Disaster Medicine and Public Health Preparedness

www.cambridge.org/dmp

Effect of Interventions on Hospital-Based Health Care Professionals' Knowledge and Skills in Disaster Preparedness: A Systematic Review

Faisal Almutairi PhD Candidate[1,2], Josephine Hegarty PhD[1], Patrick Cotter PhD[1], Serena FitzGerald PhD[1] and Domam Alomari PhD[3]

[1]Catherine McAuley School of Nursing and Midwifery, Brookfield Health Sciences Complex, University College Cork, Ireland; [2]Hail Health Cluster, Ministry of Health, Saudi Arabia and [3]Higher Colleges of Technology, Nursing Department, Ras Al Khaima Campus, United Arab Emirates

Systematic Review

Cite this article: Almutairi F, Hegarty J, Cotter P, FitzGerald S and Alomari D (2025). Effect of Interventions on Hospital-Based Health Care Professionals' Knowledge and Skills in Disaster Preparedness: A Systematic Review. *Disaster Medicine and Public Health Preparedness*, **19**, e274, 1–16
https://doi.org/10.1017/dmp.2025.10198

Received: 25 April 2025
Revised: 30 July 2025
Accepted: 25 August 2025

Corresponding author:
Faisal Almutairi;
Email: 120222604@umail.ucc.ie

Abstract

Introduction: Health care professionals have a crucial role to play in every stage of preparing for and managing disasters. Thus, it is essential to equip health care professionals with the knowledge, skill, and competency to ensure they can adequately prepare to respond to disasters. The aim of our systematic review is to describe and evaluate the effect of educational interventions on hospital-based health care professionals' knowledge, skills, and competencies pertaining to disaster preparedness.

Methods: The review was conducted on research articles published between 2013 and 2023, sourced from five databases: CINAHL, Medline, Embase, SCOPUS, and ERIC. An intervention complexity assessment tool for systematic reviews was adapted to judge the level of intervention complexity.

Results: A total of 11,688 citations were screened for eligibility, and 53 studies met the inclusion criteria. Notably, 74% of included studies focused on knowledge assessment. Judging the complexity of intervention revealed that 60% of the included interventions scored moderate complexity, and 19% scored high complexity. Notably, all high-complexity interventions resulted in significant improvements in outcomes.

Conclusion: This review demonstrates that knowledge, skills, and competencies of health care professionals and students can be enhanced through targeted disaster preparedness educational interventions. High-complexity interventions were especially successful in improving the disaster preparedness of health care participants.

Introduction

Disasters can be classified as man-made or natural hazard-induced disasters; encompass events like hurricanes and earthquakes, while man-made disasters include regional conflicts, wars, chemical incidents, biological incidents, technological disruptions, and infectious diseases.[1,2] There are various definitions of "disaster" with most addressing certain common elements, including the unexpected or sudden nature of the events, the scale or magnitude of disruption and impact resulting in unexpected deaths, injuries, illnesses, and displacement of large numbers of people. Lastly, a disaster is a disruption beyond what a population, community, or area can manage.[3–5] In 2023, the Emergency Events Database (EM-DAT) recorded 399 natural disasters, with 86,473 fatalities and 93.1 million people affected.[6]

The impact of disasters has risen worldwide over time due to various factors, including increased population, climate change, urbanization, poverty, and escalating conflict situations. Such disasters can have a significant economic impact, resulting in the loss of employment due to injury and disability, as well as the loss of personal and public assets, such as homes, businesses, and crucial infrastructure.[7,8] Disaster science is a growing global science that deals with categorizing different types of disasters, enhancing the preparedness and management of disaster cycles, and understanding specific disaster events. By identifying vulnerable communities and agencies, scientists can help establish appropriate plans to deal with the most likely type of disaster that may strike a population, community, or agency. Furthermore, through planning, scientists and policymakers can increase awareness and reduce the impact of a disaster.[9–11]

To understand disaster preparedness, the common elements in public health are proactive planning, collaboration between stakeholders, and rapid response to mitigate risks.[12–14] Moreover, in the context of health care professionals, disaster preparedness requires knowledge, skills, abilities, and actions to be prepared to respond efficiently.[15–18] It is important to prioritize certain goals, such as maintaining operational continuity and reducing the impact of the disaster.[19–21]

During a disaster, there can be a rapid and significant increase in the number of patients, leading to both an acute and prolonged strain on health care systems.[22,23] Hospitals need strategic plans to anticipate, prevent, and respond to health emergencies, and such plans are crucial for maintaining health care facilities' resilience during disasters,[24] According to Farah et al., the preparedness of hospitals for disasters had shortcomings in areas such as education and training for health workers. Such knowledge and training of health professionals is considered crucial for disaster preparedness.[25]

Therefore, it is essential to prepare for disasters by identifying potential hazards, assessing vulnerabilities, and equipping health care professionals with the necessary skills, knowledge, and competencies to respond effectively.[16,17,26] Health care professionals must be prepared through rigorous education and training to effectively meet the diverse health demands of disaster-prone populations.[27–30] The roles, scope of practice, and training requirements of health care professionals vary by discipline, and to address this variability, both undiscipline training (which reinforces discipline-specific competencies) and interdisciplinary training (which fosters team-based competencies such as collaboration, mutual understanding, and coordinated decision-making) enhance communication and coordination during emergencies, which is essential for an effective response.[31]

As defined by the US Department of Education, competency is "a combination of skills, abilities, and knowledge needed to perform a specific task"(p. Vii).[32] The core competencies for emergency preparedness training cover a wide range of knowledge and skills.[33] Walsh et al. differentiate between knowledge (facts and figures) and skills (psychomotor or mental operations).[34] Regular updates and skills testing in simulated scenarios can identify gaps in preparedness and improve health care professionals' abilities to handle a disaster.[35–37] Competency-based training programs are tailored to address the specific demands unique to a disaster situation, thereby helping to better prepare health care professionals [27]. Previous research suggests that disaster preparedness can be enhanced through various educational interventions, such as implementing an emergency preparedness curriculum in universities,[38] utilizing virtual reality (VR) and tabletop drills for practical training,[39] continuous development courses and programs to keep individuals and organizations updated,[40] and leveraging technology-based methods to improve training efficacy.[41]

This review builds on previous systematic reviews conducted on disaster preparedness among health care professionals that have predominantly focused on disaster preparedness among nurses without investigating other health care professional groups.[2,42–44] Our review focused on health care professionals and aimed to evaluate the impact of educational interventions on the knowledge, skills, and competencies of hospital-based health care professionals regarding disaster preparedness.

Methods

Review Questions

Q1: What educational interventions have been used to address hospital-based health care professionals' disaster preparedness in the hospital context?
Q2: What impact do educational interventions have on the primary outcomes of hospital-based health care professionals' knowledge, skills, and competencies in disaster preparedness?
Q3: What impact do educational interventions have on the secondary outcomes of hospital-based health care professionals' preparedness or readiness for responding to a disaster or their actual performance in responding to a disaster?
Q4: What factors and intervention components are linked to positive and/or negative changes in the primary and secondary outcomes as reported in the included interventional studies?

Search Details

The *Cochrane Collaboration Handbook of Systematic Reviews* guided the review.[45] Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines were used.[46] A protocol for this systematic review was registered on PROSPERO number CRD42023488543.

Search Strategy

The review included publications in English and Arabic from January 2013 to September 2023 and searched electronic databases, including CINAHL, Medline, Embase, SCOPUS, and ERIC. Key terms are framed around Population, Intervention, Comparison, Outcomes, Timelines, and Setting (PICOTS) with search terms supplied in supporting documentation (supplementary file 1). Limiting the language to Arabic and English was necessary as the authors are competent in both English (FA, JH, SF, DA, and PC) and Arabic (FA and DA) only. While English is the primary language used in global scientific publication, the inclusion of papers published in Arabic will ensure inclusion of regional studies for the 22 Arab speaking countries and a total of 473 million people.[47]

Eligibility Criteria

The criteria for including and excluding studies were developed using the PICOST method (Table 1).

Study Selection

One reviewer (FA) conducted the search within each database separately; search strategies were checked by review authors. All studies identified and cited were uploaded to Covidence, a web-based software platform, and duplicate citations were removed automatically. The screening process was undertaken in two stages; firstly, review authors (FA, DA, SF, PC, and JH) independently screened all study titles and abstracts against the inclusion criteria in pairs. Secondly, the potentially eligible studies identified during the title and abstract screening were screened in full text by reviewers (FA, DA, SF, PC, and JH) independently in pairs. Conflicts were resolved by discussion with a third author. The PRISMA 2020 flow diagram was used to report the screening and selection process.[46]

Study Quality Assessment

In this review, the quality of research papers was evaluated using the Mixed Methods Appraisal Tool (MMAT).[48] For randomized studies, Cochrane's Risk of Bias version 2 (RoB 2) was used to assess the risk of bias.[49]

One reviewer (FA) performed the quality assessment and risk of bias evaluation for all studies included in the review. After that, one of the other four reviewers (DA, SF, PC, and JH) assessed the evaluation process of each study independently. Any conflicts that were identified were resolved through consensus with a third reviewer.

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 1. Summary of eligibility criteria

Criterion	Description
Population	The population included hospital-based health care professionals, who were either registered health care professionals or students in health care programs. Those whose primary role or practice is outside a hospital setting and other non-hospital stakeholders were excluded.
Intervention	The educational intervention only focused on developing knowledge, skills, and competency in disaster preparedness for health care professionals. Literature not related to this topic and pandemic-related and cyber threat-related preparedness interventions were excluded.
Outcomes	The primary outcomes are knowledge, skill, and competency in disaster preparedness. Secondary outcomes include health care professionals' preparedness and readiness for responding to a disaster.
Setting	The setting included acute, elective medical, surgical, emergency, and maternity hospitals. It excluded field or temporary hospitals, dental, veterinary, psychiatric hospitals, community residential care settings, and pre-hospital settings.
Study design	Experimental and quasi-experimental studies measuring the impact of interventions on primary and/or secondary outcomes; feasibility, pilot studies, and associated process evaluations were included. Non-interventional designs were excluded.

