The meta-analysis of High-fidelity simulation in undergraduate nursing education

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ABSTRACT:

Objectives: To explore the effectiveness of high-fidelity simulation (HFS) in undergraduate nursing education. Design: A meta-analysis of randomized controlled trials and quasi-experiment. Data sources: Web of Science, PubMed, Embase, Cochrane Library, WANFANG, and CNKI were searched for eligible articles published in English and Chinese until May 28, 2021.

Review methods: The Quality Appraisal Check-list for Quantitative Intervention Studies was applied to the quality evaluation. Standard mean differences (SMD) were pooled using a random effects model. The results of the individual and combined intervention effects estimation of was displayed in a forest plot, with weight, SMD, its corresponding 95% confidence interval (CI), Z-test, p, I2. Results: Thirty-eight studies were included and 37 were analyzed. High-fidelity simulation (HFS) revealed significantly larger effect sizes for knowledge (SMD = 0.89, 95% CI [0.54 to 1.23]), skill (SMD = 0.93, 95% CI [0.69 to 1.17]), collaboration (SMD = 0.52, 95% CI [0.26 to 0.78]), caring (SMD = 1.40, 95% CI [0.23 to 2.58]) and learning interest (SMD = 0.85, 95% CI [0.00 to 2.04]) when compared with other teaching methods. However, no significant difference between HFS and other teaching methods in critical thinking (SMD = 0.46, 95% CI [1.12 to 1.58]), self-confidence (SMD = 0.22, 95% CI [0.32 to 0.75]) and learning satisfaction (SMD = 0.58, 95% CI [0.25 to 1.41]) was shown. Conclusions: High-fidelity simulation (HFS) can more effectively cultivate knowledge, skills, collaboration, caring, and learning interest of undergraduate nursing students. Since the effect of HFS is equivalent to other teaching methods in cultivating undergraduate nursing students' critical thinking, self-confidence and learning satisfaction, nursing educators can choose the most appropriate methods to achieve the intended learning out- comes according to the actual situation.

KEYWORDS Undergraduate nursing students, High-fidelity simulation, Meta-analysis

Background

High-fidelity simulation (HFS) refers to the use of full-scale computerized patient simulators to present authentic clinical manifes- tations and clinical scenarios (Au et al., 2016; Meakim et al., 2013). HFS has become an increasingly popular pedagogical approach in nursing education. Previous systematic reviews have shown that HFS promotes critical thinking, knowledge, teamwork, technique in registered nurses and nursing students (Lewis et al., 2019; Svellingen et al., 2021; Warren et al., 2016). In addition, a meta-analysis reveals that compared with low-fidelity simulation and medium-fidelity simulation, HFS has the largest effect size on cognitive and emotional learning outcome, as well as a large effect size on psychomotor for mixed samples of nursing

students, licensed nurses and nurse practitioners (Kim et al., 2016). Others show in detail that compared with no intervention, lectures or low-fidelity mannequins, HFS can significantly facilitate knowledge and skill immediately in the nursing discipline (La Cerra et al., 2019; Sher- wood and Francis, 2018). Accordingly, HFS has been considered as an ideal substitute for traditional clinical practice. California Board of Registered Nursing also allowed that simulation training in laboratory can substitute for clinical learning up to 25% of the time (Gates et al.,2012).

There have been a number of systematic reviews and meta-analyses of the effects of HFS on nursing students (La Cerra et al., 2019). How- ever, most of these systematic reviews and meta-analyses mixed nursing undergraduate students and others, such as graduate students (La Cerra et al., 2019), new graduates (Yuan et al., 2012a), prelicensure students (Hanshaw and Dickerson, 2020) and even experienced nurses (Yuan et al., 2012). Even the review (Akalin and Sahin, 2020) for Bachelor of Science in Nursing (BSN) students included some literature that included non-traditional BSN students (with previous university de- grees) (Cobbett and Snelgrove-Clarke, 2016). Due to the different learning formats (face-to-face, online, or hybrid courses) and experi- ences (the number of hours spent studying and working off campus) (Woods and Frogge, 2017), non-traditional and traditional university students have different knowledge about test-taking skills and study organizational skill (Waltman, 1997). Students' level of clinical experi- ence or previous learning was not taken into account, and more sub- stantial data are needed to identify the effects of HFS in different stages of education (Ackermann, 2009; Ahn and Kim, 2015), which limits the generalizability of the study. A meta-analysis involving different types of nursing students found that there was statistical heterogeneity among the studies included (La Cerra et al., 2019). However, the meta-analysis only carried out subgroup analysis for different scenarios and Manikin brands and did not carry out subgroup analysis for nursing students of different types (La Cerra et al., 2019). In this way, the effect of HFS on BSN students cannot be clearly understood. Results from an umbrella systematic review showed that none of the reviews of HFS studies in BSN education published between 2009 and 2015 were meta-analyses or systematic reviews (Doolen et al., 2016). Even up to now, there is no relevant literature after searching. The purpose of this meta-analysis was to explore the effectiveness of HFS in BSN education.

Method

Inclusion and exclusion criteria

Studies were included if they met the following criteria: (1) the study design was an experimental study with a control group; (2) participants were BSN students; (3) HFS was used as a major component in the experimental group. Participants had to deal with responses of high- fidelity patient manikin; (4) available full-texts had to be published in English or Chinese.

Studies were excluded if they: (1) had involved BSN students who already had a non-nursing degree, or took the programs related to nursing discipline; (2) there was no comparability between the experi- mental group and the control group. The experimental group had more interventions than the control group except for HFS; (3) the data were incomplete or could not be used for analysis. When the same samples were included in multiple publications, only the most relevant and largest data set was included.

Two authors independently screened all titles and abstracts to exclude articles that did not meet the inclusion criteria. Thereafter, two authors independently reviewed full texts to exclude articles that did not meet the eligibility criteria. Any discrepancies between the two authors were resolved through discussion with a third author.

Search strategies

According to the inclusion and exclusion criteria, Web of Science, PubMed, Embase, Cochrane Library, WANFANG, and CNKI were comprehensively searched with key words for relevant articles pub- lished in English and Chinese prior to May 28, 2021. There was no re- striction on country or published year. The search strategy is attached as Supplementary attachment 1. All articles that might qualify were considered for review. The reference lists of included studies were also manually screened.

