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Review

The efficacy of high-fidelity simulation on knowledge and performance in undergraduate nursing students: An umbrella review of systematic reviews and meta-analysis

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ABSTRACT

Objectives: This umbrella review aimed to consolidate the evidence base on the impact of high-fidelity simulation on knowledge and performance among undergraduate nursing students.
Design: Umbrella review with meta-analyses of pooled effect sizes, followed by an additional meta-analysis of primary studies from the included systematic reviews, excluding overlapping results.
Data sources: Systematic searches were performed up to August 2023 in PubMed, Embase, and Cochrane Library. We included reviews that compared high-fidelity simulation against other learning strategies.
Review methods: The risk of bias was assessed for each included systematic review (ROBIS tool) and primary study (RoB 2 or ROBINS-I as appropriate). Random-effect meta-analyses of meta-analyses were performed to estimate the pooled effects of high-fidelity simulation on knowledge and performance. Further random-effect meta-analyses of primary studies were conducted, with overlapping studies excluded (12 %). Subgroup analyses were performed to provide a more comprehensive analysis of the findings. Trim-and-fill analyses were conducted to adjust for potential publication bias.
Results: Six systematic reviews were included and encompassed 133 primary studies (2767 and 3231 participants concerning performance and knowledge, respectively). The adjusted pooled effects for knowledge (SMD = 0.877, 95 % CI: 0.182 to 1.572) and performance (SMD = 0.738, 95 % CI: 0.466 to 1.010) closely aligned with those obtained from meta-analyzing the primary studies for knowledge (SMD = 0.980) and performance (SMD = 0.540), both showing high statistical heterogeneity. Traditional lectures represented the more common comparison. The subgroup analysis revealed significant differences in effect sizes across geographic locations, topics, types of control, and how interventions were reported.
Conclusions: The results provide robust evidence supporting the integration of high-fidelity simulation into undergraduate nursing programs to enhance students' knowledge and performance. The high reported heterogeneity may be attributed to variations in study contexts or methodologies. Future research should explore the optimal use of high-fidelity simulation in different educational and cultural contexts.

1. Introduction

High-fidelity simulation is a cutting-edge pedagogical tool that utilizes full-scale computerized simulators to replicate real-world clinical scenarios (Roberts et al., 2019; Tong et al., 2022). This approach to learning has gained significant traction in the realm of nurse education,

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giving the ability to provide a realistic and immersive learning environment (Arrogante et al., 2023; MacKinnon et al., 2015). In comparison to traditional teaching methods such as lectures or low-fidelity mannequins, high-fidelity simulation has been shown to significantly enhance knowledge and performance in the nursing discipline (Sherwood and Francis, 2018). A key aspect of high-fidelity simulation that sets it apart from other teaching methods is its structured three-phase process: preparation, participation, and debriefing (INACSL Standards Committee, 2016).

The preparation phase itself is bifurcated into prebriefing and briefing. Prebriefing is a preparatory activity that equips students with the necessary information, knowledge, and skills ahead of the simulation experience, often a week in advance (INACSL Standards Committee, 2016). This phase allows students to familiarize themselves with the upcoming simulation, thereby reducing anxiety and enhancing their readiness to engage fully in the simulation experience. The participation phase involves the actual engagement with the high-fidelity simulation, where students interact with the high-tech patient simulators in a controlled and safe environment, allowing them to apply their knowledge and skills in a realistic clinical scenario (Li et al., 2021). The final phase, debriefing, is a critical component of the high-fidelity simulation process. It provides an opportunity for reflection and feedback, enabling students to consolidate their learning, identify areas of improvement, and plan for future application of the skills and knowledge gained (Toews et al., 2021). This structured approach, combined with the realistic and immersive nature of high-fidelity simulation, contributes to its efficacy in enhancing knowledge and performance in nurse education (Tong et al., 2022). However, as a recent systematic review has highlighted, it is important to note that the success of high-fidelity simulation is contingent on the quality of each phase, particularly the preparation and debriefing stages, which play a crucial role in maximizing learning outcomes (Tong et al., 2022).

Given the complexity of the high-fidelity simulation process and its potential impact on learning outcomes, recent research has begun to focus on the individual phases of the process to determine their separate effects on outcomes, such as knowledge and performance/skills (Tong et al., 2022). This shift in focus is important as it allows for a more nuanced understanding of how each phase contributes to the overall efficacy of high-fidelity simulation. This targeted approach can lead to more effective and efficient use of high-fidelity simulation in nurse education, ensuring that each phase of the process is optimized to maximize learning outcomes.

While the shift toward examining individual phases of the high-fidelity simulation process is a positive development, it is predicated on having a solid and comprehensive understanding of the overall efficacy of high-fidelity simulation. However, the current body of literature still presents a challenge because the existing systematic reviews on the efficacy of high-fidelity simulation present a fragmented and potentially incomplete picture due to the variation in the primary studies they include (Doolen et al., 2016; La Cerra et al., 2019). This variation, stemming from differences in study design, population studied, specific high-fidelity simulation interventions used, and outcomes measured, leads to potential inconsistencies in the conclusions drawn about the efficacy of high-fidelity simulation.

More precisely, the variation in primary studies included in different systematic reviews on the same research question can indeed pose a significant challenge about several aspects (Carey and Rossler, 2023). The design of the primary studies can vary considerably: some studies may be randomized controlled trials, while others may be observational studies, case studies, or quasi-experimental designs (Alshehri et al., 2023; Au et al., 2023). The population being studied can also vary across primary studies. Some studies may focus on undergraduate nursing students, while others may include registered nurses or nurse practitioners (O'Rourke et al., 2023). The variation in primary studies included in different systematic reviews can lead to a fragmented and potentially incomplete view of the evidence on the efficacy of high-fidelity simulation in undergraduate nurse education. More importantly, each systematic review may only include a subset of the available primary studies, and as a result, some studies may be overlooked, leading to a potential gap in the evidence base. This issue is further compounded by the fact that different systematic reviews may include overlapping primary studies, which can lead to overrepresenting certain findings and skew the overall conclusions (Carey and Rossler, 2023). Some primary studies may be included in one systematic review but not in others, leading to a fragmented understanding of the efficacy of high-fidelity simulation. This lack of a comprehensive and consistent view of primary studies could make it challenging to draw reliable conclusions about the efficacy of high-fidelity simulation (Carey and Rossler, 2023; Doolen et al., 2016).

In this context, a systematic review of systematic reviews, or an umbrella review, can be particularly valuable (Papatheodorou and Evangelou, 2022). An umbrella review can help to consolidate the existing evidence by synthesizing the findings of multiple systematic reviews. It can also help to identify and account for overlapping primary studies, ensuring a more balanced and comprehensive view of the evidence (Belloni et al., 2021; Cant et al., 2022). In the field of high-fidelity simulation in nurse education, some umbrella reviews have made notable contributions, such as Cant and Cooper (2017), who employed an umbrella review approach to examine a wide range of outcomes associated with high-fidelity simulation and assess its overall impact on undergraduate/pre-licensure nursing students, identifying 14 outcome variables. Similarly, Cantrell et al. (2017) conducted an umbrella review focusing on the quality of existing reviews and employed thematic analysis to explore high-fidelity simulation across different dimensions, including specific clinical practice areas, types of learners, learner outcomes, skill acquisition, elements of simulation design, and the use of simulation as a teaching tool. While these umbrella reviews have been valuable, there has not yet been a quantitative assessment of the specific effectiveness of high-fidelity simulation on knowledge and performance in nursing undergraduate settings, utilizing effect sizes from systematic reviews and primary studies after removing any overlapping effects. This approach would enhance the existing literature by offering precise, quantitative insights that complement the predominantly qualitative findings of previous reviews, addressing the issue of varying primary studies included in each existing systematic review and thereby improving the comprehensiveness of current syntheses.

Given the context and challenges outlined above, the main aim of this study is to consolidate the evidence base on the impact of high-fidelity simulation on knowledge acquisition and performance among undergraduate nursing students. More precisely, the specific aims of this study are as follows: (a) to conduct an umbrella review of systematic reviews on the efficacy of high-fidelity simulation in undergraduate nurse education on knowledge and performance; (b) to identify the rate of overlapping primary studies between the included systematic reviews; (c) to conduct a meta-analysis of meta-analyses of the included systematic reviews; (d) to conduct a meta-analysis of the primary randomized controlled trials (RCTs) included in each review after removing the overlapping studies to provide a more comprehensive view of the primary evidence and help to fill any gaps in the evidence base.

2. Methods

2.1. Design

This umbrella review of systematic reviews is designed by following the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis, Chapter 10: Umbrella reviews (JBI, 2020). The reporting of the study followed the JBI Critical Appraisal Checklist for Systematic Reviews and Research Syntheses (JBI, 2020). The review protocol has been registered with PROSPERO (Registration number: CRD42023400512). A comprehensive search strategy was developed and conducted in multiple databases, including PubMed, Embase, and Cochrane Library. The search strategies were consistent with the PRISMA statement (Sarkis-Onofre et al., 2021).