Data Extraction and Synthesis

The data extraction forms were designed to extract data from all included studies. Details of the characteristics of the included studies (author, year, country, setting, study design, aim, participant profession, sample size, outcomes and corresponding Kirkpatrick level of evaluation,[50] and quality assessment score). The Kirkpatrick Model includes four levels for evaluating educational interventions: reaction, learning, behavior, and results.[50] In this review, outcomes were assessed related to level 2 learning and level 3 behavior of the evaluation model. Data relating to each review question were extracted. Intervention details were extracted and summarized using the 12 items from the Template for Intervention Description and Replication (TIDieR) checklist.[51]

The interventions reflected in this review were considered complex interventions. Simulation fidelity is the degree of realism and accuracy with which a simulated system replicates the real world.[52,53] Many authors have noted a lack of clarity and a degree of ambiguity in assessing the level of simulation fidelity when presenting details of interventions within systematic reviews.[54–56] Therefore, the authors have used the term "complexity of the intervention" in this review to encapsulate aspects that describe the level of complexity of the included interventions. Within Cochrane training relating to intervention complexity, Thomas and colleagues defined intervention complexity by (1) the quantity of components, (2) the ways the components interact, or (3) the larger system within which the intervention is implemented.[57] Noyes et al. claim that studies frequently do not precisely define the degree, type, or dimensions of intervention complexity. Intervention complexity is the way various factors affect an intervention's outcomes, including the intervention's characteristics, the context in which it is implemented, and the interactions among them.[58]

To judge the level of complexity, we adapted and used the Intervention Complexity Assessment Tool for Systematic Reviews (iCAT_SR).[59] Dimensions considered in judging are duration and frequency of intervention, the perceived level of interaction between components of the intervention, perceived level of realism in the portrayal of the emergency situation, behavioral changes acquired or outcomes attributed to the intervention, number of components in the intervention, and delivery of the intervention as described in Table 2.

Reviewers categorized the complexity level of all included interventions into three categories across six dimensions. These categories are low complexity, scored between 1 and 2; moderate complexity, with scores ranging from 3 to 4; and high complexity, scored between 5 and 6. Such judgments were made by assessing interventions across six dimensions (duration, component interaction, realism, behavioral changes, number of components, and delivery of the intervention). Based on the total scores assigned to each intervention, the scoring system provided a systematic and standardized way to classify interventions according to their perceived complexity, defined as low complexity for scores between 1 and 12, moderate complexity for scores between 13 and 24, and high complexity for scores between 25 and 36. Interventions were categorized into six potential levels based on a combination of reviewers' judgments regarding the complexity of the intervention and the details of the modality, where single modality consists of only one type of instruction format or method, while multimodality interventions incorporate more than one type of instruction format and involve multiple modes of communication and representation of the intervention. The levels are (1) single modality, low complexity, (2) multimodality, low complexity, (3) single modality, moderate complexity, (4) multimodality, moderate complexity, (5) single modality, high complexity, and (6) multimodality, high complexity.

A narrative synthesis was conducted to describe the studies based on the following: (1) the study's characteristics (Table 3 and supplementary file 2); (2) included study's primary and secondary outcomes linked to the Kirkpatrick Model levels[50] presented in a tabular format (Table 4); (3) disaster preparedness interventions, described using the TIDieR checklist,[51] (supplementary file 3); and (4) the disaster preparedness educational interventions categorized based on their complexity levels and the modalities utilized in the included studies (Table 5).

One reviewer (FA) extracted and synthesized the data from the included studies. Four reviewers (DA, SF, PC, and JH) independently reviewed and checked the extraction and synthesis process. Disagreement was resolved through discussion between all reviewers.

Patient and Public Involvement

As this was a systematic review of the literature using existing publicly available information, no patients were directly involved in the review.

Results

Results of the Search

The initial database search identified 11,688 citations; after removing 4,826 duplicates, titles and abstracts of the remaining 6,862 citations were screened; 107 underwent full-text review, and 53 papers were selected for data extraction (Figure 1).

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 2. Description of the level of complexity

Complexity	Low (1-2)	Moderate (3-4)	High (5-6)
Duration and frequency of intervention	The intervention is either too short or not allocated enough time (e.g., could be a cross-sectional, once off, intervention of short duration).	The intervention is not long enough to adequately convey information (e.g., could be delivered more than once but judgment made that intervention duration is not long enough to adequately convey information required).	The intervention is longitudinal and perceived to be long enough to convey required information.
The perceived level of interaction between components/elements of the intervention	The intervention elements were conducted separately with minimal interaction or none at all.	Some of the intervention elements interact with each other.	The intervention elements interacted meaningfully with each other.
Perception of level of realism in the portrayal of the emergency situation	The intervention does not replicate a real disaster situation.	The intervention provided some/partial replication of a real disaster situation.	The intervention replicates a real disaster situation.
Behavioral changes acquired or outcomes attributed to the intervention	The intervention targets a single outcome, such as enhancing knowledge.	The intervention targets two outcomes.	The intervention targets three or more outcomes.
Number of components in the intervention	The intervention consists of just one component/pedagogical approach such as lecture or drill.	The intervention consists of two components/ pedagogical approaches.	The intervention consists of three or more components/ pedagogical approaches.
Delivery of the intervention	The intervention is provided by individuals with general training or experience.	The intervention is provided by health care professional with additional qualifications.	The intervention is provided by experts in disaster or health care professionals with extensive disaster training.
Total scores (range)	6–12	13–24	25–36

Items used by authors to judge the level of complexity adapted from Lewin et al. (2017). Criteria not reported or not included in description; NR = 0 for those criteria was used.

Study Characteristics

Out of the 53 studies included in the review, the majority were conducted in the United States of America (USA) (n = 24) (45%). Four studies were conducted each in South Korea (n = 4) and Iran (n = 4), three in Turkey (n = 3) and China (n = 3), and two in India (n = 2), Indonesia (n = 2), Taiwan (n = 2), and Italy (n = 2). Additionally, one study was conducted in Saudi Arabia (n = 1), Australia (n = 1), Jordan (n = 1), France (n = 1), Hong Kong (n = 1), Canada (n = 1), and Germany (n = 1). The included studies show that research was primarily conducted in continental North America (47%), Asia (38%), Europe (13%), and Australia (2%), with a notable absence of studies in Africa and South America.

The sample size ranged from a minimum of 10[60] to a maximum of 2,246 participants.[61] The total number of participants across the included papers was 7,053, which included registered health care professionals (n = 2,016) and student health care professionals (n = 5,037). The disciplines represented across studies included nurses (n = 2,530), doctors (n = 1,079), pharmacists (n = 105), and other mixed samples of health care professionals (n = 3,339).

All studies conducted in China, Turkey, South Korea, Iran, India, and Indonesia focused exclusively on nursing professionals or nursing students, with a total of 18 studies. Therefore, in these countries, the interventions targeted only nursing, with no studies involving other health care professions or multidisciplinary groups. Conversely, studies conducted in the United States included a broader range of health care professions, while nurses represented 29% of the 24 studies. Additionally, there are sixteen studies involved a diverse group of participants, including a range of health care professionals and students such as nurses, physicians, and pharmacists.

The included studies utilized a range of diverse study designs, including one-group pre/post-test design (n = 28), randomized control trial (n = 15), mixed methods approach (n = 5), and quasi-experimental design (n = 4). Studies were conducted in universities (n = 29), hospitals (n = 18), during conferences (n = 2), and completely online (n = 1) (Table 3).

Quality Assessment

The studies were evaluated using the MMAT,[48] which assessed each study with targeted questions with three distinct responses: "yes," "cannot tell," or "no." All studies had clearly defined research questions, ensuring a focused assessment. Among the fifteen randomized control trials, twelve successfully met all five appraisal criteria, achieving a score of 100%. In contrast, the lowest recorded score was 20%.[62] Furthermore, it was challenging in non-randomized studies to identify potential confounders that were accounted for in the study's design or analysis.

The assessment of the risk of bias in the fifteen randomized studies (supplementary file 4) revealed several key findings. 53% of the trials were found to have a high overall risk of bias. In terms of the randomization process, 73% of the trials demonstrated a low risk of bias. However, 60% of the trials raised concerns about deviations from the intended interventions. 73% of the trials were considered to have a low risk of bias related to missing outcome data. In terms of the measurement of outcomes, 53% of the trials were rated as having a low risk. Finally, concerns were raised about the selection of reported results in 93% of the trials, indicating that the analyses used did not specify primary outcomes, lacked sufficient information, or had no pre-registered analysis plan referenced within the paper.

Outcomes

Each study's primary and secondary outcomes were categorized according to the four levels of the Kirkpatrick Model for evaluating

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 3. Included study characteristics (n = 53 studies)

Characteristic	Detail
Country	United States of America (USA) (n = 24) Iran (n = 4) South Korea (n = 4) Turkey (n = 3) China (n = 3) Indonesia (n = 2) Taiwan (n = 2) Italy (n = 2) India (n = 2) Saudi Arabia (n = 1) Australia (n = 1) Jordan (n = 1) France (n = 1) Hong Kong (n = 1) Canada (n = 1) Germany (n = 1)
Setting	University (n = 29) Hospital (n = 18) Conference based (n = 2) Online (n = 1)
Participants and professions	Participants in total (n = 7053) Health care professional students (n = 5037) Registered health care professionals (n = 2016) Health care professional mixed sample (n = 3339) Nurse (n = 2530) Doctor (n = 1079) Pharmacists (n = 105)
Study design	A one-group pre/post-test design (n = 29) Randomized control trial (n = 15) Mixed methods approach (n = 5) Quasi-experimental design (n = 4)
Outcomes categorized according to Kirkpatrick levels+	Level 2 (learning): - knowledge (n = 39) - skills (n = 7) - competency (n = 8) Level 3 (behavior): - readiness (n = 4) - preparedness (n = 11)
Theories, frameworks, and models used in intervention	Kolb's experiential learning theory (n = 2) Eight core competencies defined by the Emergency Preparedness Information Questionnaire (n = 1) Flow theory (n = 1) The National League for Nursing Jefferies Simulation Theory (n = 1) Knowledge to Action Theoretical Framework (n = 1) The theories of situated cognition (n = 1) The theory of international disaster medicine in humanitarian assistance (n = 1) The Cognitive Load Theory (n = 1) The International Council of Nurses Framework (n = 5) The Framework of Mental Health and Psychosocial Support and the Inter-Agency Standing Committee Mental Health and Psychosocial Support Pyramid (n = 1) The National League of Nurses Laerdal Simulation Model (n = 1) Taiwan's Emergency Response Centre (n = 1) Model for Evidence-Based Practice Change (n = 1) Fink's Taxonomy of Significant Learning (n = 1) The TeamSTEPPS evidence-based framework (n = 1) Model of Pfenninger and colleagues (n = 1) The Jennings Disaster Nursing Management Model (n = 1) Core Disaster Life Support (n = 1) The framework of the "nursing practices in extraordinary conditions" (n = 1)

+ Adapted from Kirkpatrick and Kirkpatrick (2016). Level 2 Learning: Acquisition of health care professionals' knowledge, skill, and competency. Level 3 Behavior: Effect of educational interventions on health care professionals' readiness and preparedness in their workplace.

training and learning programs[50] (Table 4). Level 2 of the Kirkpatrick Model (learning) was reported as participant knowledge (n = 39 studies), skills (n = 7 studies), and competency (n = 8 studies). Notably, knowledge was measured in 74% of the included studies. For level 3 (behavior), change in behavior was referred to as readiness for disaster (n = 4 studies) and preparedness for disaster (n = 11 studies).