Quality appraisal of studies

The methodological quality of eligible studies was appraised with Quality Appraisal Checklist – Quantitative Intervention Studies designed by National Institute for Health and Care Excellence (NICE) by two authors independently. It was based on this checklist for both random- ized controlled trials and controlled before-and-after studies (National Institute for Health and Care Excellence, 2012). The result of internal and external validity identified very good (++), good (+), and not good ( ) (National Institute for Health and Care Excellence, 2012). The inconsistent result of the eligible studies in this meta-analysis was dis- cussed with the third author and reached a consensus finally.

Synthesis of results

Data extraction of the “country, research design, sample size, intervention, measurement tools, learning outcomes” from 37 included studies were executed. Then, this meta-analysis was carried out through RevMan 5 software. The Cohen's effect sizes were presented as standard mean differences (SMD) for continuous outcome parameters in this meta-analysis (Zlowodzki et al., 2007). SMD value of 0.2, 0.5, and 0.8 represents small, medium and large respectively (Richmond et al.,

2017). On the other hand, the heterogeneity analysis was implemented to decide how to generalize the results of the effects, the Cochran's Q statistic and a chi-squared test were utilized to expose an inconsistency

index I2 for quantifying the heterogeneity among studies, I2 was over

50% to 75% to be concerned with medium to high heterogeneity (Hai- dich, 2010). A fixed effect model was used when heterogeneity was not detected, and a random effect model was applied when there was moderate to high heterogeneity. Subsequently, the included studies were weighted with the heterogeneity parameter and the inverse of variance to estimate the average true intervention effect with the observed intervention effects via the random-effects model (Haidich,

2010). The available subgroup analysis would be executed for identi- fying the sources of heterogeneity (Haidich, 2010). The result of the funnel plot was applied to show the condition of publication bias through the point estimates (Zlowodzki et al., 2007). The significant difference was identified as $p \leq .05$.

Results

Studies selection

The search produced 2560 potentially relevant articles from data- bases. 1585 titles and abstracts were screened after removing duplicates. Consequently, 38 full texts met the inclusion criteria, and 37 studies were assessed (Fig. 1). Only one study (Thompson, 2021) focused on the influence of HFS on students' anxiety in a clinical setting, which could not be combined with the results of other studies, so it was not included in the analysis.

Studies characteristics

The characteristics of the included studies are shown in Table 1. The eligible studies were conducted across 10 countries. There were 4541 participants in total, 2334 participants were in the experimental group and 2207 participants were in the control group. The sample size of studies ranged from 46 to 389 BSN students. Most of the studies included in this meta-analysis were designed as RCT (n = 20; 54.1%). Among the control group interventions, more than half (n = 25; 67.6%) used low- fidelity manikin. Most studies have focused on the effect of HFS on skills (n = 24; 64.9%) and knowledge (n = 21; 56.7%); relatively few studies have evaluated the impact of HFS on caring (n = 4; 10.8%).

Quality appraisal of studies

There were 36 studies with good internal validity and 23 studies with good external validity (Table 2). The funnel plots were symmetrical, indicating that the possibility of publication bias is small.

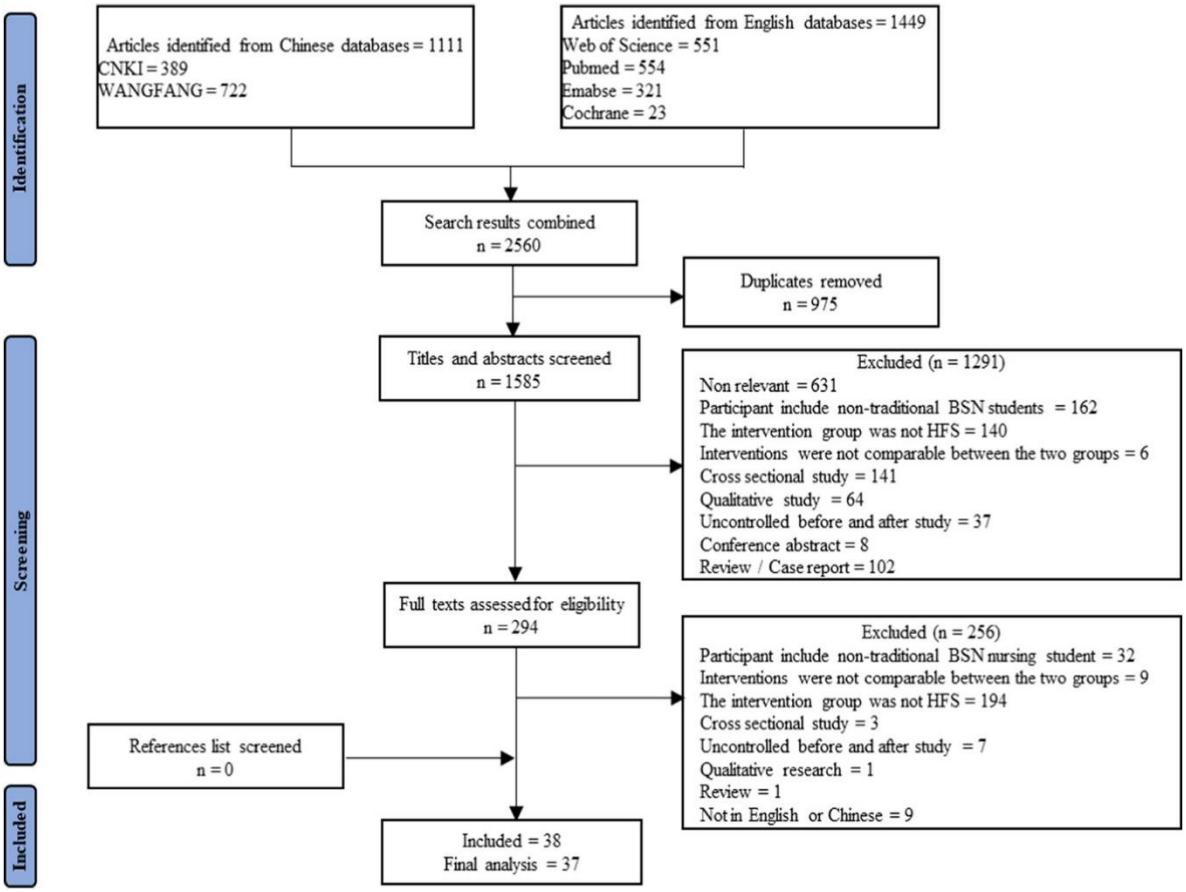

Fig. 1. Flow diagram of literature search and study selection.