The review primary question for this umbrella review is, "What is the overall efficacy of high-fidelity simulation, compared to any other learning strategies, in undergraduate nurse education on knowledge and performance, as reported in existing systematic reviews and meta-analyses?". In addition, the following secondary questions were also developed: (a) What is the rate of overlapping primary studies between the systematic reviews included in this umbrella review? (b) What is the overall effect size of the association between high-fidelity simulation and the outcomes (knowledge and performance) as determined by a meta-analysis of meta-analyses of the included systematic reviews? (c) What is the overall effect size of the association between high-fidelity simulation and the outcomes (knowledge and performance) as determined by a meta-analysis of the primary studies included in each systematic review after removing the overlapping studies? These review questions aim to consolidate the existing evidence on the efficacy of high-fidelity simulation in undergraduate nurse education, identify and account for overlapping primary studies, and provide a more robust estimate of the overall effect of high-fidelity simulation on the specific most common learning outcomes. The "Population, Intervention, Comparison, Outcome, Study Design" (PICOS) framework has guided authors in formulating research questions and operationalizing them into database-specific queries (JBI, 2020).

2.2. PICOS

The population of interest in this study is undergraduate nursing students. These are students who were enrolled in undergraduate nurse education programs and are the target group for high-fidelity simulation interventions. The intervention under examination was high-fidelity simulations, and the comparison in this study encompassed various learning strategies employed in undergraduate nursing programs, including traditional teaching methods such as lectures, low-fidelity simulations, problem-based learning, case studies, and other pedagogical approaches.

The main outcomes of interest are performance and knowledge, both of which are frequently investigated in RCTs involving high-fidelity simulation in nurse education. Knowledge, in this context, refers to the cognitive understanding of specific concepts that underlie performance. It encompasses theoretical knowledge acquired by nursing students through the simulation experience (O'Rourke et al., 2023). This encompasses understanding of particular diseases or conditions, familiarity with clinical procedures and protocols, knowledge related to medication and its administration, and comprehension of patient safety practices. Knowledge could be measured in the context of the included studies with previously validated and reliable tools or with specifically developed examination tests.

Performance within the scope of high-fidelity simulation typically pertains to the observable and measurable behaviors and actions exhibited by nursing students during and following the simulation experience (Doolen et al., 2016). It reflects the practical application of acquired knowledge in practice and the ability to carry out nursing tasks effectively and efficiently. Performance is often further categorized into various sub-subsets, including skills, clinical decision-making, and patient safety practice (Carey and Rossler, 2023). Skills refer to the technical and non-technical abilities that nursing students demonstrate during the simulation (Carey and Rossler, 2023). Skills encompass both technical and non-technical proficiencies demonstrated by nursing students during simulations (Carey and Rossler, 2023). Technical skills may involve the execution of specific medical procedures or the operation of medical equipment, while non-technical skills encompass communication, teamwork, decision-making, and problem-solving abilities. Clinical decision-making represents the capacity of nursing students to make appropriate and effective decisions in clinical scenarios by integrating theoretical knowledge, clinical information, and critical thinking skills (Bennett and James, 2022). Safety practices encompass adherence to safety protocols and guidelines, including infection control measures, medication administration safety procedures, and patient identification protocols (El Hussein and Hirst, 2023).

Both performance and knowledge are closely linked to the learning strategies employed in high-fidelity simulation and serve as pivotal indicators of the efficacy of high-fidelity simulation. Furthermore, specific details regarding the measurement of performance and knowledge, as well as the year of study of the nursing students involved and the specific topics or areas of focus of the interventions, are factors that could significantly influence the efficacy of high-fidelity simulation. In this regard, every possible year was deemed suitable for this review, as well as every topic related to the application of high-fidelity simulation.

2.3. Search strategy

For each component of the PICOS, specific keywords and phrases were identified to capture the relevant studies and adapted for each database, and the comparison section was not restricted. The full search strategy, including database-specific queries, is available in Supplementary file 1 (August 2023 was the last searched date). No restrictions based on language were applied during the search process. Non-English articles available in HTML format were translated into English to ensure comprehensive inclusion of relevant studies. We utilized the Google Translate plugin, an integrated browser extension compatible with Google Chrome, to assist in the translation of non-English articles available in HTML format. This plugin enabled us to seamlessly convert the content of these articles into English, ensuring that language barriers did not impede our comprehensive review of the literature. Additionally, no specific rationale for limiting articles to a particular publication date was provided, as our aim was to conduct a comprehensive review of the literature.

2.4. Inclusion/exclusion criteria

The inclusion and exclusion criteria for this systematic review were defined based on the PICOS framework, ensuring the selection of studies that are most relevant to the research question.

The study included (a) systematic reviews that involved undergraduate nursing students, (b) employing a high-fidelity simulation as the main intervention, (c) focusing on assessing the efficacy of the intervention on performance and/or knowledge, and (d) systematic reviews and meta-analyses of RCTs and/or non-randomized studies. This approach, therefore, ensures that our review's conclusions are based on the most robust and real-world evidence available, providing a solid foundation for decision-making in undergraduate nurse education, and it differentiates the approach from the previous studies in this regard (Cant et al., 2022).

The exclusion criteria were referred to those systematic reviews where it was not possible to discriminate the efficacy of high-fidelity simulation in the only subsample of nursing students (in reviews aimed to synthesize evidence on both nursing students and registered nurses), studies that do not compare high-fidelity simulation with other learning strategies, studies that do not measure outcomes related to performance and knowledge, and studies that do not provide sufficient data for extraction.

2.5. Selection process

The selection process is depicted in Fig. 1 and was performed independently by two reviewers (IV e RC) who aligned their findings for each step of the process and solved disagreements by employing a consensus discussion with a third (CA) reviewer. A total of 124 records were initially identified and screened. Duplicate records were removed, resulting in 110 records being excluded. Further exclusions were made based on the study design and focus of the studies. Studies that were not systematic reviews or did not focus on the efficacy of high-fidelity

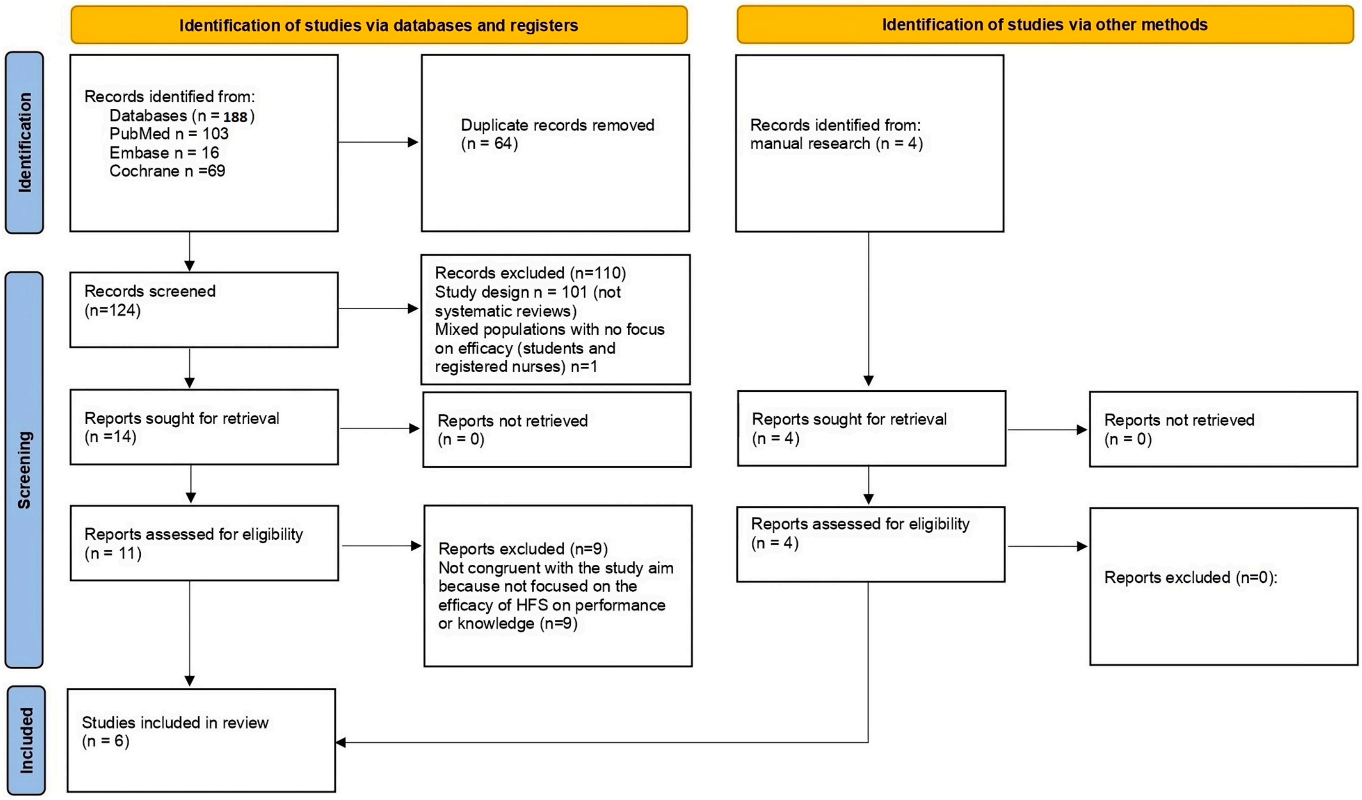

Fig. 1. Flow diagram of the umbrella review.

simulation on performance or knowledge in undergraduate nursing students were excluded. Following these exclusions, 14 reports were sought for retrieval, all of which were successfully retrieved and assessed for eligibility. Nine of these reports were further excluded as they were not congruent with the study aim because they did not focus on the efficacy of high-fidelity simulation on performance or knowledge. In addition to the database search, four reports were identified through manual research from references of eligible reviews, all of which were retrieved and assessed for eligibility. None of these reports were excluded. In total, six studies were included in the review.