In 30 studies out of 39, statistically significant improvements in disaster preparedness knowledge were observed (77%). Disaster preparedness knowledge was operationalized in different ways measuring slightly different aspects of a concept. These included disaster preparedness knowledge in a generic context (n = 18 studies).[35,36,61,63–77] In addition, studies operationalized disaster preparedness knowledge across various fields, including disaster triage knowledge and accuracy (n = 4),[78–81] knowledge of Mass Casualty Incidents (MCI) (n = 2),[82,83] disaster knowledge through drills (n = 2),[84,85] psychological first aid performance (n = 1),[86] biological incidents (n = 1),[87] the Disaster Olympics model (n = 1),[88] and evacuation procedures during disasters (n = 1).[89]

Participants' disaster preparedness skills were evaluated in seven studies, with six showing statistically significant improvement post-intervention.[35,71,73,81,90,91] Al-Qbelat et al. found that disaster preparedness skills had mean scores rising from 3.88 to 4.79 ($p \leq .001$),[35] and Ma et al. reported significant improvement in disaster nursing skills for nursing students, especially in the intervention group ($p = 0.008$).[90]

Eight studies evaluated disaster preparedness competency, and results showed significant improvements in all studies across various areas. Improvements in competencies related to general disaster preparedness were reported in five studies.[69,75,90,92,93] Other studies took a more focused approach and described significant improvements in psychological first aid performance competence,[86] competency of nurses in biological incidents,[87] and competencies in MCI management.[94] Disaster preparedness competencies across studies demonstrated significant improvement following targeted interventions ($p < 0.001$).[86,87,92]

Two out of four studies showed significant improvement in disaster readiness, with one reporting on perceived readiness for evacuating ill patients ($p < 0.001$)[91] and the other reporting on nursing students' readiness ($p < 0.001$).[36]

The preparedness of participants was evaluated in 11 studies, with 10 studies reporting significant improvements in preparedness generally (n = 8),[35,60,79,95–99] and preparedness in specific situations including chemical[39] and bioterrorism incidents.[66] A study on nursing students' preparedness for bioterrorism across three areas indicates significant findings in three domains: communication ($p = 0.001$), command system ($p = 0.001$), and isolation ($p = 0.002$).[66]

Outcome results varied by setting, although a definitive pattern was not evident. Interventions were administered in universities in 29 studies, with significant improvements in 20 studies at level 2 and 6 at level 3, where 2 studies measured both outcome levels.[36,66] Conversely, interventions in hospitals were delivered in 16 studies, with significant improvements in 12 at level 2 and 3 at level 3, where 2 studies assessed both outcome levels. Two studies conducted in hospital and university settings reported significant improvements in level 2 outcomes.[67,100] A variety of tools were identified to measure disaster preparedness. The most frequently used is the Emergency Preparedness Information Questionnaire (EPIQ), utilized in four studies,[66,75,76,95] while two studies created their tools based on EPIQ.[39,99]

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 4. Summary of findings on the effectiveness of disaster preparedness interventions using Kirkpatrick model (N = 53)

Author (year)	Overall categorization of the intervention 1. Single modality, low complexity 2. Multimodality, low complexity 3. Single modality, moderate complexity 4. Multimodality, moderate complexity 5. Single modality, high complexity 6. Multimodality, high complexity	Level 2A: knowledge	Level 2B: skill	Level 2C: competency	Level 3A: readiness	Level 3B: preparedness
Al-Qbelat (2022)[35]	3	1	1			1
Alim (2015)[84]	6	1				
Aluisio (2016)	4	0				
Amberson (2020)[95]	3					1
ArunKumar (2018)[70]	1	1				
Bajow (2022)[27]	6	1				
Bank (2016)[93]	4			1		
Becker (2021)[89]	4	1				
Betka (2021)[92]	4			1		
Castoldi (2022)[94]	6			1		
Chang (2022)[39]	4					1
Dadario (2022)[82]	4	1				
Daniel (2016)[88]	1	1				
Davis (2020)[65]	6	1				
Ebadi (2015)[87]	2	1		1		
Georgino (2015)[75]	4	1		1		
Ghahremani (2022)[66]	4	1				1
Ghezeljeh (2019)[63]	1	1				
Glow (2013)[26]	4	0				
Gray (2020)[91]	4		1		1	
Hermann (2021)[77]	6	1				
Hollister (2021)[83]	1	1				
Hosseini (2022)[67]	6	1				
Huh (2019)[36]	1	1			1	
Hung (2021)[68]	6	1				
Husna (2020)[85]	2	1				
Ingrassia (2014)[78]	4	1				
Iqbal (2022)[69]	6	1		1		
Jung (2016)[114]	4	0	0			
Kim (2020)[105]	4	0				
Kim (2022)[86]	6	1		1		
Kılıç (2019)[98]	4					1
Koca (2020)[97]	1					1
Li (2022)[79]	6	1				1
Ma (2021)[90]	4		1	1		
Marks (2022)[60]	4					1

(*Continued*)

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 4. (*Continued*)

Author (year)	Overall categorization of the intervention	Level 2A: knowledge	Level 2B: skill	Level 2C: competency	Level 3A: readiness	Level 3B: preparedness
Montana (2019)	1	0				
Ngo (2016)[100]	4	0				
Noh (2020)[71]	4	1	1			
Owens (2017)[61]	4	1				
Phan (2023)[62]	4	0				
Scott (2013)[73]	4	1	1			
Scott (2018)[72]	4	1				
Sena (2020)[106]	4	0				
Shannon (2015)[101]	4				0	
Shostrand (2023)[76]	4	1				
Shujuan (2022)[99]	2					1
Tsai (2020)[74]	4	1				
Unver (2018)[96]	4				0	1
Vargas (2019)[80]	4	1				
Watson (2021)[104]	2					0
Wiese (2021)[111]	4	0				
Xia (2020)[81]	4	1	1			

1 indicates a statistically significant improvement in outcome ($P < 0.05$); 0 indicates that no statistically significant change has been observed (Kirkpatrick and Kirkpatrick, 2016). Modality refers to the approaches used in intervention, and the complexity associated with the judgment scores provided by authors.

Template for Intervention Description and Replication (TIDieR) Checklist

We aimed to answer the key questions related to the intervention components using the TIDieR (supplementary file 3). Among the 35 studies, ten studies utilized a single modality approach. In contrast, multimodality approaches were used in 43 studies. In 43 studies simulation was used. Lectures were used in 35 studies. Multiple mixed procedures interventions were employed in nineteen studies, while debriefing was utilized in 17 studies. Pre-briefing was implemented in six studies. Additionally, simulation and lectures were combined in 32 studies.

The intervention facilitators were reported as nurses (20/53), interprofessional education teams (11/53), doctors (6/53), and other professions (5/53). The information about the intervention provider in 11 studies was not explicitly reported. The researchers participated in delivering the intervention in 14 studies. A total of 21 studies employed various theories, models, and frameworks to provide a foundation for the intervention reported in Table 3. The interventions were administered in a university (n = 29), a hospital (n = 16), and other settings (n = 7). Three studies did not report the setting in which the intervention was delivered. Two studies delivered their intervention in two settings: a hospital and a university.[67,100]

Complexity

The reviewers created a structured framework to analyze and compare the effectiveness of various approaches by categorizing interventions based on their modality and complexity (Tables 2 and 5). These results do not reflect effect sizes or meta-analysis.

A review of the studies reveals that out of a total of 15 studies; 3 studies were judged based on the level of complexity of their interventions; 11 (21%) are categorized as low complexity, 31 (60%) as having moderate complexity, and 10 (19%) as high complexity. The complexity scores ranged from a low of 7,[70] to a high of 29.[77] This range of scores illustrates the diversity in complexity of interventions across the examined studies, as summarized in Table 6.

For both Kirkpatrick levels (2 and 3), 82% of included studies achieved significant changes for low complexity interventions, 72% for moderate complexity, and 100% for high complexity. Regarding Kirkpatrick level 2 outcomes; 86% of low complexity interventions, 64% of moderate complexity, and 100% of high complexity interventions achieved statistically significant improvements in the outcomes measured. For Kirkpatrick level 3 outcomes, 75% of low complexity interventions, 75% of moderate complexity, and 100% of high complexity interventions achieved statistically significant improvements in outcomes.