Effectiveness of HFS in BSN students

Seven English and fourteen Chinese studies (2149 participants) were included in the analysis of knowledge. HFS showed significantly larger effect sizes for knowledge than other teaching methods ($p < .001$). A significant heterogeneity was detected ($p < .001$), then the studies were divided into subgroups by the teaching method. The effect sizes were as follows: clinical practice (SMD = 0.65), non-high fidelity manikin (SMD = 0.87), case study (SMD = 0.92) and others (such as vSim, lecture) (SMD = 1.09) (Fig. 2).

Twenty-four studies (2916 participants) assessed the effect of HFS on skill. As shown in Fig. 3, the result showed a large benefit with HFS when compared with other teaching methods in skill performance ($p < .001$). In subgroup analyses,

the results revealed that HFS had large benefits compared with non-high fidelity manikin ($p < .001$) or clinical practice ($p < .001$) or others (such as vSim) ($p = .05$), however, no difference was shown when compared with case study ($p = .48$).

Six studies (734 participants) were combined to determine the effectiveness of collaboration (Fig. 4). The SMD was 0.52 ($P < .001$), indicating that HFS is more effective in fostering BSN students' collab- oration in contrast with other teaching methods. Similarly, after analyzing the four Chinese studies (568 participants), HFS displayed that the effect size for caring is significantly larger ($p = .02$) than other teaching methods (Fig. 5). The significant differences were also found between HFS and other teaching methods for learning interest in one English and five Chinese studies (544 participants) ($p = .05$) (Fig. 6).

A synthesis of nine studies (1363 participants) showed that HFS had the same effect as other teaching methods in cultivating critical thinking (SMD = 0.23, $p < .001$) (Fig. 7). Furthermore, there was no significant difference between HFS and other teaching methods for self-confidence in six English studies and one Chinese study (567 participants) ($p = .43$) (Fig. 8). No significant difference was also found between HFS and other

teaching methods in three English and three Chinese studies (527 par- ticipants) ($p = .17$). The subgroup analyses revealed no differences be- tween the HFS and non-high fidelity manikin teaching method in five studies ($p = .08$), and also no difference was discovered between HFS and the case study teaching method in two studies ($p = .67$) (Fig. 9).

Discussion

To our knowledge, this study may be the first meta-analysis to identify the effectiveness of HFS in BSN students. The results included the contribution of HFS on eight aspects of knowledge, skills, collabo- ration, caring, interest in learning, critical thinking, self-confidence and satisfaction in undergraduate nursing education.

HFS improves knowledge acquired by BSN students

The results of this meta-analysis indicated that HFS was more effective in improving the knowledge acquisition of nursing students than other teaching methods. This result is inconsistent with previous systematic reviews (Hegland et al., 2017; Lee and Oh, 2015). The effect of HFS is influenced by teachers, students and teaching design (Jeffries,

2005). In most of the included studies, teachers (68.4%) and students (100%) in the control and intervention groups were comparable. How- ever, the previous systematic review included studies in which partici- pants were not comparable, mixed undergraduate and graduate nursing students, and the comparability of teachers was not mentioned. In this study, the degree of benefits was larger in the outcome when comparing HFS to case study than when comparing HFS to clinical practice. Meta- analysis applies well only when the heterogeneity was less than 50% (Higgins et al., 2019). The heterogeneity of the

included studies (I2 = 93%) should be carefully considered if the substitution of HFS for non- high fidelity manikin or clinical practice is to learn new knowledge. In addition to the high purchase and maintenance costs of HFS (Garrett et al., 2011), there are additional costs associated with scenario devel- opment and programming, and staff extra set-up time (Lapkin and Levett-Jones, 2011). Medium-fidelity simulation could have achieved the same knowledge acquisition effect for only one-fifth of the cost of HFS (Lapkin and Levett-Jones, 2011). This means that nursing educators need to choose the best teaching method to acquire knowledge based on their own situation in terms of cost utility.

HFS is an effective way to improve BSN students' skill

Nursing education hopes that nursing students can apply what they have learned to practice. The improvement of nursing students' ability needs continuous practice. But now with more and more attention paid to patient safety, nursing students have fewer and fewer practice op- portunities. HFS replicates real clinical situations and allows nursing students to make mistakes and learn from them (Gaba, 2004; Seropian et al., 2004). Through mistake analysis and instructor feedback, nurse students may improve their skills and increase knowledge retention and application by repeating the scenario with HFS. Results of a longitudinal randomized controlled study showed that up to half of the high quality HFS hours instead of traditional clinical hours showed no statistically significant difference in student skill performance at 6 weeks, 3 months, and 6 months (Hayden et al., 2014). Previous systematic reviews have found that HFS enhanced skill performance, but their results were inconsistent (Huang et al., 2019; La Cerra et al., 2019; Yuan et al.,

2012b). A systematic review results showed that although HFS can improve the skill examination scores, it has no significant effect on the objective structured clinical examination performance (Yuan et al.,

2012a, b). A medium (La Cerra et al., 2019) to large (Huang et al., 2019; Yuan et al., 2012a, b) benefit in skill performance with HFS was found when compared with other teaching methods, while the present study found a large effect.

The results of this study show that HFS has the same effect as case study in improving students' skills. Case study can provide students with reflective observation and active experimentation opportunities, so as to effectively facilitate learning and improve problem-solving ability (Kunselman and Johnson, 2004; Mayo, 2004). The research conducted by Schwartz et al. (2007) shows that HFS is equivalent to case study in training the skills of medical students. Based on empirical research,

some scholars proposed that teaching methods should be selected based on teaching objectives. When the teaching objective is mainly to acquire knowledge, case study is preferred, while when the teaching objective is mainly to cultivate technical and non-technical abilities, HFS is preferred (Couto et al., 2015). Moreover, scholars suggest that simula- tion can be combined with traditional teaching methods to enhance students' learning more effectively (Shepherd et al., 2007). The acqui- sition of clinical skills is complex, and it may

be difficult to achieve the best effect by relying solely on a single teaching method. In the future, more studies are needed to explore the effect of the combination of multiple teaching methods.

HFS can effectively promote nursing students' collaborative competency

The results of this meta-analysis showed that HFS was superior to other teaching methods in the cultivation of collaborative ability of BSN students, which is similar to the results of a research on health profes- sional education (Maxson et al., 2011; Wellmon et al., 2017). Collabo- ration is a complex process that requires sharing, respect, and teamwork (Emich, 2018). Under the circumstance of the increasing complexity of the healthcare environment, nurses need be familiar with the re- sponsibilities and obligations of colleagues in other professions and be able to communicate and practice effectively in multidisciplinary teams (Astbury et al., 2020). Hence, the development of collaborative com- petencies was strongly demanded by the work process of nursing (Bochatay et al., 2019). In addition, the American Association of Col- leges of Nursing also emphasized that collaboration is one of the core essentials for BSN programs (American Association of Colleges of Nursing, 2008). Introducing collaboration during baccalaureate training is important to establish a basis for multidisciplinary collaboration in future practice (Chen et al., 2015).