2.6. Quality appraisal

Two reviewers (IV e RC) conducted the quality appraisal process independently, with any disagreements resolved through discussion or consultation with a third reviewer (CA) if necessary. The quality appraisal of the included systematic review in this umbrella review was conducted using the Risk of Bias in Systematic Reviews (ROBIS) (Whiting et al., 2016). ROBIS is a comprehensive tool designed to evaluate the risk of bias in systematic reviews themselves. It assesses bias across four domains: study eligibility criteria, identification and selection of studies, data collection and study appraisal, and synthesis and findings. This tool provides a structured approach to assess the risk of bias in these domains based on signaling questions and criteria. It is a valuable tool for identifying areas where improvements can be made in conducting systematic reviews and selecting systematic reviews for inclusion in several healthcare fields, including health technology assessments, clinical practice guidelines, and other evidence-based decision-making processes.

Version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB 2) tool was used to assess the risk of bias in the RCTs included in each systematic review (Loef et al., 2022). The RoB 2 tool is a widely used tool for assessing the risk of bias in RCTs. It evaluates bias across five domains: bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in the measurement of the outcome, and bias in the selection of the reported result. This tool provides a detailed assessment of the risk of bias in RCTs, thereby enhancing the reliability and validity of the review's findings. The risk of bias of non-randomized studies was assessed using the Risk Of Bias In Non-randomized Studies - of Interventions (ROBINS-I) (Sterne et al., 2022). The domains of the ROBINS-I are pre-intervention, confounding, selection of participants, classification of interventions, deviation from intended interventions, missing data, and measurement of outcomes.

2.7. Data extraction

The data extraction process for this systematic review was conducted in two stages to ensure a comprehensive and accurate collection of relevant data from the included studies. In the first stage, data were extracted from the included systematic reviews. This stage involved extracting key information such as the year of publication, research question, the overall effect size of the association between high-fidelity simulation and outcomes with their 95 % confidence interval (95 % CI), and information regarding the review quality using the ROBIS tool. This data extraction stage allowed for an initial understanding of the overall findings of the systematic reviews and their methodological quality. In the second stage, data were extracted from each primary study included in the systematic reviews. This second stage involved extracting detailed information about the study design, population, intervention, comparison, outcomes, and results. It allowed for a more in-depth analysis of the individual studies contributing to the systematic reviews, providing a more granular understanding of the efficacy of high-fidelity simulation on performance and knowledge in undergraduate nursing students. Both stages of data extraction were conducted independently by two reviewers, with any discrepancies resolved through discussion or consultation with a third reviewer if necessary.

2.8. Data analysis

For each meta-analysis, the standardized mean difference was calculated using Cohen's d, applied within random-effects models with the restricted maximum likelihood (REML) method for estimation (Andrade, 2020). The standardized mean difference is a summary statistic used in a meta-analysis when the studies all assess the same outcome but measure it by employing different tools. This approach was appropriate for our umbrella review as the included studies, while all focusing on the efficacy of high-fidelity simulation on performance and knowledge in undergraduate nursing students, used different scales or methods to measure these outcomes. The random-effects model was chosen because it takes into account both within-study and between-study variation, making it more suitable for reviews that include studies with significant heterogeneity. The effect sizes and standard errors were pooled for each outcome for the meta-analysis of meta-analyses. This approach provided an overall summary of the effect of high-fidelity simulation on performance and knowledge across all the included systematic reviews. A second round of meta-analysis was conducted after removing duplicated primary studies from the included reviews to corroborate these results. The standardized mean difference was used at the last available follow-up to determine the efficacy of high-fidelity simulation on the two outcomes. This approach allowed for a more precise estimation of the effect of high-fidelity simulation, taking into account the potential impact of time on the outcomes.

When encountering studies that reported multiple comparison groups or distinct outcome measures in data analysis, we treated each as an independent dataset. Specifically, for shared groups within our study, proportional allocation was implemented by first identifying the total number of participants across all relevant intervention arms. We then calculated the proportion of participants that would be allocated to each intervention group based on the total sample size involved in the shared groups. This allocation allowed us to accurately distribute participants for each pairwise comparison, ensuring that each intervention was represented proportionately. This approach was pivotal in avoiding unit-of-analysis errors, ensuring that each unique dataset was treated as independent yet appropriately integrated, maintaining the integrity of our meta-analysis and preventing the overrepresentation of any single study's results.

Subgroup analyses were also performed considering the locations where the studies were conducted. This allowed for an exploration of potential geographical variations in the efficacy of high-fidelity simulation. Additionally, we conducted further subgroup analyses based on the type of control, intervention characteristics, and the specific topic related to the high-fidelity simulation scenarios used in the included primary studies. The type of control was categorized into several groups, including traditional learning approaches, lower-fidelity simulations, or other educational methods used as comparators to high-fidelity simulation. The intervention itself was categorized as either "yes" or "partially yes" versus "no" or "partially no" to assess its features. "Yes" indicates that the primary study described all of the following elements: the nursing context or topic, a detailed simulation description, debriefing procedures, the number of simulation sessions, and the modality used (e.g., manikin simulations). "Partially yes" indicates that at least three out of these four intervention features were described, "partially no" suggests that two out of the four features were described, and "no" indicates that none of the features of the intervention were mentioned. Lastly, the topics covered in the studies fell into categories such as resuscitation practices, pediatric care, general clinical aspects, and other related subjects.

A quantitative trim-and-fill method was used to estimate publication bias. This method estimates the number and outcomes of potentially missing studies due to publication bias and adjusts the meta-analysis to account for these missing studies. It works by "trimming" (removing) the smallest studies causing asymmetry in the funnel plot, calculating the true center (filling) of the funnel, and then replacing the omitted studies and their missing counterparts around the center. This analysis was relevant as publication bias, the tendency for studies with positive results to be more likely to be published, could skew the results of a meta-analysis. This approach was preferred in this research over funnel plots because these are visual tools for assessing publication bias and could be subjective because they rely on visual interpretation (Peters et al., 2007). Funnel plots do not provide a way to adjust the results for the estimated bias. Statistical heterogeneity was assessed for each meta-analysis using the I^2 statistic, which describes the percentage of total variation across studies that is due to heterogeneity rather than chance. An I^2 value of 0 % indicates no observed heterogeneity, while 25 %, 50 %, and 75 % values are considered low, moderate, and high heterogeneity, respectively (Migliavaca et al., 2022). In addition, the Q statistics were assessed as the weighted sum of squared differences between individual study effects and the pooled effect across studies., where the weights are the inverse of the variance of the effect estimate in each study. A significant Q statistic ($p < 0.05$) rejects the null hypothesis of homogeneity, indicating that the differences in study results are more than what would be expected by chance alone, suggesting the presence of heterogeneity. For the assessment of the heterogeneity, the tau^2 statistic was also estimated as the measure of the between-study variance in a random-effects meta-analysis, where a larger tau^2 value indicates a greater dispersion of true effect sizes.

All statistical analyses for this systematic review were conducted using STATA 18 MP—Parallel Edition (StataCorp. 2023. Stata Statistical Software: Release 18. College Station, TX: StataCorp LLC).

3. Results

3.1. Characteristics of the included studies and risk of bias

Six systematic reviews were included (La Cerra et al., 2019; Lee and Oh, 2015; Lei et al., 2022; Li et al., 2022; Tonapa et al., 2023; Vincent et al., 2015). Studies involving a total of 2767 participants related to performance were included in the analysis, while another set of studies comprising 3231 participants was considered in the knowledge assessment. As described in Table 1, five studies reported a low risk of bias (La Cerra et al., 2019; Lee and Oh, 2015; Lei et al., 2022; Li et al., 2022; Tonapa et al., 2023), while one study reported a high risk of bias (Vincent et al., 2015). This high risk of bias evaluation was given by the assessment of domain 1 (study eligibility criteria), which was rated as "unclear", domain 2 (identification of the studies), where the risk of bias was rated as "high", and domain 4 (synthesis and findings), in which the risk of bias was rated as "high". More details are available in Supplementary file 2.

Table 1 summarizes the characteristics of the included systematic review. La Cerra et al. (2019) conducted a systematic review that included 33 studies focusing on the impact of high-fidelity simulation on knowledge and performance among nursing students. The authors found that high-fidelity simulation was effective in improving knowledge, skills, and confidence. They also noted a significant increase in the number of studies about high-fidelity simulation over the last 30 years, indicating a growing interest in this pedagogical approach. Lee and Oh (2015) included 40 studies in their systematic review, which also examined the effects of high-fidelity simulation on knowledge and performance. Their findings suggested that high-fidelity simulation had positive effects on knowledge, self-confidence, performance, and satisfaction among nursing students, further supporting the use of high-fidelity simulation in nurse education.