When combining intervention modality and level of complexity into six categories, 13% were single modality low complexity interventions (7/53), 8% were multimodality low-complexity interventions (4/53), 4% were single modality-moderate complexity interventions (2/53), 56% were multimodality-moderate complexity (30/53), and 19% were multimodality-high complexity (10/53). Notably, no studies were available for single modality-high complexity. In terms of Kirkpatrick level 2 outcomes; 83% of single modality-low complexity interventions, 100% of multimodality-low complexity interventions, 100% of single modality-moderate complexity interventions, 68% of multimodality-moderate complexity, and 100% of multimodality-high complexity achieved statistically significant improvements in outcomes. Moreover, for Kirkpatrick level 3 outcomes; 67% of single modality-low complexity interventions, 50% of multimodality-low complexity interventions, 100% of single

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 5. Intervention complexity and modality of disaster preparedness educational interventions (N = 53)

Author (year)	Modality of intervention	Modality of intervention: Simulation	Complexity of intervention	Overall categorization of the intervention
	1. Lecture/Power-Point 2. Pre-reading or pre-preparation 3. Pre-briefing 4. Debriefing 5. Multiple mixed procedures	1. Using task trainers 2. Virtual simulation 3. Augmented reality 4. Gamed simulation 5. Tabletop simulation 6. Live simulation/simulation of a real-world emergency/disaster using drill 7. Hybrid simulation	1. Low 2. Moderate 3. High	1. Single modality, low complexity 2. Multimodality, low complexity 3. Single modality, moderate complexity 4. Multimodality, moderate complexity 5. Single modality, high complexity 6. Multimodality, high complexity
Al-Qbelat (2022)	5		2	3
Alim (2015)	1,4	6	3	6
Aluisio (2016)		5,6	2	4
Amberson (2020)	5		2	3
ArunKumar (2018)	1		1	1
Bajow (2022)	1	1,6	3	6
Bank (2016)	1,4	6	2	4
Becker (2021)	5	6	2	4
Betka (2021)	1	1,6	2	4
Castoldi (2022)	1,4	2,6	3	6
Chang (2022)	1	2,5	2	4
Dadario (2022)	5	5,6	2	4
Daniel (2016)	5		1	1
Davis (2020)	3,4	1,6	3	6
Ebadi (2015)	1,5		1	2
Georgino (2015)	1,5	5	2	4
Ghahremani (2022)	1	6	2	4
Ghezeljeh (2019)	5		1	1
Glow (2013)	1	6	2	4
Gray (2020)	1	6	2	4
Hermann (2021)	1,5	2,5,6	1	6
Hollister (2021)		6	1	1
Hosseini (2022)	1,4,5	7	3	6
Huh (2019)	5		1	1
Hung (2021)	1,5	1	3	6
Husna (2020)	3	5	1	2
Ingrassia (2014)	1	2,5	2	4
Iqbal (2022)	1	1,6	1	6
Jung (2016)	4	6	2	4
Kim (2020)	1,4	6	2	4
Kim (2022)	1,3,4,5	6	3	6
Kılıç (2019)	1	1	2	4
Koca (2020)	5		1	1
Li (2022)	1,4	6	3	6
Ma (2021)	4,5	6	2	4

(*Continued*)

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 5. (*Continued*)

Author (year)	Modality of intervention	Modality of intervention: Simulation	Complexity of intervention	Overall categorization of the intervention
Marks (2022)	4	6	2	4
Montana (2019)	5		1	1
Ngo (2016)	1,5	2,5,7	2	4
Noh (2020)	1	1,5	2	4
Owens (2017)	1,5		2	4
Phan (2023)	3,4	6	2	4
Scott (2013)	1	1,6	2	4
Scott (2018)	1	1,4	2	4
Sena (2020)	1,5	5	2	4
Shannon (2015)	1	1,4	2	4
Shostrand (2023)	1	5	2	4
Shujuan (2022)	1	6	1	2
Tsai (2020)	1	1,2	2	4
Unver (2018)	1,2,3,4	1	2	4
Vargas (2019)	1	6	2	4
Watson (2021)	1	1	1	2
Wiese (2021)	2,4	1,2,6	2	4
Xia (2020)	1,4,5		2	4

modality-moderate complexity interventions, 75% of multimodality-moderate complexity, and 100% of multimodality-high complexity interventions demonstrated statistically significant improvements in outcomes.

Discussion

This systematic review identified 53 studies, encompassing (n = 7,053) health care professionals and students, that assessed the effectiveness of educational interventions specifically designed to improve the disaster preparedness of health care professionals and students within hospital settings. Evidence shows that disaster preparedness education interventions must provide comprehensive, structured training to address the number of components and their interaction, sufficient time to cover disaster topics, and replicate real disaster events. These interventions equip participants with essential knowledge, skills, and competencies.

The details of interventions included in the review were extracted using The TIDieR,[51] we found that all studies labelled their interventions according to either the descriptions of the intervention or delivery method, resulting in unique names for each intervention, with no study employing the same educational intervention or programs. The rationale behind various interventions highlights the importance of basing these interventions on robust research and expert advice, with the primary goal of establishing a strong foundation for disaster preparedness educational interventions. Furthermore, most of the interventions examined in this review are grounded in well-established theories and frameworks. One such theory used is Kolb's experiential learning theory,[76,101] which is instrumental in creating interventions that offer more impactful and engaging learning experiences. Additionally, the International Council of Nurses framework was employed to ensure the interventions were comprehensive, focused, and effective.[36,67,68,84,90]

The duration of educational interventions varied significantly across the selected studies. In this review, the implementation of training ranged from approximately 10 minutes[91] to over 37 hours.[64] There is a relationship between the duration and the level of intervention complexity, as the duration influences the judgment of intervention complexity. Specifically, the duration allocated to an intervention plays a crucial role, as more time ordinarily ensures that more of the key topics and components are covered. Moreover, Alim argues that challenges arise in covering disaster preparedness topics within a limited time.[84] Longer interventions involve simulations, workshops, and team drills that demonstrate enhanced response skills and coordination among health care workers and emergency responders.[102] Tailoring the intervention is an essential aspect of meeting the specific needs of participants while developing education content and during implementation.[18,103] Moreover, in the included studies, the authors noted reasons for tailoring interventions, such as limited resources,[95] meeting the requirements of particular settings,[94,104] and the necessity to improve implementation.[101] Among the modalities employed, simulation-based training has become the most implemented method, followed closely by didactic lectures, multiple mixed procedures, as well as pre-briefing and debriefing sessions.

The primary outcomes associated with level 2 outcomes of the Kirkpatrick Model, which focus on learning in this review, were the knowledge, skills, and competencies of health care professionals. Our findings indicated that knowledge pertaining to disaster preparedness emerged as the most frequently assessed outcome following the

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

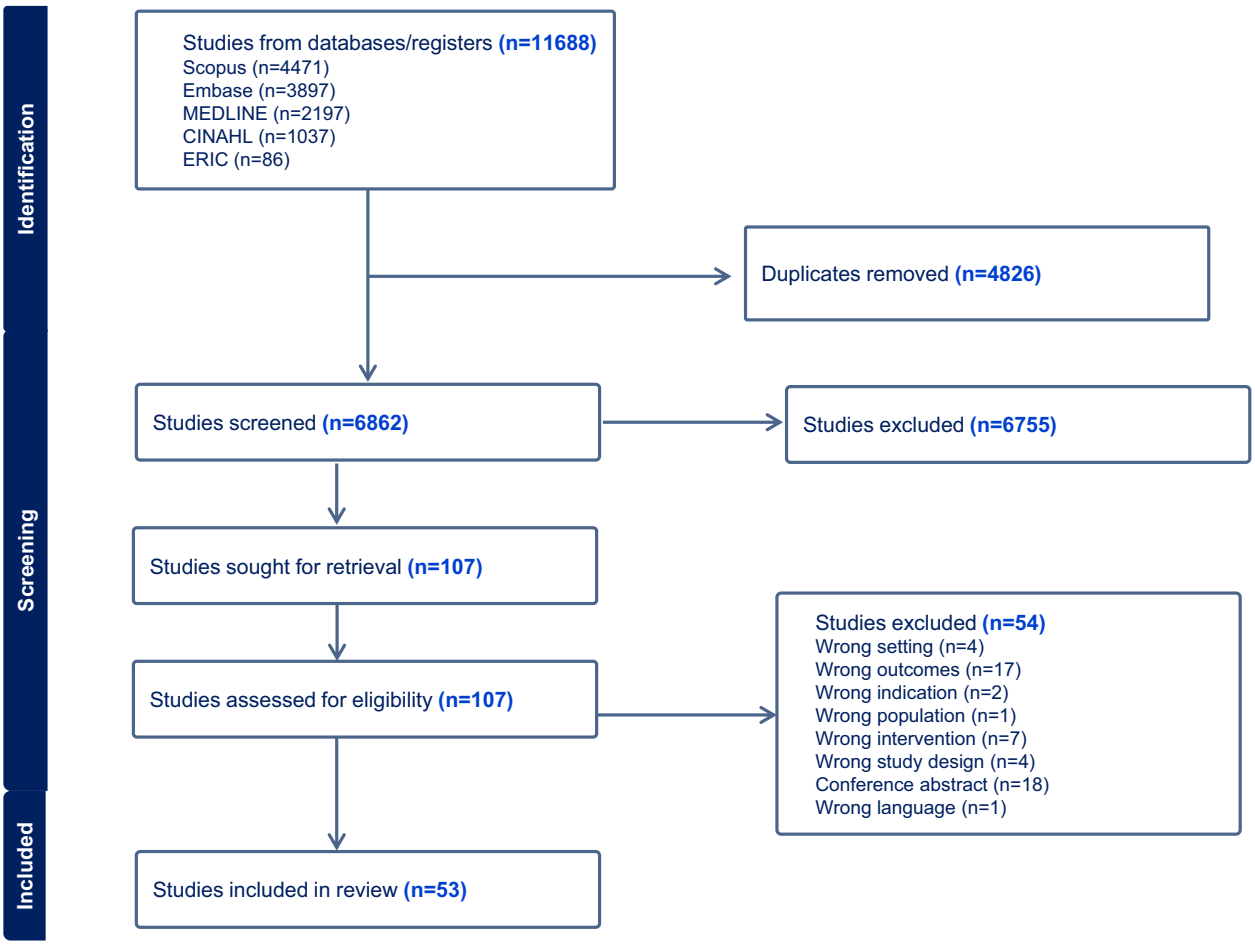

Figure 1. PRISMA flow diagram.

intervention, highlighting a strong focus on this topic within the included studies. Additionally, 77% of studies that measured knowledge reported significant improvements across various domains, covering both general and specific topics such as Mass Casualty Incidents (MCI) and evacuation procedures. Specifically, despite this there were noticeable knowledge deficits among nurses in triage accuracy[105] and among medicine residents in disaster knowledge.[106] Furthermore, studies that evaluated disaster preparedness competencies reported significant enhancements across all assessed areas. Regarding tools that comprehensively measure primary outcomes, Al-Qbelat et al. utilized the Disaster Preparedness Evaluation Tool (DPET) to assess disaster preparedness knowledge, skills, and competencies.[35] Nonetheless, the EPIQ remains the most utilized tool across all included studies.