Good interprofessional collaboration benefits not only clinical care delivery, but also organizational outcomes (World Health Organization,

2010). A recent meta-analysis declared that simulation-based interpro- fessional education can provide a favorable learning environment to enhance collaboration competency and the quality of services (Marion- Martins and Pinho, 2020). In the simulation-based setting, through interacting with other healthcare professionals, students can learn from, with and about each other, and then be well prepared to work together

Educators can enact culturally sustaining pedagogy by meaningfully creating spaces and opportunities that provide windows and mirrors and what Botelho and Rudman (2009) call doors for all students in their classrooms. Botelho and Rudman (2009) propose the idea of a critical multicultural analysis as a way to open the door for students to learn to read power within the embedded discourses of the texts, tasks, and talk that create perceptions of normality. Considering recent public debates and tensions around U.S. immigration (Capps, et al., 2016; Muzaffar & Hipsman, 2014) and the continued marginalization of linguistically and culturally diverse peoples, the value and importance of culturally sustaining pedagogy is perhaps more important than ever. The neglected rights for equal educational access and the lack of equality of resources and equality of capital, combined with the push for English-only legislation have ignited a growing concern for linguistically and culturally diverse students in schools and made the need for students to learn to read power in the discourses that surround them an essential literacy practice. Enacting culturally sustaining pedagogy, then, is actualized as students engage in critically reading literature that serves as a window, a mirror, and a door. Critically reading power in this way pushes back and challenges normalized assumptions about race, language, ability, gender, and all

matters of difference. A more critical intentionality to employ a culturally sustaining in the future. Consequently, nursing educators can consider inviting other students from different disciplines, such as medical students and pharmacy students, to participate in the scenarios to better cultivate students' ability to collaborate across specialties. Nonetheless, another meta-analytical investigation revealed that nurses had a more positive attitude toward collaboration as compared to physicians, while physi- cians showed more perception of existing cooperation than nurses (Sollami et al., 2015). This finding seems to indicate that the sensitivity of nurses to perceive existing cooperation still needs to be further enhanced. In the future, nursing educators can consciously guide students to perceive cooperation in the work environment while con- ducting the HFS training.

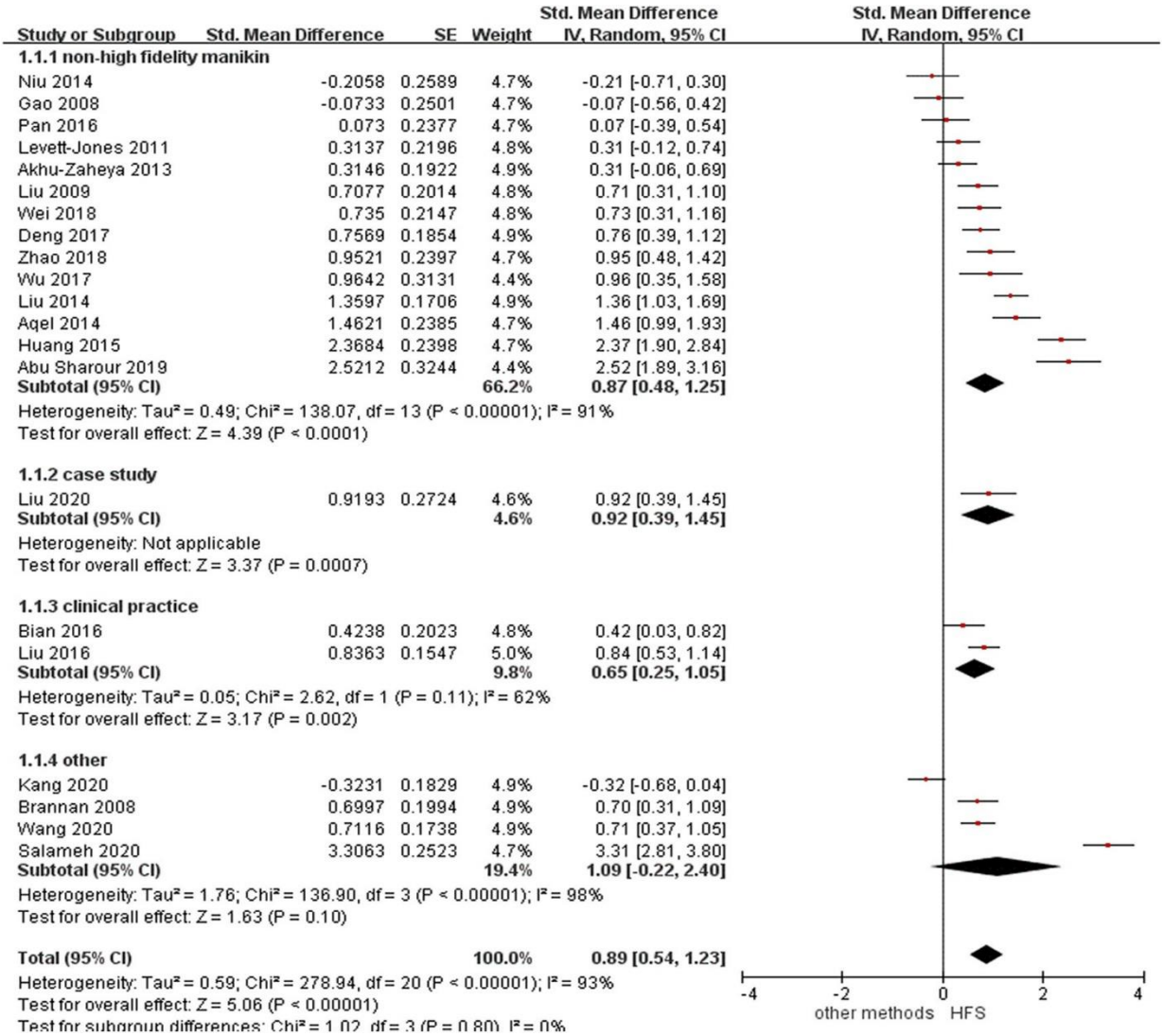

Fig. 2. Effect of high-fidelity simulation on undergraduate nursing students' knowledge.