Lee and Oh (2015) included 26 studies in their systematic review, which also examined the effects of high-fidelity simulation on knowledge and performance. Their findings suggested that high-fidelity simulation had positive effects on knowledge, self-confidence, performance, and satisfaction among nursing students, further supporting the use of high-fidelity simulation in nurse education. Lei et al. (2022) reviewed 15 studies focusing on the impact of high-fidelity simulation

Table 1
Characteristics of the included systematic reviews.

Study	Year	Number of included studies	ROBIS Score	Outcomes	Main results	Primary studies focused on knowledge and/or performance
La Cerra et al.	2019	33	Overall: Low Study eligibility criteria (D1): Low Identification and selection of studies (D2): Low Data collection and study appraisal (D3): Low Synthesis and findings (D4): Low	Knowledge and performance	The review found that HFS was effective in improving knowledge, skills, and confidence among nursing students. The authors noted a significant increase in the general number of studies about HFPS over the last 30 years.	Knowledge (Ackermann, 2009, 2009; Akhu-Zaheya et al., 2013; Aqel and Ahmad, 2014; Cobbett and Snelgrove-Clarke, 2016; Corbridge et al., 2010; Kang et al., 2015; Lee et al., 2017; Rodgers et al., 2009; Shinnick and Woo, 2014; Tubaishat and Tawalbeh, 2015; Tuzer et al., 2016) Performance (Ackermann, 2009; Alinier et al., 2006; Aqel and Ahmad, 2014; Baxter et al., 2012; Brannan et al., 2008; Brown and Chronister, 2009; Chen et al., 2015; Harris, 2011; King and Reising, 2011; Liaw et al., 2012; Luctkar-Flude et al., 2012; Merriman et al., 2014; Powell-Laney et al., 2012; Rodgers et al., 2009)
Lee and Oh	2015	26	Overall: Low Study eligibility criteria (D1): Low Identification and selection of studies (D2): Low Data collection and study appraisal (D3): Low Synthesis and findings (D4): Low	Knowledge and performance	This review concluded that HFS had positive effects on knowledge, self-confidence, performance, and satisfaction among nursing students.	Knowledge (Hur and Roh, 2013) Performance (Alinier et al., 2006; Hur and Roh, 2013; Kim et al., 2012; Yang, 2012).
Lei et al.	2022	15	Overall: Low Study eligibility criteria (D1): Low Identification and selection of studies (D2): Low Data collection and study appraisal (D3): Low Synthesis and findings (D4): Low	Knowledge and performance	The review found that HFS training can significantly improve the critical thinking skills of nursing students.	Knowledge (Aqel and Ahmad, 2014; Park and Kim, 2020; Raman et al., 2019; Salameh et al., 2021; Sharour, 2019; Tawalbeh, 2020; Tubaishat and Tawalbeh, 2015) Performance (Aqel and Ahmad, 2014).
Li et al.	2022	37	Overall: Low Study eligibility criteria (D1): Low Identification and selection of studies (D2): Low Data collection and study appraisal (D3): Low Synthesis and findings (D4): Low	Knowledge and performance	The review concluded that HFS could significantly improve the emergency response ability of nursing students.	Knowledge (Akhu-Zaheya et al., 2013; Aqel and Ahmad, 2014; Brannan et al., 2008; Kang et al., 2020; Levett-Jones et al., 2011; Salameh et al., 2021).
Tonapa et al.	2023	14	Overall: Low Study eligibility criteria (D1): Low Identification and selection of studies (D2): Low Data collection and study appraisal (D3): Low Synthesis and findings (D4): Low	Knowledge and performance	The review found that HFS significantly increased nursing students' knowledge acquisition, self-confidence, and skills performance	Knowledge (Craig et al., 2021; Lee et al., 2019; Levett-Jones et al., 2011; Liaw et al., 2012; Salameh et al., 2021; Tawalbeh, 2020; Tubaishat and Tawalbeh, 2015; Vural Doğru and Zengin Aydın, 2020). Performance (Liaw et al., 2012, 2011; Salameh et al., 2021; Wood and Toronto, 2012)
Vincent et al.	2015	8	Overall: High Study eligibility criteria (D1): Unclear Identification and selection of studies (D2): High Data collection and study appraisal (D3): High Synthesis and findings (D4): High	Performance	The review concluded that HFS is an effective teaching strategy that can improve the critical thinking skills of nursing students.	Performance (Alinier et al., 2006; Baxter et al., 2012; Blum et al., 2010; Kim et al., 2012; Kirkman, 2013; Liaw et al., 2012; Smith et al., 2013; Walshe et al., 2013)

Legend: HFS = high-fidelity simulation.
Note: The details of the ROBIS assessments are available in Supplementary file 2.

on knowledge and performance. Their review concluded that high-fidelity simulation training could significantly improve the critical thinking skills of nursing students, an essential competency in nursing practice. Li et al. (2022) included 37 studies in their systematic review, examining the effects of high-fidelity simulation on knowledge and performance. They found that high-fidelity simulation could significantly enhance the emergency response ability of nursing students, a critical skill in the nursing profession. Tonapa et al. (2023) reviewed 14 studies focusing on the impact of high-fidelity simulation on knowledge and performance. Their findings suggested that high-fidelity simulation significantly increased nursing students' knowledge acquisition, self-confidence, and skills performance, further emphasizing the benefits of high-fidelity simulation in nurse education. Finally, Vincent et al. (2015) conducted a systematic review of 8 studies focusing on the impact of high-fidelity simulation on performance. Despite the high risk of bias in their review, they concluded that high-fidelity simulation is an effective teaching strategy that can improve the critical thinking skills of nursing students.

3.2. Meta-analysis of meta-analyses

As depicted in Fig. 2a, the meta-analysis of meta-analyses for the outcome of knowledge in undergraduate nurse education revealed a significant overall effect size (theta) of 1.298, with a 95 % CI ranging from 0.693 to 1.903. This result suggested that high-fidelity simulation substantially positively impacts knowledge acquisition among undergraduate nursing students. The z-test for the overall effect size further confirmed this finding, yielding a significant result ($z = 4.21$, $p < 0.0001$), indicating that the pooled effect size is significantly different from zero, providing strong evidence of the efficacy of high-fidelity simulation in enhancing knowledge in this context. The analysis included five studies: La Cerra et al. (2019), Li et al. (2022), Lee and Oh (2015), Lei et al. (2022), and Tonapa et al. (2023). These studies reported individual effect sizes ranging from 0.490 (La Cerra et al., 2019) to 2.150 (Lee and Oh, 2015), further illustrating the heterogeneity in the effects of high-fidelity simulation on knowledge among different study populations. The analysis also revealed significant heterogeneity among the included studies, as indicated by the Q statistic ($Q = 41.23$, $df = 4$, $p < 0.0001$), and the I^2 equal to 88.92 % with a tau^2 value of 0.4090 further underscoring the presence of significant heterogeneity. This observed statistical heterogeneity indicated that the variation in effect sizes across the included studies is greater than what would be expected by chance alone, indicating substantial differences in the studies' contexts, methodologies, or both.

The trim-and-fill analysis imputed two studies, indicating that there might be some evidence of publication bias in the included studies. After the trim-and-fill analysis, the observed effect size (Effect size = 1.298, 95 % CI: 0.693 to 1.903) was adjusted to 0.877 (95 % CI: 0.182 to