The preparedness and readiness of health care professionals for disasters were examined in relation to level 3 of the Kirkpatrick Model, which focuses on changes in behavior. We found that studies measuring readiness for responding to disasters indicated a 50% significant improvement in readiness, and 91% of the interventions significantly improved the preparedness of participants.

The diversity in reported outcomes across studies may partly result from differences in setting, geographic distribution, and profession. There was no clear distinction between outcomes when the setting of intervention was considered; however, preregistration programs tended to be delivered more within university settings. Having a single institution, whether a university or a hospital, for the educational program carries certain risks. For example, university-led interventions can potentially be more theoretical or disconnected from the daily realities of the hospital context, involve only single disciplines, and may not reflect the real-world health system's infrastructure.[107] This highlights the need to embed interventions more deeply into practice by connecting both universities and hospitals in educational endeavors. Regarding the profession, nurses are the most targeted profession, with fewer interventions involving other health care professionals such as physicians, pharmacists, or allied health staff. This single-profession approach in studies may cause an inequality that could result in gaps in communication, role overlaps, and negatively affect the overall efficiency, coordination, and effectiveness of disaster response operations.[108] The geographical distribution of the interventions, with 45% of the included studies taking place in the United States, may reflect that in 2024, the US faced 27 weather and climate disasters, each causing at least $1 billion in damages, totaling an estimated $182.7 billion,[109] and a high number of agencies and governmental departments focused on being prepared to manage disasters within the timeframe of this review. This level of focus and educational funding is beneficial for enhancing global knowledge on the topic, but the result of such research needs to be considered in the context of the US cultural norms, structures, and potential disaster types.[110]

This review has also highlighted the components of educational interventions focused on disaster preparedness, which authors

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 6. Judgment on level of complexity of interventions (N = 53)

Author	Duration	Components interaction	Realism	Behavioral changes	Number of components	Delivery of the intervention	Total	Complexity level
Al-Qbelat (2022)	3	2	1	5	1	4	16	Moderate
Alim (2015)	2	6	5	2	6	4	25	High
Aluisio (2016)	0	3	5	2	3	2	15	Moderate
Amberson (2020)	5	2	1	2	2	2	14	Moderate
ArunKumar (2018)	2	1	1	2	1	0	7	Low
Bajow (2022)	4	5	6	2	4	6	27	High
Bank (2016)	2	6	5	2	5	0	20	Moderate
Becker (2021)	5	3	3	1	3	0	15	Moderate
Betka (2021)	0	3	6	2	4	4	19	Moderate
Castoldi (2022)	6	6	6	2	6	0	26	High
Chang (2022)	1	4	6	2	4	2	19	Moderate
Dadario (2022)	3	3	5	1	4	6	22	Moderate
Daniel (2016)	2	1	1	2	1	3	10	Low
Davis (2020)	4	5	6	2	4	4	25	High
Ebadi (2015)	1	3	1	4	3	0	12	Low
Georgino (2015)	2	3	3	4	3	3	18	Moderate
Ghahremani (2022)	0	3	3	4	4	3	17	Moderate
Ghezeljeh (2019)	3	1	1	2	1	3	11	Low
Glow (2013)	3	4	4	2	4	0	17	Moderate
Gray (2020)	1	3	4	4	3	0	15	Moderate
Hermann (2021)	6	6	5	2	6	4	29	High
Hollister (2021)	1	1	3	2	1	2	10	Low
Hosseini (2022)	4	6	6	2	6	4	28	High
Huh (2019)	3	1	1	3	1	2	11	Low
Hung (2021)	5	5	4	2	6	4	26	High
Husna (2020)	1	3	3	2	3	0	12	Low
Ingrassia (2014)	5	4	5	2	4	2	22	Moderate
Iqbal (2022)	3	5	4	4	4	6	26	High
Jung (2016)	2	3	4	4	4	0	17	Moderate
Kim (2020)	2	4	3	2	4	2	17	Moderate
Kim (2022)	2	5	5	4	6	4	25	High
Kılıç (2019)	2	3	3	2	3	2	15	Moderate
Koca (2020)	3	1	1	2	1	2	10	Low
Li (2022)	4	5	4	4	6	4	27	High
Ma (2021)	2	4	3	4	3	2	18	Moderate
Marks (2022)	6	4	4	2	4	4	24	Moderate
Montana (2019)	3	1	2	2	1	3	12	Low
Ngo (2016)	3	5	5	1	6	0	20	Moderate
Noh (2020)	3	4	3	4	4	0	18	Moderate
Owens (2017)	5	3	1	2	2	6	19	Moderate
Phan (2023)	1	4	4	2	3	1	15	Moderate
Scott (2013)	3	4	4	4	4	5	24	Moderate
Scott (2018)	2	4	3	2	3	1	15	Moderate

(*Continued*)

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Table 6. (*Continued*)

Author	Duration	Components interaction	Realism	Behavioral changes	Number of components	Delivery of the intervention	Total	Complexity level
Sena (2020)	6	6	2	0	5	4	23	Moderate
Shannon (2015)	3	4	4	2	4	4	21	Moderate
Shostrand (2023)	4	4	1	2	4	2	17	Moderate
Shujuan (2022)	0	2	2	2	3	2	11	Low
Tsai (2020)	0	5	3	2	4	2	16	Moderate
Unver (2018)	1	4	2	4	5	5	21	Moderate
Vargas (2019)	2	3	3	2	3	6	19	Moderate
Watson (2021)	1	3	1	2	3	2	12	Low
Wiese (2021)	0	5	4	2	5	2	18	Moderate
Xia (2020)	3	3	1	4	5	6	22	Moderate

Score items: Not reported (0), low complexity (1-2), moderate complexity (3-4), high complexity (5-6). Interpretation of total scores: Low complexity (1-12), moderate complexity (13-24), high complexity (25-36).

found led to positive or negative impacts on outcomes. The study authors noted that the impact of disaster simulation activities improved knowledge and competence in managing disasters and these had a better teaching effect compared to traditional workshops, and suggested that in-person simulations were more beneficial for students.[85,86,92,93,96,99,100,111] Simulation-based training effectively enhances disaster knowledge and skills[112] and creates realistic disaster scenarios that provide valuable learning opportunities in a safe environment.[113] In addition, the combination of simulation and lectures helped integrate theory with practice.[39,64,66,79,94] Moreover, the debriefing sessions emphasized the practical application of the knowledge gained from these sessions in the exercises[64] and facilitated deeper learning through reflection, feedback, and metacognition. Also, the scenario-based tabletop format yielded positive effects.[85,89,104] On the other hand, authors noted that challenges exist in addressing all essential disaster preparedness topics within limited intervention time,[84] the importance of considering language preferences, such as Arabic, to ensure inclusivity and effective communication,[64] as well as communication breakdowns between participants during practical sessions.[114]

To the best of our knowledge, this is the first review focusing on the complexity of educational interventions in the context of disaster preparedness, using the Intervention Complexity Assessment Tool for Systematic Reviews (iCAT_SR). Key dimensions included duration and frequency, interaction level, realism, behavioral changes, component count, and intervention delivery. Each of these dimensions has been adapted to provide a more in-depth understanding of the complexity of included interventions. We found that all high-complexity interventions showed significant positive outcomes at Kirkpatrick levels 2 and 3, indicating substantial improvement in participant learning and behaviors because of these interventions. Students learn more when educators appeal to different learning styles at the same time using multimodal, pedagogical approaches over time, helping to improve memory and consolidate learning.[115] Evaluating complexity in educational interventions is important because educational interventions are rarely simple or linear, thus reviews which focus solely on simple cause-effect evaluations might miss how the ingredients of the intervention and the interaction between its components may influence outcomes.[116]

In a review of the dimensions of complexity of health interventions (n = 179 included papers), Trompette et al noted that the dimensions of complexity can be classified in multiple ways, with many authors choosing to create a classification of complexity dimensions within the pragmatic and realist context or the confines of their study.[117] However, by attempting to describe and utilize the dimensions of complexity we chose, we had hoped to help others better understand the "how" and "why" interventions are successful in attaining positive outcomes. In analyzing the complexity dimensions, we compared the scores across all studies to identify which dimension tends to have the lowest and highest overall scores; behavioral changes have the lowest scores, and the dimension with the highest-scoring number of components is also noted. High complexity interventions in this review appeared to have positive outcomes. This may be due to such interventions addressing multiple leverage points at once thus amplifying impact through synergistic effects, fostering deeper and more sustained learning, and supporting prolonged engagement with the topic by aligning more closely with real-world contexts. However, implementing high-complexity interventions alone does not guarantee better outcomes and high complexity interventions are generally more resource intensive and costly to implement. Interventions must still be coherent, sensitive to the context, and supported by the capacity and resources within the system to respond to disasters.

We identified key areas for improvement in disaster preparedness among health care professionals. Future research should expand the scope of outcome measures to include not only knowledge but also skills, competencies, and behavioral changes. This expansion would enable a more comprehensive evaluation of interventions aimed at enhancing disaster preparedness within health care settings. Subsequent recommendations for policymakers, researchers, and educators regarding disaster preparedness interventions for health care professionals should emphasize detailed reporting of interventions. This clarity improves the evaluation of training impact, supports evidence-based improvements in disaster education, and allows for replication and adaptation across various settings and scenarios. Moreover, we recommend that future research expand to underrepresented regions, promoting international collaboration and culturally sensitive adaptation of educational programs and emphasize the importance of future research interventions being co-designed with clinicians, delivered on operational sites, and evaluated within real-world operational settings to ensure effective and sustainable disaster preparedness training.

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

Also, further investigation into the effects of intervention complexity levels in the context of disaster preparedness, especially high-complexity interventions, is needed.

Artificial intelligence (AI) has the potential to support educators in planning and implementing strategies tailored to educational needs to improve disaster preparedness.[118,119] Combining AI with technologies like augmented reality (AR) and VR can produce highly realistic simulations, interactive disaster scenarios that reflect real-world complexities in decision-making under pressure, enhancing situational awareness, and refining skills in a safe yet authentic environment.[120] Also, AI can potentially improve health care professionals' training experience by providing more personalized learning experiences, providing instant feedback, and adaptive learning paths, with more rapid analyses of data for continuous improvement.[121] Current limitations of the use of AI in the provision of automated feedback also need to be considered, including the instructor being required to pre-register the answer in the simulation system; the rigidity of feedback and lack of contextual understanding of AI systems.