This meta-analysis showed that a HFS learning environment could foster nursing students' caring more effectively, no matter awareness of caring (Wang and Xu, 2020), attitude of caring (Li and Li, 2019), or characteristic of caring (Liu

et al., 2015; Liu et al., 2020). It may be the first meta-analysis to report that caring as an effective learning outcome is cultivated through high-fidelity simulation. As known as caring can be an actual existence of reality in nursing discipline that nursing pro- fessionals have to interact with clients/individuals/families/communities with the feeling of empathy and sensitivity (Bruce, 2018). It is a significant nursing professional value and should be trained during BSN education (Poorchangizi et al., 2019). In addition, the one way of teaching methods to raise caring competency of nursing students is providing the learning environment for caring practice (Subke et al., 2020). As mentioned, the reason that a HFS learning environment can foster nursing student's caring effectively may be that the scenario running session of HFS can provide an opportunity for students to carry out the action of caring. Students can practice interacting with simulated patients, be aware of understanding simulated patients as a human being, and respond to simulated patients' need with caring competency in the HFS learning environment. In particular, the high-fidelity simu- lator can display the signs, symptoms and can also communicate with students. It allows students to be there and follow the needs of the simulated patients (high-fidelity simulator) (Holopainen et al., 2019). In contrast, the low fidelity simulator or standard patient (other teaching methods) cannot fulfill the high-fidelity condition of a simulated real patient. In addition, the debriefing session of HFS also can let teachers guide students to be aware of what caring is, take an attitude toward caring, and retain the characteristics of caring. It seems that the benefit of HFS to foster BSN nursing students' care competency is to achieve caring with a real action.

Effects of HFS on cultivating critical thinking is not obvious

For nursing, critical thinking was defined as a reflective reasoning process that guides a nurse to generate approaches to deal with nursing problems (Carvalho et al., 2017). Previous studies had shown that nurses who can think critically and creatively have the potential to effectively cope with the diversity and complexity of the nursing environment, ensure patient safety and improve patient outcomes (Carvalho et al., 2017; Von Colln-Appling and Giuliano, 2017). Since critical thinking has been considered as one of the criteria for accreditation of nursing pro- grams (National League for Nursing Accrediting Commission, 2016), it is crucial to identify the best strategies for cultivating critical thinking in undergraduate nursing education.

The present meta-analysis found that compared with other teaching methods, HFS had no obvious advantage in developing students' critical thinking, which was consistent with recent research (Blakeslee, 2020). Conversely, previous research (Lee and Oh, 2015; Lewis et al., 2012) revealed that HFS could effectively lead to an improvement in critical thinking, which is different from the current findings. These inconsistent findings may be partly attributed to the application of multifarious measurement instruments (Adib-Hajbaghery and Sharifi, 2017).

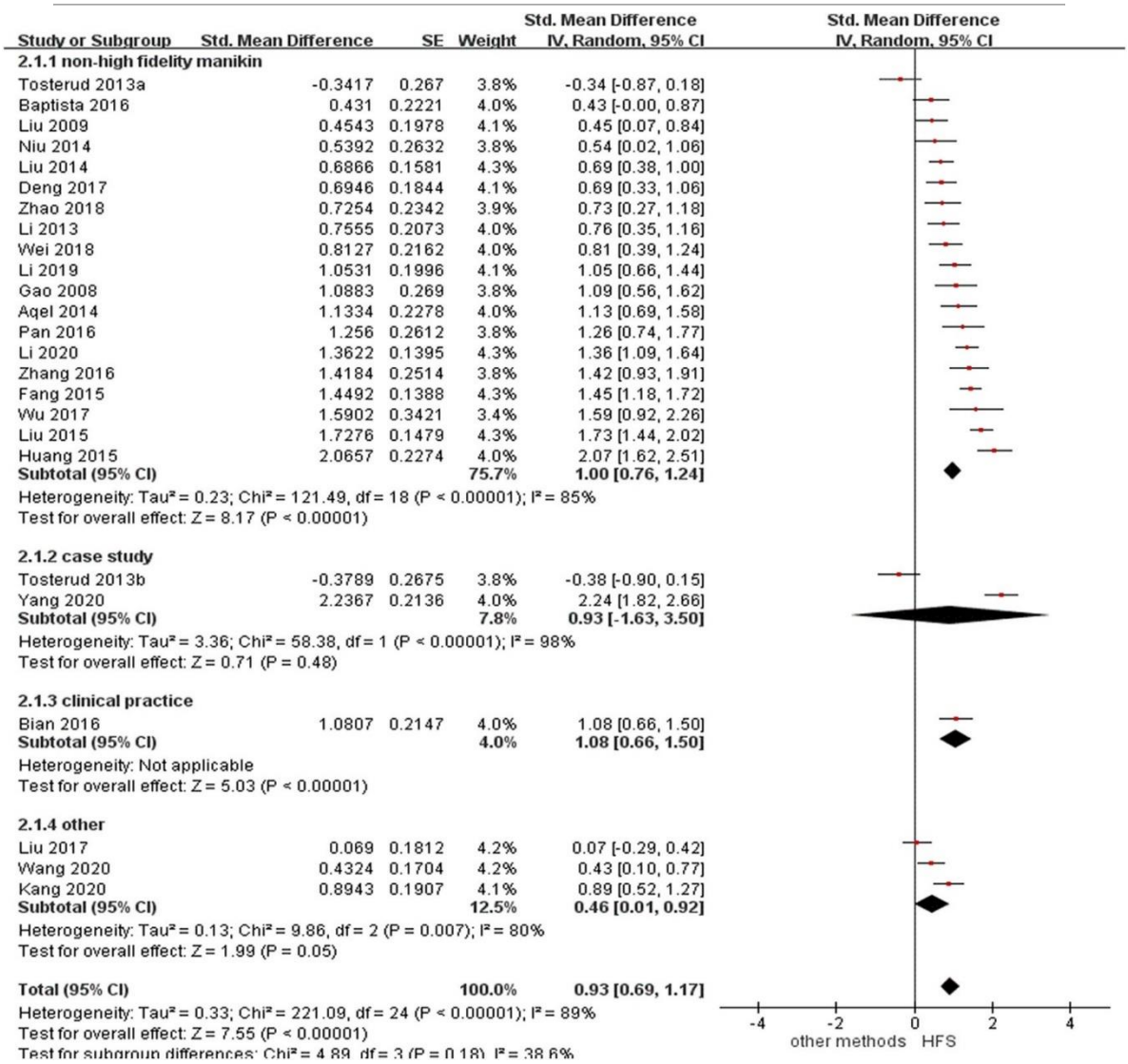

Fig. 3. Effect of high-fidelity simulation on undergraduate nursing students' skill.