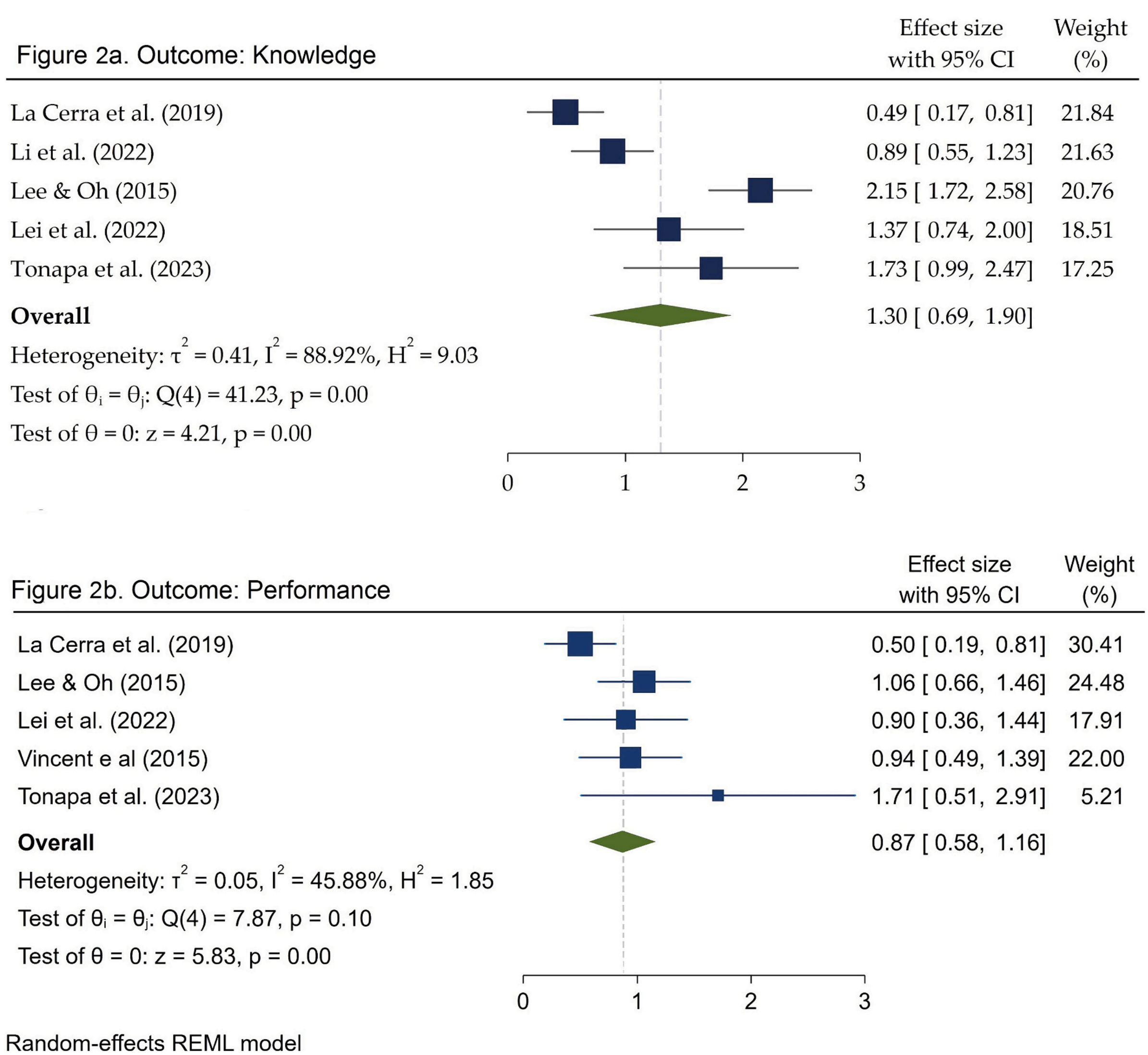

Fig. 2. Meta-analysis of meta-analyses.

1.572). This result suggests that the significant positive effect of high-fidelity simulation on knowledge among undergraduate nursing students might be slightly overestimated in the meta-analysis of meta-analyses due to slight publication bias. Therefore, the results of the meta-analysis should be interpreted with some caution.

As illustrated in Fig. 2b, the meta-analysis of meta-analyses for the outcome of performance in undergraduate nurse education demonstrated a significant overall effect size (theta) of 0.869, with a 95 % CI ranging from 0.577 to 1.160. This result indicates that high-fidelity simulation has a pronounced positive influence on the performance of undergraduate nursing students. The z-test for the overall effect size further substantiated this finding, yielding a significant result ($z = 5.83$, $p < 0.0001$). This suggests that the combined effect size is significantly different from zero, offering robust evidence of the effectiveness of high-fidelity simulation in boosting performance in this context. The analysis encompassed five studies: La Cerra et al. (2019), Lee and Oh (2015), Lei et al. (2022), Vincent et al. (2015), and Tonapa et al. (2023). These studies reported individual effect sizes ranging from 0.500 (La Cerra et al., 2019) to 1.710 (Tonapa et al., 2023), highlighting the variability in the effects of high-fidelity simulation on performance across different study populations. Furthermore, the analysis revealed moderate heterogeneity among the included studies, as indicated by the Q statistic ($Q = 7.87$, $df = 4$, $p = 0.0964$). The I^2 value of 45.88 % and a tau^2 value of 0.0479 further confirmed this moderate heterogeneity. This observed statistical heterogeneity suggests that the differences in effect sizes across the included studies might be attributed to variations in study contexts, methodologies, or both, but not solely due to chance.

The trim-and-fill analysis imputed two studies, suggesting that there might be some evidence of publication bias in the included studies. After the trim-and-fill analysis, the observed effect size (Effect size = 0.869, 95 % CI: 0.577 to 1.160) was adjusted to 0.738 (95 % CI: 0.466 to 1.010). This reduction in the effect size suggests that the significant positive effect of high-fidelity simulation on performance among undergraduate nursing students might be slightly overestimated in the meta-analysis of meta-analyses due to publication bias. Therefore, the results of the meta-analysis should be interpreted with some caution.

3.3. Overlapping primary studies in the included systematic reviews

The six included systematic reviews (La Cerra et al., 2019; Lee and Oh, 2015; Lei et al., 2022; Li et al., 2022; Tonapa et al., 2023; Vincent et al., 2015) reported to include a total of 133 primary studies. However, only 75 were focused on outcomes related to knowledge or performance. The overlapping studies, those studies included in more than one systematic review, were nine (12 %) (Brannan et al., 2008; Akalin and Sahin, 2020; Rodgers et al., 2009; Hur and Roh, 2013; Liu et al., 2016; Aqel and Ahmad, 2014; Niu et al., 2014; Tubaishat and Tawalbeh, 2015; Salameh et al., 2021). The remaining 66 studies were included only individually in the included systematic reviews.

3.4. Meta-analysis of primary studies encompassed in the included systematic reviews: knowledge

As shown in Table 1, in the study of La Cerra et al. (2019), the studies useful for the meta-analysis on knowledge were 12. Considering the study of Lee and Oh (2015), only one study was available in relation to knowledge. Seven studies were included by Lei et al. (2022). Considering the systematic review performed by Li et al. (2022), six primary studies were related to knowledge. There were eight primary studies retrievable from Tonapa et al. (2023). Overall, 40 studies (19 RCTs) were included in the meta-analysis after removing duplicates. The summary plot and the traffic plot of the evaluations using RoB2 of the 19 RCTs included in the meta-analysis of the primary studies included from each systematic review are available in Supplementary file 3a.

As shown in Fig. 3, it was possible to extract data from 32 included primary studies that revealed a significant overall effect size of 0.980, with a 95 % CI ranging from 0.671 to 1.284. This result indicates that high-fidelity simulation substantially positively impacts undergraduate nursing students' knowledge. The z-test for the overall effect size further substantiated this finding, yielding a significant result ($z = 6.22$, $p < 0.0001$). This suggests that the combined effect size is significantly different from zero, providing strong evidence of the effectiveness of high-fidelity simulation in enhancing knowledge in this context. The analysis encompassed 32 primary studies, with individual effect sizes ranging from −0.714, favouring the control (White et al., 2013), to 3.323 (Salameh et al., 2021). These results highlight the variability in the effects of high-fidelity simulation on knowledge across different study populations and contexts. Furthermore, the analysis revealed significant heterogeneity among the included primary studies, as indicated by the Q statistic ($Q = 432.53$, $df = 31$, $p < 0.0001$). The I^2 value of 92.8 % and a tau^2 value of 0.720 further underscores the presence of significant heterogeneity. The observed statistical heterogeneity suggests that the differences in effect sizes across the included studies might be attributed to variations in study contexts, methodologies, or both, but not solely due to chance.

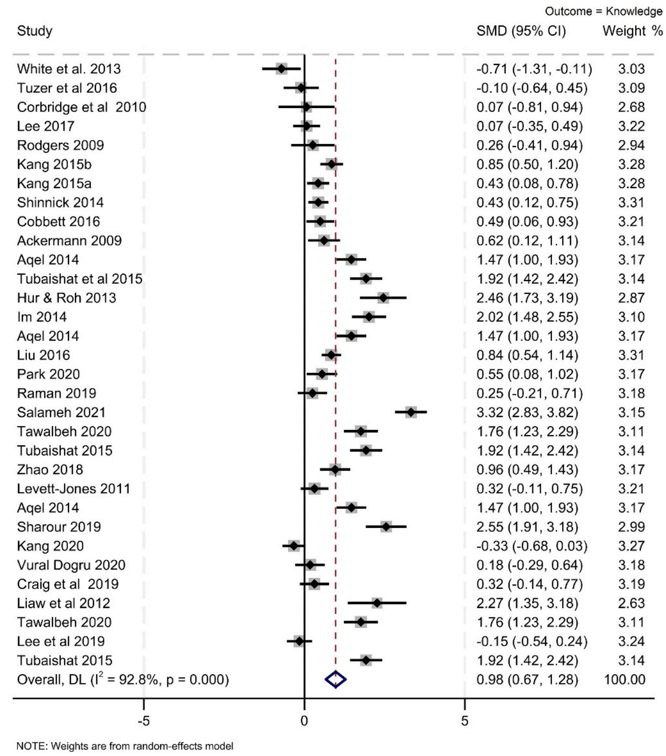

Fig. 3. Meta-analysis of the primary studies included in the systematic review.