Given the resource-intensive nature of disaster preparedness interventions, having national consensus on priority areas, educational content, and educational approaches could help to ensure standardized programs are developed, implemented, and evaluated on a regional basis, enhancing the preparedness of a larger number of stakeholders and health care professionals in the future. Due to the lack of consensus on educational interventions in fifty-three studies, this review found that high-complexity interventions are effective. However, high-complexity interventions may present a challenge for individuals and institutions that lack the resources to support such technologies.[122] Also, the cost of these interventions can be considerable, often requiring a significant investment in programs and resources[123] and implementing high-fidelity simulations necessitates financial investment in equipment, facilities, qualified instructors, and maintenance.[124] Together, these factors highlight barriers that must be addressed in developing high-complexity interventions for health care professionals to improve disaster preparedness education globally.

This systematic review has some limitations that need to be acknowledged. First, a meta-analysis was not performed as the studies were highly heterogeneous, differing substantially in terms of study designs, interventions, and outcomes. Second, due to eligibility restrictions on language and databases searched there is a possible language bias (English and Arabic). Third, the lack of complete or consistent descriptions of intervention components limits the accurate comparison, potentially impacting authors' judgments on the complexity of interventions and synthesis of findings. Lastly, the lack of standardized assessment tools across studies created challenges in systematically synthesizing and comparing outcomes.

Conclusion

Disasters impact people across different communities and regions, often striking without warning. Therefore, it is essential for all health care professionals on the frontline of disaster response to be well-prepared to respond effectively. The findings indicate that disaster preparedness educational interventions had a positive impact on both primary and secondary outcomes for health care professionals and students.

Overall, high-complexity interventions are particularly effective in improving health care professionals' disaster preparedness. Participants in these interventions demonstrated significant improvements in measured outcomes. High-complexity interventions can provide realism, appropriate interactions, and targeted behavioral changes, which enhance participant engagement and equip them with knowledge and practical skills to manage challenges during crises.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/dmp.2025.10198.

Data availability statement. Not applicable.

Acknowledgments. None

Authors' contribution. FA: Conceptualization, methodology development, screening, data extraction, quality assessment, data verification, analysis, writing, and editing. JH, PC, SF, and DA: Contributed to methodology development, screening, analysis, editing, and provided intellectual input for the paper.

Funding. This review is part of a PhD sponsored by Hail Health Cluster, Ministry of Health in Saudi Arabia.

Competing interests. None.

Ethics approval and consent to participate. This review synthesized data from publications which are publicly available. Thus, this review does not require ethical approval.

Consent for publication. Not applicable.

Reference

1. **Srivastava K.** Disaster: challenges and perspectives. *Ind Psychiatry J.* 2010; **19**(1):1–4.
2. **Said NB**, **Chiang VC**. The knowledge, skill competencies, and psychological preparedness of nurses for disasters: a systematic review. *Int Emerg Nurs.* 2020;**48**:100806.
3. International Federation of Red Cross and Red Crescent Societies (IFRC). What is a disaster?. https://www.ifrc.org/our-work/disasters-climate-and-crises/what-disaster
4. **CRED**. *Disasters in numbers*. Brussels: CRED. 2023. https://cred.be/sites/default/files/2022_EMDAT_report.pdf
5. **Asian Disaster Reduction Center**. Good practices. *Total Disaster Risk Management.* ADRC. https://www.adrc.asia/publications/TDRM2005/TDRM_Good_Practices/GP2009_e.php
6. **CRED**. The Emergency Events Database, 2023. 2023 EM-DAT Report. https://files.emdat.be/reports/2023_EMDAT_report.pdf
7. **Madu CN**, **Kuei CH**, **Madu IE**, et al. Introduction to disaster risk reduction and management. In: Madu CN, Kuei C-H, eds. *Handbook of Disaster Risk Reduction & Management*. Singapore: World Scientific; 2018:1–29.
8. **Panwar V**, **Sen S.** Economic impact of natural disasters: an empirical re-examination. *Margin: J Appl Econ Res.* 2019;**13**(1):109–139.
9. **United Nations Office for Disaster Risk Reduction**. Sendai Framework for Disaster Risk Reduction 2015-2030. UNISDR. https://cdn.who.int/media/docs/default-source/health-security-preparedness/drr/sendai-framework-for-disaster-risk-reduction-2015-2030.pdf?sfvrsn=8aa55898_23&download=true
10. **Integrated Research on Disaster Risk**. *Integrated Research on Disaster Risk Strategic Plan 2013–2017*, Beijing, China. IRDR. https://www.irdrinternational.org/uploads/files/2020/08/9jxwLoCrcYQWyRHYBHU4PEXPnvypr2kNmaLpsHw5/IRDR-Strategic-Plan-2013-2017.pdf
11. **De Smet H**, **Lagadec P**, **Leysen J.** Disasters out of the box: a new ballgame? *J Conting Crisis Manage.* 2012;**20**(3):138–148.
12. **Verheul ML**, **Dückers ML**. Defining and operationalizing disaster preparedness in hospitals: a systematic literature review. *Prehosp Disaster Med.* 2020;**35**(1):61–68.
13. **Isangula KG**, **Lyimo M**, **Ndungile Y**, **Robert E.** Nurses' preparedness for disaster response in rural and urban primary healthcare settings in Tanzania. *Rural Remote Health.* 2023;**23**(2):1–11.

14. **Ortiz-Barrios M**, **Gul M**, **López-Meza P**, **Yucesan M**, **Navarro-Jiménez E.** Evaluation of hospital disaster preparedness by a multi-criteria decision making approach: the case of Turkish hospitals. *Int J Disaster Risk Reduct.* 2020;**49**:101748.
15. **Tichy M**, **Bond AE**, **Beckstrand RL**, **Heise B.** NPs' perceptions of disaster preparedness education: quantitative survey research. *Am J Nurse Pract.* 2009;**13**(1):10–22.
16. **Pregoner JD**, **Josol RA**, **Lim L.** Combating urban hazard: a qualitative study on the perception on disaster preparedness of STEM students. 2020. doi:10.35542/osf.io/bvcgj
17. **Alrazeeni D.** Saudi EMS Students' perception of and attitudes toward their preparedness for disaster management. *J Educ Pract.* 2015;**6**(35): 110–116.
18. **Al Harthi M**, **Al Thobaity A**, **Al Ahmari W**, **Almalki M.** Challenges for nurses in disaster management: a scoping review. *Risk Manag Healthc Policy.* 2020;**13**:2627–2634.
19. **Abrams AM**. *Emergency/Disaster Preparedness of Rural Healthcare Providers*. North Dakota State University; 2018.
20. **Abdelaliem SMF**, **Baghdadi NA**, **Al Anizi AS**. A cross-sectional study about nurses' and physicians' experience of disaster management preparedness throughout COVID-19. *Disaster Med Public Health Prep.* 2023; **17**:e125.
21. **Savoia E**, **Preston J**, **Biddinger PD**. A consensus process on the use of exercises and after action reports to assess and improve public health emergency preparedness and response. *Prehosp Disaster Med.* 2013;**28**(3): 305–308.
22. **Persoff J**, **Ornoff D**, **Little C.** The role of hospital medicine in emergency preparedness: a framework for hospitalist leadership in disaster preparedness, response, and recovery. *J Hosp Med.* 2018;**13**(10):713–718.
23. **Azarmi S**, **Pishgooie AH**, **Sharififar S**, **Khankeh HR**, **Hejrypour SZ**. Challenges of hospital disaster risk management: a systematic review study. *Disaster Medicine Public Health Prep.* 2022;**16**(5):2141–2148.
24. **Tang R.** *Evaluation of Hospital Preparedness for Public Health Emergencies in Sichuan (China)*. Queensland University of Technology; 2015.
25. **Farah B**, **Pavlova M**, **Groot W.** Hospital disaster preparedness in sub-Saharan Africa: a systematic review of English literature. *BMC Emerg Med.* 2023;**23**(1):71.
26. **Glow SD**, **Colucci VJ**, **Allington DR**, **Noonan CW**, **Hall EC**. Managing multiple-casualty incidents: a rural medical preparedness training assessment. *Prehosp Disaster Med.* 2013;**28**(4):334–341.
27. **Bajow N**, **Mortelmans LJ**, **Maghraby N**, **Alatef Sultan SA**, **Mani ZA**, **Aloraifi S.** Disaster health education framework for short and intermediate training in Saudi Arabia: a scoping review. *Front Public Health.* 2022; **10**:932597.
28. **Alshahrani F.** *Exploring Saudi Emergency Room Nurses' Perceptions About Their Disaster Preparedness*. Seton Hall University; 2021.
29. **Nofal A**, **Alfayyad I**, **Khan A**, **Al Aseri Z**, **Abu-Shaheen A.** Knowledge, attitudes, and practices of emergency department staff towards disaster and emergency preparedness at tertiary health care hospital in central Saudi Arabia. *Saudi Med J.* 2018;**39**(11):1123.
30. **Almukhlifi Y**, **Crowfoot G**, **Wilson A**, **Hutton A.** Emergency healthcare workers' preparedness for disaster management: an integrative review. *J Clin Nurs.* 2021;1–16. doi:10.1111/jocn.15965
31. **Ersöz Genç E.** Improving disaster preparedness among healthcare professionals: a comprehensive approach. *Eurasian J Emerg Med.* 2025;**24**(2): 132–139.
32. **Jones E**, **Voorhees R**, **Paulson K.** *Defining and Assessing Learning: Exploring Competency-Based Initiatives, US Department of Education. National Center for Education Statistics*, Washington, DC: US Department of Education, National Center for Education Statistics[15] Cranton, P. (ed). (1997). Transformative Learning in Action: Insights From Practice, San Francisco, CA: Jossey-Bass; 2001.
33. **Hsu EB**, **Thomas TL**, **Bass EB**, **Whyne D**, **Kelen GD**, **Green GB**. Healthcare worker competencies for disaster training. *BMC Med Educ.* 2006;**6**:1–9.
34. **Walsh L**, **Subbarao I**, **Gebbie K**, et al. Core competencies for disaster medicine and public health. *Disaster Med Public Health Prep.* 2012;**6**(1): 44–52.
35. **Al-Qbelat RM**, **Subih MM**, **Malak MZ**. Effect of educational program on knowledge, skills, and personal preparedness for disasters among emergency nurses: a quasi-experimental study. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing.* 2022;**59**: 00469580221130881.
36. **Huh SS**, **Kang HY**. Effects of an educational program on disaster nursing competency. *Public Health Nurs.* 2019;**36**(1):28–35.
37. **Langan JC**, **Lavin R**, **Wolgast KA**, **Veenema TG**. Education for developing and sustaining a health care workforce for disaster readiness. *Nurs Adm Q.* 2017;**41**(2):118–127.
38. **Ashcroft J**, **Byrne MH**, **Brennan PA**, **Davies RJ**. Preparing medical students for a pandemic: a systematic review of student disaster training programmes. *Postgrad Med J.* 2021;**97**(1148):368–379.
39. **Chang C-W**, **Lin C-W**, **Huang C-Y**, **Hsu C-W**, **Sung H-Y**, **Cheng S-F**. Effectiveness of the virtual reality chemical disaster training program in emergency nurses: a quasi experimental study. *Nurse Educ today.* 2022; **119**:105613.
40. **Sahebzadeh M**, **Gherekhloo AH**, **Atighechian G.** The effect of educational intervention on health care providers' preparedness in the natural disasters: a case study of health care providers in Shahreza City, Iran. *Health Emerg Disasters Q.* 2020;**6**(1):39–46.
41. **Baetzner AS**, **Wespi R**, **Hill Y**, et al. Preparing medical first responders for crises: a systematic literature review of disaster training programs and their effectiveness. *Scandinavian J Trauma Resusc Emerg Med.* 2022; **30**(1):76.
42. **Labrague LJ**, **Hammad K**, **Gloe D**, et al. Disaster preparedness among nurses: a systematic review of literature. *Int Nurs Rev.* 2018;**65**(1):41–53.
43. **Veenema TG**, **Lavin RP**, **Bender A**, **Thornton CP**, **Schneider-Firestone S.** National nurse readiness for radiation emergencies and nuclear events: a systematic review of the literature. *Nurs Outlook.* 2019;**67**(1):54–88.
44. **Yousefi K**, **Larijani HA**, **Golitaleb M**, **Sahebi A.** Knowledge, attitude and performance associated with disaster preparedness in Iranian nurses: a systematic review and meta-analysis. *Adv J Emerg Med.* 2019;**3**(4):e42.
45. **Higgins JPT**, **Thomas J**, **Chandler J**, **Cumpston M**, **Li T**, **Page MJ**, **Welch VA**. Cochrane Handbook for Systematic Reviews of Interventions version 6.4 (updated August 2023). www.training.cochrane.org/handbook
46. **Page MJ**, **McKenzie JE**, **Bossuyt PM**, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Int J Surg.* 2021;**88**: 105906.
47. Higher Population Council. Arab Day for Population and Development. https://www.hpc.org.jo/en/content/arab-day-population-and-development-october-28-2023
48. **Hong QN**, **Pluye P**, **Fàbregues S**, et al. Mixed methods appraisal tool (MMAT), version 2018. *Registration of copyright.* 2018;**1148552**(10).
49. **Flemyng E**, **Dwan K**, **Moore TH**, **Page MJ**, **Higgins JP**. Risk of bias 2 in Cochrane reviews: a phased approach for the introduction of new methodology. *Cochrane Database of Syst Rev.* 2020;(10).
50. **Kirkpatrick JD**, **Kirkpatrick WK**. *Kirkpatrick's Four Levels of Training Evaluation*. Association for Talent Development; 2016.
51. **Hoffmann TC**, **Glasziou PP**, **Boutron I**, et al. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ.* 2014;**348**:g1687.
52. **Ye X**, **Backlund P**, **Ding J**, **Ning H.** Fidelity in simulation-based serious games. *IEEE Trans Learn Technol.* 2019;**13**(2):340–353.
53. **Lopreiato JO**. *Healthcare Simulation Dictionary*. Agency for Healthcare Research and Quality; 2016.
54. **Hamstra SJ**, **Brydges R**, **Hatala R**, **Zendejas B**, **Cook DA**. Reconsidering fidelity in simulation-based training. *Acad Med.* 2014;**89**(3):387–392.
55. **Palaganas JC**, **Epps C**, **Raemer DB**. A history of simulation-enhanced interprofessional education. *J Interprof Care.* 2014;**28**(2):110–115.
56. **Ketelaars E**, **Flandin S**, **Poizat G.** One fidelity fits all? How civil protection simulations afford (or not) improvement opportunities for novice and occasional crisis managers. *Saf Sci.* 2023;**165**:106189.
57. **Thomas J**, **Petticrew M**, **Noyes J**, et al. Chapter 17: Intervention complexity. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, eds. *Cochrane Handbook for Systematic Reviews of Interventions*. 2nd ed. Chichester: John Wiley & Sons; 2019:451–478. doi:10.1002/9781119536604.ch17