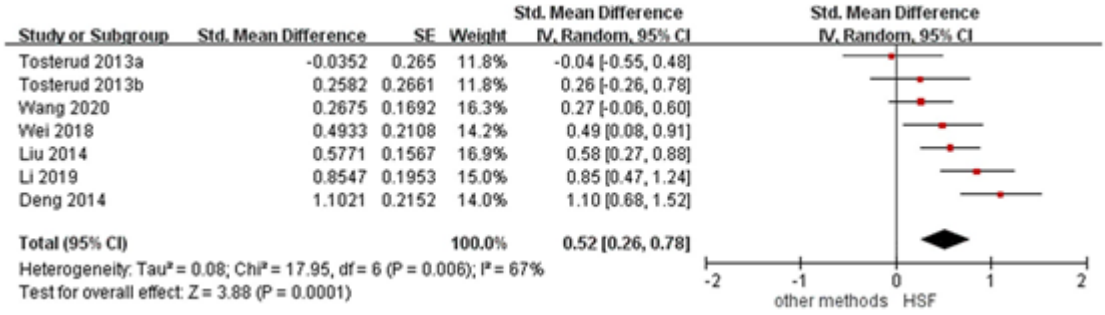

Fig. 4. Effect of high-fidelity simulation on undergraduate nursing students' collaboration.

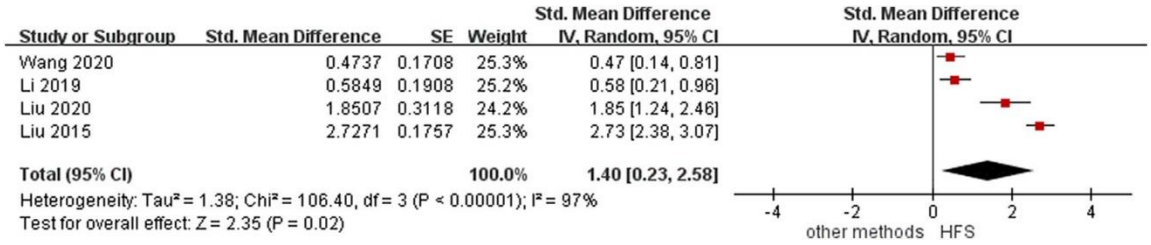

Fig. 5. Effect of high-fidelity simulation on undergraduate nursing students' caring.

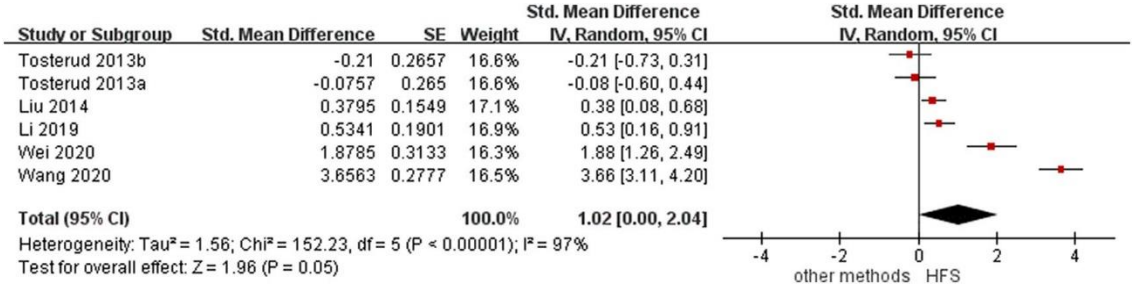

Fig. 6. Effect of high-fidelity simulation on undergraduate nursing students' learning interest.

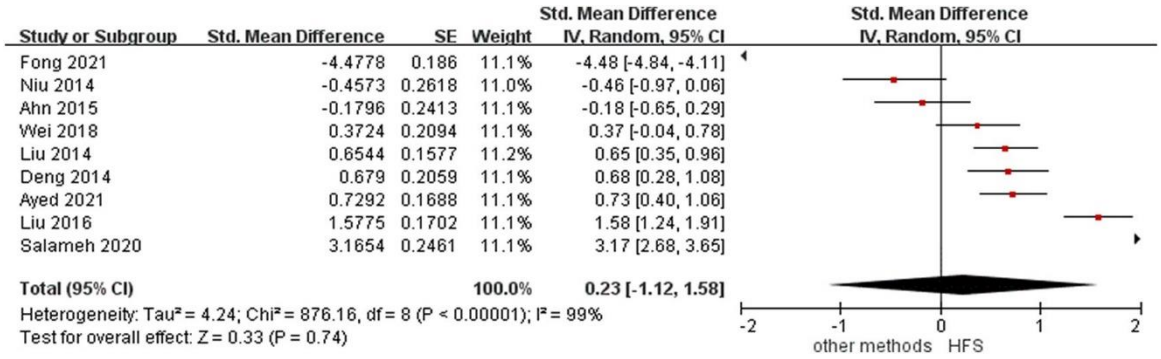

Fig. 7. Effect of high-fidelity simulation on undergraduate nursing students' critical thinking.

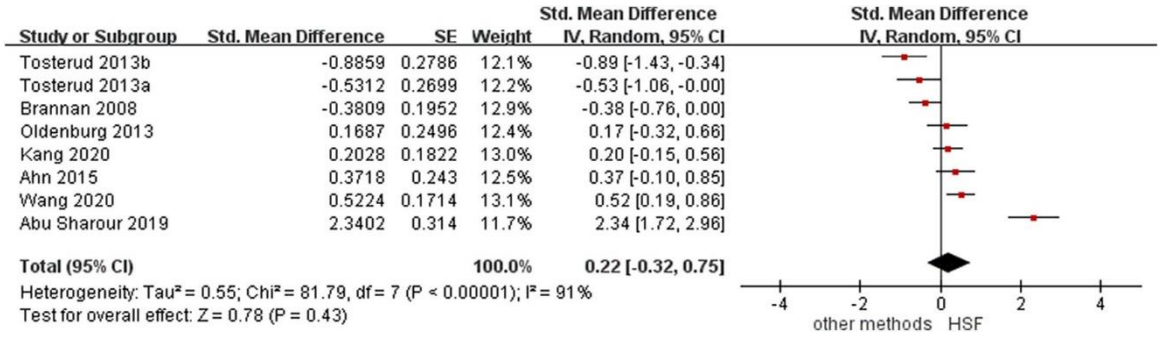

Fig. 8. Effect of high-fidelity simulation on undergraduate nursing students' self-confidence.