For this reason, a subgroup analysis, as shown in Supplementary file 4a, was conducted based on the location where each study was conducted. The analysis revealed significant differences in the effect sizes across the subgroups, as indicated by the test of group differences ($Q\_b = 291.56$, $df = 12$, $p < 0.0001$). This suggests that the location of where the study was conducted might have influenced the effects of high-fidelity simulation on the knowledge of undergraduate nursing students. The overall effect size for each location ranged from −0.152 (Taiwan; single study) to 3.323 (Palestine; single study). The subgroup analysis also revealed varying degrees of heterogeneity within some subgroups. For instance, the studies conducted in the USA showed moderate heterogeneity ($Q = 13.49$, $df = 5$, $p = 0.019$, $I^2 = 62.9$ %, $tau^2 = 0.136$). This aspect suggests that the effects of high-fidelity simulation on knowledge among undergraduate nursing students might vary significantly within the USA, possibly due to differences in study contexts or methodologies. The studies from South Korea exhibited a higher level of heterogeneity ($Q = 26.79$, $df = 3$, $p < 0.0001$, $I^2 = 93.1$ %, tau^2

= 0.227). This aspect indicates a substantial variation in the effects of high-fidelity simulation on performance and knowledge among undergraduate nursing students within South Korea, which could be attributed to differences in the study designs, populations, or both. This significant heterogeneity suggests a considerable variation in the effects of high-fidelity simulation on knowledge among undergraduate nursing students in South Korea.

In the subgroup analysis regarding the type of control (Supplementary file 4c), the subgroup effect size for traditional learning was 0.951 (87.27 % weight), while the subgroup effect size for low fidelity was 1.170 (12.73 % weight). Tests of subgroup effect size indicated significant differences between Traditional Learning and Low Fidelity groups ($p < 0.001$), indicating that high-fidelity simulation demonstrated more significant effects when compared to traditional learning approaches. Heterogeneity was observed in all subgroups, with I^2 values ranging from 84.8 % to 93.3 %, and between-subgroup heterogeneity was not statistically significant ($p = 0.760$).

In the "No Intervention Features Subgroup" (Supplementary file 4d), standardized mean difference was 0.800, representing a weight of 55.64 %. In the "Intervention Features (Yes) Subgroup," standardized mean difference ranged from 0.264 to 3.323, and the highest weight was 3.28 %. The subgroup effect size for studies incorporating intervention features was notably higher at 1.400, with a weight of 18.86 %. Within the "Partially Yes Intervention Features Subgroup", standardized mean difference ranged from 0.251 to 1.467 and was equal to 0.959, representing a weight of 19.05%. In the "Partially No Intervention Features Subgroup," standardized mean difference ranged from 0.840 to 1.922, which was equal to 1.362, with a weight of 6.46 %. Tests of subgroup effect size demonstrated significant differences ($p < 0.05$) among all categories, indicating variations in effect sizes linked to the presence and completeness in the reporting of the included primary studies of intervention features. While heterogeneity was evident within all subgroups, with I^2 values spanning from 82.8 % to 95.4 %, statistical analysis did not identify significant between-subgroup heterogeneity ($p = 0.152$). These findings emphasize the impact of well-reported intervention features ("yes") on effect sizes, with studies incorporating complete features showing higher effect sizes compared to those with partial or no features.

In relation to the topics (i.e., general clinical aspects, critical care, resuscitation practices, pediatric care, maternity care, and cardiac auscultation) (Supplementary file 4e), the standardized mean difference regarding general clinical aspects (standardized mean difference = 0.940) represented the highest weight, which was 52.92 %. Tests of subgroup effect size indicated significant differences ($p < 0.05$) among all categories, suggesting variations in effect sizes based on the topic of the study, with significant between-subgroup heterogeneity ($p = 0.002$). These results emphasize that the study topic, particularly resuscitation practices, has a substantial impact on effect sizes, with significant variations observed across different clinical aspects.

The trim-and-fill analysis did not impute any studies, indicating that there is no evidence of publication bias in the included studies. Therefore, the observed effect size remained unchanged even after the trim-and-fill analysis, further confirming the robustness of the meta-analysis results.

3.5. *Meta-analysis of primary studies encompassed in the included systematic reviews: performance*

As indicated in Table 1, in the study of La Cerra et al. (2019), the primary studies useful for the meta-analysis on performance were 14. From Lee and Oh (2015), four primary studies were available. One study was included in the systematic review by Lei et al. (2022). The primary studies retrievable from Tonapa et al. (2023) were four. Finally, Vincent et al. (2015) allowed authors to include eight studies. Overall, 31 studies (15 RCTs) were included in the meta-analysis after removing duplicates.

The summary and traffic plots of the evaluations using RoB2 of the 15 RCTs included in the meta-analysis of the primary studies for the performance outcome are available in Supplementary file 3b. Most studies demonstrated a low risk of bias in most assessed domains, indicating a solid research methodology (Liaw et al., 2012).

As shown in Fig. 4, the meta-analysis for the performance outcome, using a random-effects model, showed an overall effect size equal to 0.540 with a 95 % confidence interval ranging from 0.213 to 0.846. This suggests a moderate positive effect of high-fidelity simulation on the performance of undergraduate nursing students. The test for the overall effect size being equal to zero was significant ($z = 3.23$, $p = 0.0012$), indicating that high-fidelity simulation has a statistically significant effect on performance. However, the studies had significant heterogeneity ($Q = 486.75$, $df = 35$, $p < 0.0001$), with an I^2 statistic of 92.80 % and tau^2 of 0.9192. The studies contributing to this meta-analysis varied in their effect sizes, with some studies showing a negative effect of high-fidelity simulation on performance (e.g., Aqel and Ahmad, 2014; King and Reising, 2011; Kwon, 2013; Niu 2014; Smith et al., 2013), while others showed a positive effect (e.g., Ackermann, 2009; Brannan et al., 2008; Chae & Lee, 2012; Hur and Roh, 2013; Kim et al., 2012). These findings underscore the importance of considering the specific context and implementation of high-fidelity simulation when interpreting its effects on performance. For this reason, a subgroup analysis was performed by considering the location where the primary study was performed. As shown in Supplementary file 4b, the results show that the effect of high-fidelity simulation on the performance of undergraduate nursing students varied significantly across different locations. In Canada, the overall effect size was 0.268 (95 % CI: −0.387 to 0.900), based on six studies. In China, the overall effect size was 0.466 (95 % CI: −0.652 to 1.580), based on three studies. The single study from Ireland showed a large effect size of 2.052 (95 % CI: 1.465 to 2.639). In Jordan, the single study showed a negative effect size of −1.143 (95 % CI: −1.589 to −0.697). The overall effect size in South Korea was 0.648 (95 % CI: 0.087 to 1.210), based on eleven studies. In Singapore, the overall effect size was 1.630 (95 % CI: 0.668 to 2.589). In the USA, the overall effect size was 0.196 (95 % CI: −0.359 to 0.749), based on eight studies. In the United Kingdom, the overall effect size was 0.317 (95 % CI: −0.655 to 1.288), based on two studies. The test for group differences was significant ($Q\_b = 82.41$, $df = 7$, $p < 0.0001$), indicating that the effect of high-fidelity simulation on performance significantly differed across locations. This result could be due to differences in educational systems, cultural contexts, or the implementation of high-fidelity simulation in different places. It is important to note that there was significant heterogeneity within some of the subgroups. For instance, the studies conducted in South Korea showed significant heterogeneity ($Q = 170.91$, $df = 10$, $p < 0.0001$, $I^2 = 94.5$ %, $tau^2 = 0.930$), as did the studies from the USA ($Q = 82.42$, $df = 7$, $p < 0.0001$, $I^2 = 91.50$ %, $tau^2 = 0.681$).

In the subgroup analysis focused on the type of control (Supplementary file 4f), the effect size for traditional learning was 1.106 (85.90 % weight), while the subgroup effect size for low fidelity was 1.001 (14.10 % weight). Tests of subgroup effect size indicated significant differences between the traditional learning and low-fidelity groups ($p < 0.001$), highlighting that high-fidelity simulation demonstrated more significant effects when compared to traditional learning approaches. Heterogeneity was observed in all subgroups, with I^2 values ranging from 87.0 % to 95.0 %, suggesting variability in effect sizes within these categories, with between-subgroup heterogeneity was not statistically significant ($p = 0.760$), indicating that the observed differences in effect sizes are more likely due to factors within each subgroup rather than differences between them.

As shown in Supplementary file 4g, tests of subgroup effect size demonstrated non-significant differences ($p = 0.692$) among all categories, indicating variations in effect sizes were not linked to the presence and completeness in reporting the included primary studies of intervention features. Statistical analysis did not identify significant between-subgroup heterogeneity ($p = 0.152$).

In relation to the topics (i.e., general clinical aspects, critical care, resuscitation practices, pediatric care, maternity care, percutaneous nephrolithotomy, respiratory care, symptom management, and legal and ethical issues) (Supplementary file 4h), the standardized mean difference regarding respiratory care (=1.051) and critical care (standardized mean difference = 0.878) were greater over the effect sizes of the other topics. Tests of subgroup effect size indicated significant differences ($p < 0.05$) among all categories, suggesting variations in effect sizes based on the topic of the study, with significant between-subgroup heterogeneity ($p < 0.001$). These results pointed out that the study topic, particularly respiratory care and critical care, substantially impacts effect sizes, with significant variations observed across different clinical aspects.

As no studies were imputed during the trim-and-fill analysis of publication bias, there was no evidence of publication bias.