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

58. **Noyes J**, **Gough D**, **Lewin S**, et al. A research and development agenda for systematic reviews that ask complex questions about complex interventions. *J Clin Epidemiol.* 2013;**66**(11):1262–1270.
59. **Lewin S**, **Hendry M**, **Chandler J**, et al. Assessing the complexity of interventions within systematic reviews: development, content and use of a new tool (iCAT_SR). *BMC Med Res Methodol.* 2017;**17**:1–13.
60. **Marks K**, **Chung S**, **Li J**, **Waltzman M**, **Manzi S**, **Shah D.** Experience of pharmacy involvement in a disaster simulation exercise within a pediatric hospital emergency department: a pilot project. *AmJ Health Syst Pharm.* 2022;**79**(9):e124–e134.
61. **Owens MP**, **Buffington C**, **Frost MP**, **Waldner RJ**. The South Dakota model: health care professions student disaster preparedness and deployment training. *Disaster Med Public Health Prep.* 2017;**11**(6):735–740.
62. **Phan Q**, **Geller DE**, **Broughton AS**, **Swan BA**, **Wells JS**. Evaluating a low-cost disaster preparedness simulation for prelicensure nursing students. *Disaster Med Public Health Prep.* 2023;**17**:e343.
63. **Ghezeljeh TN**, **Aliha JM**, **Haghani H**, **Javadi N.** Effect of education using the virtual social network on the knowledge and attitude of emergency nurses of disaster preparedness: a quasi-experiment study. *Nurse Educ Today.* 2019;**73**:88–93.
64. **Bajow N**, **Alkhalil S**, **Maghraby N**, **Alesa S**, **Najjar AA**, **Aloraifi S.** Assessment of the effectiveness of a course in major chemical incidents for front line health care providers: a pilot study from Saudi Arabia. *BMC Med Educ.* 2022;**22**(1):350.
65. **Davis AH**, **Manning J**, **Germain DS**, **Hayes S**, **Pigg C.** Implementing disaster simulations for baccalaureate nursing students in the Gulf-Coast region. *Clini Simul Nurs.* 2020;**43**:26–34.
66. **Ghahremani M**, **Rooddehghan Z**, **Varaei S**, **Haghani S.** Knowledge and practice of nursing students regarding bioterrorism and emergency preparedness: comparison of the effects of simulations and workshop. *BMC Nurs.* 2022;**21**(1):152.
67. **Hosseini MM**, **Hosseini TM**, **Qayumi K**, **Baeradeh N.** Game-based vs. case-based training for increasing knowledge and behavioral fluency of nurse students regarding crisis and disaster management: a quasi-experimental study. *Arch Acad Emerg Med.* 2022;**10**(1):e77.
68. **Hung MSY**, **Lam SKK**, **Chow MCM**, **Ng WWM**, **Pau OK**. The effectiveness of disaster education for undergraduate nursing students' knowledge, willingness, and perceived ability: an evaluation study. *Int J Environ Res Public Health.* 2021;**18**(19):10545.
69. **Iqbal M**, **Mashal M**, **Khan MA**, et al. Should we offer disaster preparedness and response training workshops across Idaho? A feasibility study. *J Emerg Manag (Weston, Mass)*. 2022;**20**(4):351–364.
70. **Arun Kumar SK**, **John B**, **Thadathil SG**. Effectiveness of a training programme on knowledge regarding disaster preparedness among nursing students in a selected College of Nursing. *Asian J Microbiol Biotechnol Environ Sci.* 2018;**20**:184–188.
71. **Noh J**, **Oh EG**, **Kim SS**, **Jang YS**, **Chung HS**, **Lee O.** Development and evaluation of a multimodality simulation disaster education and training program for hospital nurses. *Int J Nurs Pract.* 2020;**26**(3):e12810.
72. **Scott LA**, **Madden LA**, **Wahlquist AE**, **Fisher DW**. Preparing for the surge: a half-day emergency preparedness training course for the "second front." *Disaster Med Public Health Prep.* 2018;**12**(1):121–126.
73. **Scott LA**, **Swartzentruber DA**, **Davis CA**, **Maddux PT**, **Schnellman J**, **Wahlquist AE**. Competency in chaos: lifesaving performance of care providers utilizing a competency-based, multi-actor emergency preparedness training curriculum. *Prehosp Disaster Med.* 2013;**28**(4):322–333.
74. **Tsai Y-D**, **Tsai S-H**, **Chen S-J**, et al. Pilot study of a longitudinal integrated disaster and military medicine education program for undergraduate medical students. *Medicine.* 2020;**99**(20):e20230.
75. **Georgino MM**, **Kress T**, **Alexander S**, **Beach M.** Emergency preparedness education for nurses: core competency familiarity measured utilizing an adapted emergency preparedness information questionnaire. *J Trauma Nurs.*| *JTN.* 2015;**22**(5):240–248.
76. **Shostrand LM**, **Miller G**, **Bowers C.** Using experiential learning to affect perceived knowledge of disaster preparedness among hospital-based personnel. *J Nurses Prof Dev.* 2023;**39**(4):E50–E55.
77. **Hermann S**, **Gerstner J**, **Weiss F**, et al. Presentation and evaluation of a modern course in disaster medicine and humanitarian assistance for medical students. *BMC Med Educ.* 2021;**21**(1):610.
78. **Ingrassia PL**, **Ragazzoni L**, **Tengattini M**, **Carenzo L**, **Della Corte F.** Nationwide program of education for undergraduates in the field of disaster medicine: development of a core curriculum centered on blended learning and simulation tools. *Prehosp Disaster Med.* 2014;**29**(5):508–515.
79. **Li J**, **Kaziny BD**, **Perron C**, **Downey D**, **Monuteaux MC**, **Chung S.** The first 15 minutes: a novel disaster simulation exercise. *Disaster Med Public Health Prep.* 2023;**17**:e133.
80. **Vargas JP**, **Hubloue I**, **Pinzón JJ**, **Duque AC**. The effect of training and experience on mass casualty incident triage performance: evidence from emergency personnel in a high complexity university hospital. *Am J Disaster Med.* 2019;**14**(2):113–119.
81. **Xia R**, **Li S**, **Chen B**, **Jin Q**, **Zhang Z.** Evaluating the effectiveness of a disaster preparedness nursing education program in Chengdu, China. *Public Health Nurs.* 2020;**37**(2):287–294.
82. **Dadario NB**, **Bellido S**, **Restivo A**, et al. Using a logic model to enable and evaluate long-term outcomes of a mass casualty training program: a single center case study. *Disaster Med Public Health Prep.* 2022;**16**(3):1116–1122.
83. **Hollister LM**, **Zhu T**, **Edwards N**, **Good B**, **Hoeppner S.** Mass casualty mini drills on trauma surgery department staff knowledge: an educational improvement study. *J Trauma Nurs.*| *JTN.* 2021;**28**(2):135–141.
84. **Alim S**, **Kawabata M**, **Nakazawa M.** Evaluation of disaster preparedness training and disaster drill for nursing students. *Nurse Educ Today.* 2015;**35**(1):25–31.
85. **Husna C**, **Kamil H**, **Yahya M**, **Tahlil T**, **Darmawati D.** Doestabletop exercise enhance knowledge and attitude in preparing disaster drills? *Nurse Media J Nurs.* 2020;**10**(2):182–190. doi:10.14710/nmjn.v10i2.29117.
86. **Kim H-w**, **Choi Y-J**. A simulation-based nursing education of psychological first aid for adolescents exposed to hazardous chemical disasters. *BMC Med Educ.* 2022;**22**(1):93.
87. **Ebadi A**, **Yousefi S**, **Khaghanizade M**, **Saeid Y.** Assessment competency of nurses in biological incidents. *Trauma Mon.* 2015;**20**(4):e25607.
88. **Daniel P**, **Gist R**, **Grock A**, **Kohlhoff S**, **Roblin P**, **Arquilla B.** Disaster Olympics: a model for resident education. *Prehosp Disaster Med.* 2016;**31**(3):237–241.
89. **Becker R**, **Majers JS**, **Moody J.** Disaster preparedness for charge nurses: a program evaluation. *J Emerg Manag (Weston, Mass).* 2021;**19**(1):39–45.
90. **Ma D**, **Shi Y**, **Zhang G**, **Zhang J.** Does theme game-based teaching promote better learning about disaster nursing than scenario simulation: a randomized controlled trial. *Nurse Educ Today.* 2021;**103**:104923.
91. **Gray MM**, **Thomas AA**, **Burns B**, **Umoren RA**. Evacuation of vulnerable and critical patients: multimodal simulation for nurse-led patient evacuation. *Simul Healthc.* 2020;**15**(6):382–387.
92. **Betka AA**, **Bergren MD**, **Rowen JL**. Improving rural disaster response preparedness. *Public Health Nurs.* 2021;**38**(5):856–861.
93. **Bank I**, **Khalil E.** Are pediatric emergency physicians more knowledgeable and confident to respond to a pediatric disaster after an experiential learning experience? *Prehosp Disaster Med.* 2016;**31**(5):551–556.
94. **Castoldi L**, **Greco M**, **Carlucci M**, **Lennquist Montán K**, **Faccincani R.** Mass Casualty Incident (MCI) training in a metropolitan university hospital: short-term experience with MAss Casualty SIMulation system MACSIM®. *Eur J Trauma Emerg Surg.* 2022;**48**(1):283–291.
95. **Amberson T**, **Wells C**, **Gossman S.** Increasing disaster preparedness in emergency nurses: a quality improvement initiative. *J Emerg Nurs.* 2020;**46**(5):654–665.e21.
96. **Unver V**, **Basak T**, **Tastan S**, et al. Analysis of the effects of high-fidelity simulation on nursing students' perceptions of their preparedness for disasters. *Int Emerg Nurs.* 2018;**38**:3–9.
97. **Koca B**, **Arkan G.** The effect of the disaster management training program among nursing students. *Public Health Nurs.* 2020;**37**(5):769–777.
98. **Kılıç N**, **Şimşek N.** The effects of psychological first aid training on disaster preparedness perception and self-efficacy. *Nurse Educ Today.* 2019;**83**:104203.