Researchers used a variety of tools to measure critical thinking in the included studies. Different kinds of measures may supply biased results favoring either HFS or other teaching methods. On the other hand, the duration of the HFS training might be another reason for the inconsistent results among the studies. Critical thinking requires personal awareness, willingness to accept challenges, and personal traits (Fong et al., 2021). Critical thinking is cultivated over time through varied experiences, not by merely a lecture or a clinical experience (Oermann, 1997). In the included studies, the number and duration of training sessions varied, ranging from a single 10-minute session (Fong et al., 2021) to up to six

20-minute sessions (Salameh et al., 2021). The advantages of different teaching strategies in cultivating students' critical thinking may not be well demonstrated in a short period of time. Therefore, the effectiveness of intervention dosage of HFS needs to be identified.

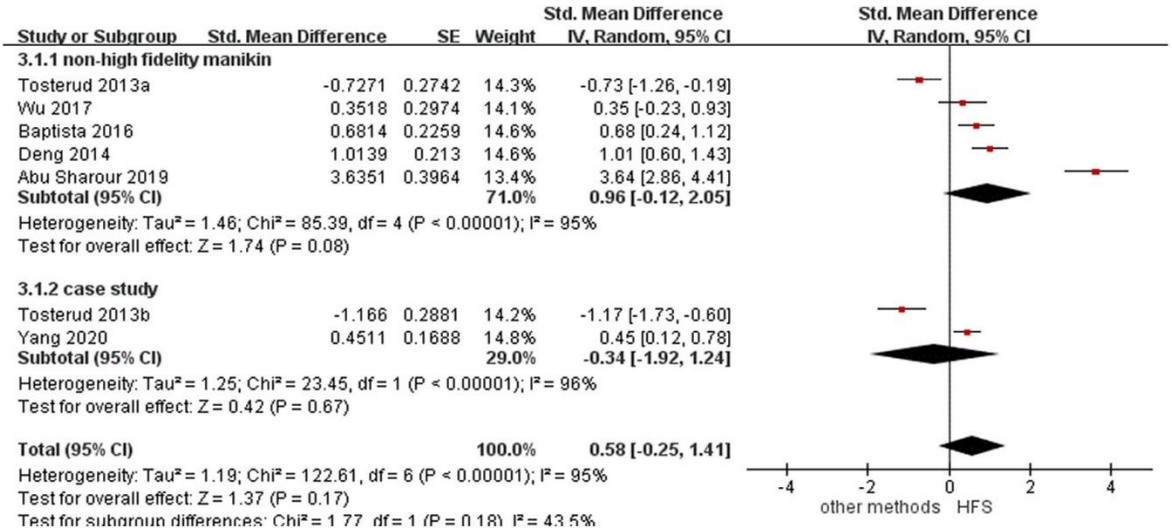

Fig. 9. Effect of high-fidelity simulation on undergraduate nursing students' learning satisfaction.

HFS and other teaching methods have nearly the same effect in self-confidence

The result of this meta-analysis did not disclose that HFS can raise BSN students' self-confidence more effectively. This result was similar to previous study (Yuan et al., 2012a, b). Different and appropriate teaching strategies based on students' autonomy can develop students' self-confidence (Ratnasari et al., 2020). Students who have self- confidence can be ready to meet future barriers and make them estab- lish a positive belief to achieve goals (Johnson et al., 2020). It is bene- ficial for students to learn more actively. Accordingly, nursing educators should consider that self-confidence is involved in knowledge of a given domain. Maclellan (2014) suggested that implementing a "voluntary knowledge sharing" within the teaching strategies to enhance domain knowledge is very important, such as the debriefing session for HFS, discussion session for case study, or question session for lecture. On the other hand, educators also think that self-confidence is involved in cognitive standpoint (confident thoughts)

and feel standpoint (feel confident) (Guerin et al., 2010), a session should be created to let stu- dents express their emotion, which serves as an emotional reflection session for different teaching strategies. Hence, nursing educators should arrange an interaction session in the class to promote students' self-confidence (Maclellan, 2014).

HFS is ineffective in learning satisfaction but effective in learning interest

It may be the first meta-analysis to reveal the effect of HFS on BSN students' learning interest. A previous study proves that a positive cor- relation is between learning interest and learning satisfaction (Hong et al., 2016). The mechanism shows that the individual affective tier affects perceived satisfaction (Liaw and Huang, 2013). As learning in- terest is the emotional engagement (Oriol et al., 2016), students who are interested in learning are involved in learning with motivation and positive/high energy, they will insist on learning and be satisfied with the learning activity (Hong et al., 2016; Sansone et al., 2012).

However, the result of this meta-analysis is inconsistent with the mentioned evidence. HFS could not increase BSN students' learning

satisfaction but could increase learning interest significantly when compared with other teaching method. The reason for this result may be that nursing students prefer non-traditional teaching methods to enhance the learning satisfaction (Abarghouie et al., 2020). In addition, HFS provides students with a highly simulated learning environment, which can greatly enhance their interest in learning (Hicks et al., 2008). Given the large number of students and the limitation of equipment, the students were grouped as hand-on roles and observer roles in the sce- narios running. Previous study showed that the satisfaction of observer roles was lower than hand-on roles (Blani´e et al., 2018). In actual practice, about half or more of the students are observers in each sce- nario (Hober and Bonnel, 2014), which partly affects the learning satisfaction of HFS. In the future, nursing educators are required to think about how to improve the learning satisfaction of observers, and nursing researchers also need to explore the appropriate number of students in the scenarios.

Limitation

There were a few limitations in the present meta-analysis. First, we included randomized controlled studies and quasi-experimental studies, which could have led to uneven quality of the literature. Second, the included studies were from 10 different countries, with unequal regional distribution, so interpreting the results should be carried out carefully. Third, the tools of assessing learning effects varied between studies and most of them were self-reported, which may have contributed to het- erogeneity among studies. Forth, the heterogeneity of comparison for each group was relatively high. In order to further explore the original source of the heterogeneity, subgroup analyses were performed in partly learning effects.