4. Discussion

This umbrella review of systematic reviews aimed to consolidate the evidence base on the efficacy of high-fidelity simulation on knowledge and performance outcomes in undergraduate nurse education. This review goes beyond previous literature by conducting an umbrella review of systematic reviews, a meta-analysis of meta-analyses, and a meta-analysis of primary studies included in the systematic reviews (Tong

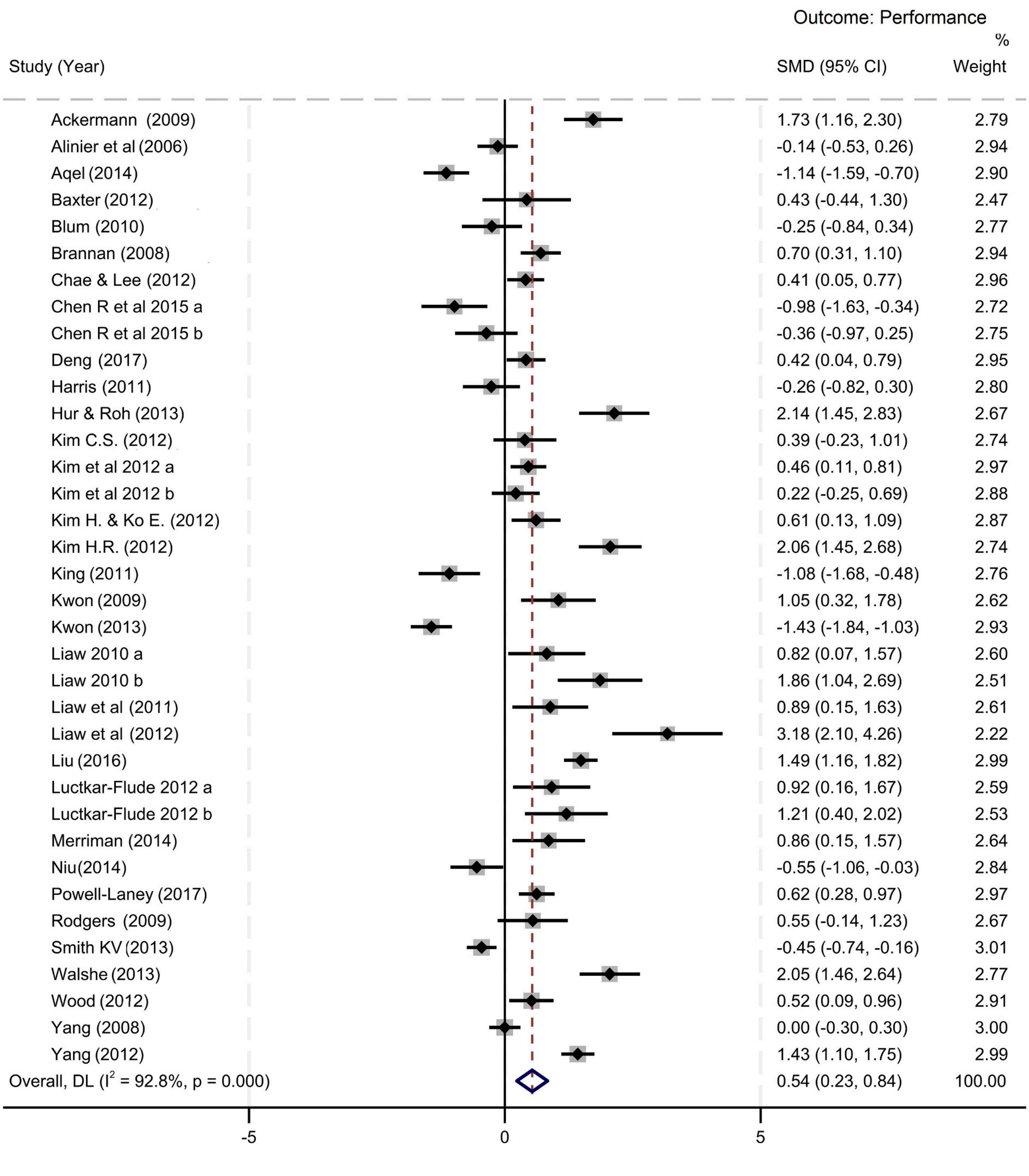

Fig. 4. Meta-analysis of the primary studies included in the systematic reviews.

et al., 2022). After applying trim-and-fill analyses to adjust for potential publication bias, the pooled effects of the two meta-analyses of meta-analyses (knowledge and performance) remained significant (moderate/large effect). For the outcome of knowledge, the adjusted pooled effect size was 0.877 (95 % CI: 0.182 to 1.572), while for the outcome of performance, the adjusted pooled effect size was 0.738 (95 % CI: 0.466 to 1.010). Interestingly, these adjusted estimates from the meta-analyses of meta-analyses closely align with those obtained from meta-analyzing the primary studies included in the systematic reviews after removing overlapping primary studies that were included in more than one systematic review. For the outcome of knowledge, the pooled effect size from the meta-analysis of primary studies was 0.980 (95 % CI: 0.671 to 1.281), while for the outcome of performance, it was 0.540 (95 % CI: 0.213 to 0.846). These findings underscore the robustness of the evidence supporting the positive effects of high-fidelity simulation on knowledge and performance outcomes in undergraduate nursing education. The consistency of the estimates obtained from the meta-analyses of meta-analyses and the meta-analyses of primary studies further strengthens the confidence in these results (Cant et al., 2022; JBI, 2020).

These findings align with the existing literature, which has consistently reported the benefits of high-fidelity simulation in enhancing knowledge acquisition and skills performance among nursing students (Doolen et al., 2016; La Cerra et al., 2019; MacKinnon et al., 2015; Roberts et al., 2019; Tong et al., 2022). The use of high-fidelity simulation in nursing education provides a safe and controlled environment where students are able to practice clinical skills, make mistakes, and learn from them without causing harm to actual patients (Roberts et al., 2019). This experiential learning approach is known to enhance the understanding and retention of knowledge, which is reflected in the significant effect size for the knowledge outcome in this review. Similarly, the significant effect size for the performance outcome supports the role of high-fidelity simulation in improving the practical skills of nursing students. High-fidelity simulation allows students to apply theoretical knowledge to practice, thereby enhancing their clinical performance (O'Rourke et al., 2023). This aspect is particularly important in nurse education, where the ability to effectively perform clinical procedures is crucial.

However, the review also revealed significant heterogeneity among the included studies for both outcomes. This heterogeneity suggests that the effects of high-fidelity simulation on knowledge and performance may vary significantly across different study contexts and methodologies. This result is not surprising given the complex nature of high-fidelity simulation, which can be influenced by various factors such as the design and implementation of the simulation scenarios, the debriefing process, the facilitators' expertise, and the students' level of engagement (INACSL Standards Committee, 2016). For instance, the design and complexity of the simulation scenarios can significantly influence the learning outcomes (Doolen et al., 2016). Scenarios that are too simple may not challenge the students enough to promote significant learning, while overly complex scenarios may overwhelm the students and hinder learning. In this regard, future research should control potential confounders, such as the complexity and validity of the scenarios, the expertise of the facilitators, and the students' level of engagement (Watson et al., 2021).

The subgroup analyses of this umbrella review provide nuanced insights into the efficacy of high-fidelity simulation on knowledge and performance outcomes in undergraduate nurse education. When examining the type of control, high-fidelity simulation exhibited more substantial effects compared to traditional learning methods, reaffirming its value as an advanced pedagogical tool. The differentiation in effect sizes between traditional learning and low-fidelity simulation underscores high-fidelity simulation's potential for a more engaging and realistic educational experience that traditional methodologies may lack (O'Rourke et al., 2023). However, the significant heterogeneity within the subgroups suggests that factors beyond the type of control, such as the educational environment and implementation fidelity, may influence these outcomes.

The analyses related to intervention features revealed that studies with well-documented and complete intervention features generally reported higher effect sizes. This finding emphasizes the importance of rigorous reporting and the careful design of simulation interventions to maximize educational outcomes. It also suggests that partial or incomplete utilization of high-fidelity simulation's capabilities might not harness its full educational potential. Interestingly, the topic of study further impacted the effect sizes, with clinical aspects like respiratory care and critical care showing greater benefits. This variation indicates that high-fidelity simulation may be particularly effective in areas requiring complex decision-making and procedural competencies.

The subgroup analysis based on the location where each study was conducted revealed significant differences in the effect sizes across subgroups, suggesting that the impact of high-fidelity simulation on undergraduate nursing students' knowledge and performance may vary across different places. For instance, the largest effect size was observed in studies conducted in Palestine (Salameh et al., 2021), suggesting that high-fidelity simulation had a substantial positive impact on the performance and knowledge of undergraduate nursing students. On the other hand, the smallest effect size was observed in studies conducted in Taiwan (Lee et al., 2019), indicating a less pronounced effect of high-fidelity simulation in this context. These differences across locations could be attributed to a variety of factors.