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press

99. **Shujuan L**, **Mawpin T**, **Meichan C**, **Weijun X**, **Jing W**, **Biru L.** The use of virtual reality to improve disaster preparedness among nursing students: a randomized study. *J Nurs Educ.* 2022;**61**(2):93–96.
100. **Ngo J**, **Schertzer K**, **Harter P**, **Smith-Coggins R.** Disaster medicine: a multi-modality curriculum designed and implemented for emergency medicine residents. *Disaster Med Public Health Prep.* 2016;**10**(4): 611–614.
101. **Shannon CC**. Using a simulated mass casualty incident to teach response readiness: a case study. *J Nurs Educ.* 2015;**54**(4):215–219.
102. **Lin C-H**, **Tzeng W-C**, **Chiang L-C**, **Lu M-C**, **Lee M-S**, **Chiang S-L**. Effectiveness of a structured disaster management training program on nurses' disaster readiness for response to emergencies and disasters: a randomized controlled trial. *J Nurs Manag.* 2024;**2024**(1):5551894.
103. **Brinjee D**, **Al Thobaity A**, **Almalki M**, **Alahmari W.** Identify the disaster nursing training and education needs for nurses in Taif City, Saudi Arabia. *Risk Manag Healthc Policy.* 2021;**14**:2301–2310. doi:10.2147/RMHP.S312940.
104. **Watson KE**, **Waddell JJ**, **McCourt EM**. "Vital in today's time": evaluation of a disaster table-top exercise for pharmacists and pharmacy staff. *Res Social Adm Pharm.* 2021;**17**(5):858–863.
105. **Kim J**, **Lee O.** Effects of a simulation-based education program for nursing students responding to mass casualty incidents: a pre-post intervention study. *Nurse Educ Today.* 2020;**85**:104297.
106. **Sena A**, **Forde F**, **Yu C**, **Sule H**, **Masters MM**. Disaster preparedness training for emergency medicine residents using a tabletop exercise. *MedEdPORTAL.* 2021;**17**:11119.
107. **Schilly K**, **Huhn M**, **Visker JD**, **Cox C.** Evaluation of a disaster preparedness curriculum and medical students' views on preparedness education requirements for health professionals. *Disaster Med Public Health Prep.* 2024;**18**:e8.
108. **Goniewicz K**, **Goniewicz M.** Disaster preparedness and professional competence among healthcare providers: pilot study results. *Sustainability.* 2020;**12**(12):4931.
109. National Centers for Environmental I. Assessing the U.S. Climate in 2024. January 10, 2025.
110. **Hanushek EA**. Addressing cross-national generalizability in educational impact evaluation. *Int J Educ Dev.* 2021;**80**:102318.
111. **Wiese LK**, **Love T**, **Goodman R.** Responding to a simulated disaster in the virtual or live classroom: is there a difference in BSN student learning? *Nurse Educ Pract.* 2021;**55**:103170.
112. **Hawsawi Al**, **Thobaity A**, **MSM S**. The impact of simulated education and training on undergraduate students' disaster evacuation competencies. *Adv Med Educ Pract.* 2025;**16**:189–203.
113. **Farhat H**, **Alinier G**, **Chaabna K**, et al. Preparedness and emergency response strategies for chemical, biological, radiological and nuclear emergencies in disaster management: a qualitative systematic review. *J Conting Crisis Manage.* 2024;**32**(3):e12592.
114. **Jung D**, **Carman M**, **Aga R**, **Burnett A.** Disaster preparedness in the emergency department using in situ simulation. *Adv Emerg Nurs J.* 2016; **38**(1):56–68.
115. **Muryani C**, **Ni'matussyahara D.** Strengthening student empathy in Geo-Capabilities: digital learning innovations and pedagogical strategies for disaster mitigation. *Contemp Educ Technol.* 2024;**16**(3):ep521.
116. **Skivington K**, **Matthews L**, **Simpson SA**, et al. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *BMJ.* 2021;**374**:n2061.
117. **Trompette J**, **Kivits J**, **Minary L**, **Alla F.** Dimensions of the complexity of health interventions: what are we talking about? A review. *Int J Environ Res Public Health.* 2020;**17**(9):3069.
118. **Narayanan S**, **Ramakrishnan R**, **Durairaj E**, et al. Artificial intelligence revolutionizing the field of medical education. *Cureus.* 2023;**15**(11): e49604. doi:10.7759/cureus.4960.
119. **Chumachenko D**, **Morita PP**, **Ghaffarian S**, **Chumachenko T.** Artificial intelligence solutions for global health and disaster response: challenges and opportunities. *Frontiers Media SA*. 2024:1439914.
120. **Albahri A**, **Khaleel YL**, **Habeeb MA**, et al. A systematic review of trustworthy artificial intelligence applications in natural disasters. *Comput Electr Eng.* 2024;**118**:109409.
121. **Devagiri JS**, **Paheding S**, **Niyaz Q**, **Yang X**, **Smith S.** Augmented reality and artificial intelligence in industry: trends, tools, and future challenges. *Expert Syst Appl.* 2022;**207**:118002.
122. **Baniasadi T**, **Ayyoubzadeh SM**, **Mohammadzadeh N.** Challenges and practical considerations in applying virtual reality in medical education and treatment. *Oman Med J.* 2020;**35**(3):e125.
123. **Idris I.** Cost-effectiveness in humanitarian work: preparedness, pre-financing and early action. *K4D Helpdesk Report.* 2018;461.
124. **Elendu C**, **Amaechi DC**, **Okatta AU**, et al. The impact of simulation-based training in medical education: a review. *Medicine.* 2024;**103**(27): e38813.

https://doi.org/10.1017/dmp.2025.10198 Published online by Cambridge University Press