowledgements. The authors acknowledge the assistance of Claudia Martinich, Reference Librarian for Clinical Fields at Universidad San Sebastián, Chile.

Competing interests. Authors 1 and 3 are employed at Unidad de Simulación e Innovación en Salud, Universidad San Sebastián, Chile.

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