One potential explanation could be variations in educational systems. Different places may have different curricula, teaching methodologies, and assessment strategies, which could influence the effectiveness of high-fidelity simulation (Alshehri et al., 2023). For example, some locations might integrate high-fidelity simulation more thoroughly into their nursing curricula or use more effective debriefing strategies, which have been shown to enhance the learning outcomes of high-fidelity simulation (Tong et al., 2022). Cultural contexts could also play a role in these differences because they could influence learning styles, attitudes toward simulation, and the way feedback is received and incorporated, all of which could impact the effectiveness of high-fidelity simulation (Watson et al., 2021). For example, in cultures where students are more accustomed to passive learning styles, the active learning approach required in high-fidelity simulation might be particularly effective in enhancing knowledge and performance. Furthermore, the significant heterogeneity observed within some subgroups, such as the studies conducted in South Korea and the USA (Kang et al., 2020; Lee et al., 2019; Rodgers et al., 2009), suggests that even within the same geographical location, the effects of high-fidelity simulation on undergraduate nursing students' knowledge and performance can vary significantly, reflecting differences in study contexts, such as the specific implementation of high-fidelity simulation, or the characteristics of the student population. Future research should aim to identify the specific factors within different educational systems and cultural contexts that can enhance the effectiveness of high-fidelity simulation in nursing education.

In light of the comprehensive data from Supplementary 4, our analysis elucidates the differentiated impact of high-fidelity simulation on knowledge and performance outcomes in nursing education, notably in resuscitation practices, critical care, and general clinical aspects. The meta-analysis reveals substantial variability in effect sizes across subgroups, reflecting the complex interplay of high-fidelity simulation with educational strategies and student engagement. Specifically, the distinct positive impact on knowledge, compared to the complex results for performance, emphasizes the need for a diverse approach in high-fidelity simulation applications. For instance, the pronounced impact observed in the resuscitation practices subgroup, where specific studies like those by Salameh et al. (2021) demonstrated a significant standardized mean difference, showcasing high-fidelity simulation's efficacy in enhancing critical care skills. Such findings highlight the necessity of adapting high-fidelity simulation methodologies to suit the educational goals of different nursing specialities, ensuring that learners are knowledgeable and can effectively translate theory into practice in high-stakes environments. This aspect underscores the importance of a tailored high-fidelity simulation curriculum that aligns with the specific learning needs and contexts of nursing students. These results affirm the pivotal role of contextual factors—ranging from curriculum design to the fidelity of simulation scenarios—in optimizing the educational benefits of high-fidelity simulation for nursing students.

The results of this umbrella review have significant implications for both nurse education practice and future research. The positive high-fidelity simulation on undergraduate nursing students' knowledge and performance underscores the value of incorporating this pedagogical approach into nursing education programs by corroborating previous findings (La Cerra et al., 2019; Lee and Oh, 2015; Lei et al., 2022; Li et al., 2022; Tonapa et al., 2023; Vincent et al., 2015). Given the complexity and dynamic nature of nursing practice, it is crucial for nursing students to not only acquire theoretical knowledge but also to develop practical skills and critical thinking abilities. In this regard, high-fidelity simulation provides a safe and controlled environment where students can practice clinical skills, make decisions, and learn from their mistakes without risking patient safety (Doolen et al., 2016). Therefore, educators should consider integrating high-fidelity simulation into their curricula to complement traditional teaching methods and to better prepare students for clinical practice. However, the observed heterogeneity among studies indicates that the efficacy of high-fidelity simulation may depend on various factors, such as the design and implementation of the simulation, the debriefing process, and the learning objectives. Therefore, it is not enough to simply incorporate high-fidelity simulation into the curriculum; educators need to carefully plan and implement the simulation to maximize its benefits. For instance, they should ensure that the simulation scenarios are realistic and relevant to the student's level of knowledge and skills, provide structured and constructive debriefing, and align the simulation's learning objectives with the course's overall objectives (Arrigoni et al., 2017).

For future research, the results highlight several areas that need further exploration. First, more research is needed to understand the specific factors contributing to the efficacy of high-fidelity simulation. Further in-depth studies could include aspects investigating the optimal design and implementation of high-fidelity simulation, the role of each phase of the high-fidelity simulation conceptualized as a three-phase process (preparation, participation, and debriefing) (INACSL Standards Committee, 2016), and the influence of students' characteristics on learning outcomes. Second, given the significant differences in effect sizes across different locations, future studies should explore the impact of cultural and educational contexts on the effectiveness of high-fidelity simulation. This further research could help to develop guidelines for adapting high-fidelity simulation to different cultural and educational settings. Future research should also focus on the long-term outcomes of high-fidelity simulation, such as its impact on the transition from undergraduate settings to first employment.

Additionally, a critical area for future research is the retention of knowledge and skills acquired through high-fidelity simulation and their transferability to a range of clinical settings. Studies should focus on understanding the retention duration and identifying strategies to enhance the durability of learned knowledge and skills. This aspect could include investigating the role of reinforcement sessions, periodic assessments, and integrating high-fidelity simulation with other educational strategies. In this regard, longitudinal studies with mixed methods are needed to understand the retention duration and identify effective strategies for enhancing it by considering participants' views.

4.1. Limitations

While this umbrella review provides valuable insights into the impact of high-fidelity simulation on undergraduate nursing students' knowledge and performance, several limitations should be acknowledged. First, the significant heterogeneity observed among the included studies is a major limitation. This heterogeneity suggests that there are substantial differences among the studies in terms of their contexts, methodologies, or both. While we conducted subgroup analyses based on the geographic location where each study was conducted to explore potential sources of heterogeneity, it was not possible to account for all potential sources of variation. For instance, differences in the design and implementation of high-fidelity simulation, the characteristics of the participants, and the outcome measures used could all contribute to the observed heterogeneity. Therefore, the pooled effect sizes should be interpreted with caution, and readers should consider the individual study results as well as the overall pooled estimates.

Second, although the trim-and-fill analyses did not impute any studies in the meta-analysis of primary studies, suggesting no evidence of publication bias in the included studies, the potential influence of publication bias cannot be completely ruled out. This method assumes that the effect sizes of studies are normally distributed around the true effect size, and it imputes hypothetical missing studies to the meta-analysis to create a symmetrical funnel plot; however, it cannot account for other types of bias that might affect the publication of studies, such as language bias, citation bias, or time-lag bias. Therefore, while the results of the trim-and-fill analyses are reassuring, we cannot completely rule out the potential influence of publication bias on our findings.

Third, the quality of the included studies varied, with some studies reporting a high risk of bias. Although we used a rigorous methodology to assess the risk of bias and conducted sensitivity analyses to assess the impact of study quality on the results, the presence of high-risk studies could potentially influence the reliability of the findings. In addition, in the meta-analysis of primary research, not all the included studies were RCTs because some reported quasi-experimental designs. Including quasi-experimental studies was a deliberate choice, as these studies are able to provide valuable insights into the effects of high-fidelity simulation in real-world settings where randomization may not be feasible or ethical. However, quasi-experimental designs are generally considered to be less robust than RCTs in terms of controlling for potential confounding factors, which could introduce bias into the results. Therefore, including these studies could potentially affect the reliability and validity of the pooled effect sizes. Despite these limitations, this approach allows for a broader range of studies to be considered, increasing the generalizability of the findings. In this regard, future research should aim to conduct more high-quality RCTs to strengthen the evidence base further on the effects of high-fidelity simulation in nursing education.

Fourth, this review primarily focused on the immediate efficacy of high-fidelity simulation in imparting knowledge and skills. However, it did not explore the long-term retention of these skills and knowledge. Future studies should aim to fill this gap by examining the duration and factors influencing the retention of skills and knowledge post-high-fidelity simulation training, which is crucial for ensuring sustained competency in nursing practice.

Additionally, it is important to acknowledge that some missing information within the included articles constrained the analytic capacity of this review. Specifically, critical details such as the number of high-fidelity simulation sessions, the specific nursing context or topic addressed, a comprehensive simulation description, debriefing procedures, the number of simulation sessions conducted, and the modality used (e.g., manikin simulations) were available in less than half of the included studies. Consequently, in our subgroup analysis, we categorized the completeness of information into "yes" or "partially yes" versus "no" or "partially no" to evaluate these aspects. Information on the year of the nursing course was retrievable in only approximately one-third of the included studies, rendering it unfeasible to perform a subgroup analysis based on this variable. These limitations stemming from missing data underscore the need for future research that clearly highlights these aspects when describing high-fidelity simulation to provide more comprehensive and standardized reporting, facilitating more robust subsequent meta-analyses and specific subgroup assessments.

5. Conclusions

This umbrella review of systematic reviews provides robust evidence supporting the positive impact of high-fidelity simulation on knowledge acquisition and performance among undergraduate nursing students. The adjusted pooled effects from the meta-analyses of meta-analyses, even after trim-and-fill analyses, closely align with those obtained from meta-analyzing the primary studies included in the systematic reviews, further strengthening the validity of our findings. Significant heterogeneity among the studies may be attributed to variations in study contexts or methodologies. However, the overall positive effects of high-fidelity simulation were consistent across different settings and populations, underscoring the generalizability of our findings. The findings of this review have important implications for nursing education practice and future research. They provide strong evidence supporting the integration of high-fidelity simulation into undergraduate nursing programs to enhance students' knowledge and performance. Future research should explore the optimal use of high-fidelity simulation in different educational and cultural contexts to maximize its benefits for nursing students. Further, shifting the research focus to the individual phases of the process is key to allowing educators and researchers to better understand how each phase contributes to the overall efficacy of high-fidelity simulation, thereby maximizing learning outcomes.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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