Conclusion

These study results have provided in-depth evidence for the effectiveness of HFS in BSN education. Compared with other teaching methods, HFS is effective in cultivating BSN students' knowledge, skills, collaboration, caring, and learning interest. However, the effectiveness of HFS is equivalent to other teaching methods in improving BSN students' critical thinking, self-confidence, and learning satisfaction. Since different teaching methods have their own advantages and disadvantages, in the future, nursing educators can choose the most appropriate teaching methods based on the actual situation to achieve the intended learning outcomes.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Appendix

Table 1

Studies characteristics.

Study	Study design	Sample size (experimental)	Intervention		Outcomes (measures)
			Experimental	Control	
(Ahn and Kim, 2015) (South Korea)	Quasi-experimen	69 (35)	Lecture + HFS	Lecture + case study	Self-confidence (self-confidence questionnaire) critical thinking (Korean nursing students' critical thinking tendency)
(Gharaibeh, & Alostaz, 2013) (Jordan)	RCT	110 (52)	Lecture + HFS	Lecture + LFS	Knowledge (theoretical examination score)
(Aqel & Ahmad, 2014) (Jordan)	Quasi-experimen	90 (45)	Lecture + HFS	Lecture + LFS	Knowledge (theoretical examination score) Skill (the adult CPR skills
(Ayed et al., 2021) (Palestine)	RCT	150 (75)	Lecture + HFS	Lecture + LFS	Critical thinking (Clinical Decision-Making Nursing Scale)
(Baptista et al., 2016) (Portugal)	RCT	85 (49)	HFS	MFS	Skill (gains perceived with high-fidelity simulation scale) Satisfaction (satisfaction with clinical experience simulation scale)
(Bian & Guo, 2016) (China)	Quasi-experiment	100 (50)	HFS	Clinical	Knowledge (theoretical examination score) Skill (practical examination score)
(Brannan, White, & Bezanson, 2008) (USA)	Quasi-experiment	107 (54)	HFS	Lecture	Knowledge (theoretical examination score) Self-confidence (the Confidence Level tool)
(Deng & Wang, 2014) (China)	RCT	100 (50)	HFS	LFS	Collaboration, satisfaction, critical thinking (self-designed questionnaire)
(Deng, Sun, & Li, 2017) (China)	RCT	125 (63)	HFS	LFS	Knowledge (theoretical examination score) Skill (practical examination score)
(Fang, Yang, Wang, Guo, & Zeng, 2015) (China)	Quasi-experimen	263 (132)	Lecture + HFS	Lecture + LFS	Skill (practical examination score)
(Fong et al., 2021) (Malaysia)	RCT	389 (209)	Lecture + HFS	Lecture + LFS	Critical thinking (the California Critical Thinking Disposition Inventory)
(Gao & Zhao, 2008) (China)	RCT	64 (32)	Lecture + HFS	Lecture + LFS	Knowledge (theoretical examination score) Skill (practical examination
(Huang, Li, Li, & Wu, 2015) (China)	Quasi-experiment	120 (60)	HFS	LFS	Knowledge (theoretical examination score) Skill (practical examination score)
(Kang, Kim, Lee, Kim, & Kim, 2020) (South Korea)	Quasi-experimen	123 (69)	Lecture + HFS	Lecture + vSim	Knowledge (self-designed questionnaire) Skill (self-designed Self-confidence (Confidence in Practice Scale)
(Levett-Jones, Lapkin, Hoffman, & Roche, 2011) (Australia)	Quasi-experiment	84 (42)	HFS	MFS	Knowledge (theoretical examination score)
(Li, 2013) (China)	Quasi-experimen	100 (50)	Lecture + HFS	Lecture + LFS	Skill (practical examination score)
(Li and Li, 2019) (China)	Quasi-experiment	115 (60)	HFS	LFS	Skill (practical examination score) Collaboration (self-designed questionnaire) Caring (self-designed questionnaire) Interest in learning (self-designed questionnaire)
(Liu et al., 2020) (China)	Quasi-experiment	254 (129)	HFS	LFS	Skill (practical examination score)
(Liu, 2009) (China)	RCT	105 (53)	HFS	LFS	Knowledge (theoretical examination score) Skill (practical examination score)
(Liu & Tan, 2014) (China)	RCT	171 (93)	Lecture + HFS	Lecture + LFS	Knowledge (theoretical examination score) Skill (practical examination Collaboration, critical thinking, interest in learning (self-designed questionnaire)
(Liu et al., 2015) (China)	RCT	252 (126)	HFS	LFS	Skill (practical examination score) Caring (self-designed questionnaire)
(Liu, Jin, & Wang, 2016) (China)	RCT	180 (90)	Lecture + HFS	Lecture + clinical practice	Knowledge (theoretical examination score) Critical thinking (self-designed
(Liu, Huang, Tan, & Liu, 2017) (China)	Quasi-experimen	122 (62)	LFS + HFS	LFS	Skill (practical examination score)
(Liu et al., 2020) (China)	RCT	60 (30)	HFS	Case study	Knowledge, caring (The Nurses Humanistic Care Quality Questionnaires)
(Niu, Sun, Wu, Yang, & Song, 2014) (China)	RCT	60 (30)	Lecture + HFS	Lecture + LFS	Knowledge (theoretical examination score) Skill (practical examination Critical thinking (self-designed questionnaire)
(Oldenburg, Maney, & Plonczynski, 2013) (USA)	Quasi-experiment	95 (64)	HFS	Clinical	Self-confidence (self-designed questionnaire)
(Pan, Zhao, Yuan, Zheng, & Yuan, (China)	Quasi-experiment	71 (37)	HFS	LFS	Knowledge (theoretical examination score) Skill (practical examination score)
(Salameh et al., 2021) (Palestine)	Quasi-experimen	151 (76)	Lecture + HFS	Lecture	Critical thinking (The Lasater Clinical Judgment Rubric) Knowledge (self-designed questionnaire)
(Sharour, 2019) (Middle-East country)	Quasi-experiment	70 (35)	HFS	LFS	Knowledge (theoretical examination score) Self-confidence (the self-confidence scale) Satisfaction (students' satisfaction scale)
(Tosterud, Hedelin, & Hall-Lord, (Norway)	RCT	57 (29)	HFS	LFS	Satisfaction, self-confidence (The Student and Self-Confidence in Learning Scale) Skill, interest in learning, collaboration (The Educational Practices Questionnaire)

(*continued on next page*)

Study	Study design	Sample size (experimental)	Intervention		Outcomes (measures)
			Experimental	Control	
(Tosterud et al., 2013)b (Norway)	RCT	57 (29)	HFS	Case study	Satisfaction, self-confidence (The Student and Self-Confidence in Learning Scale) Skill, interest in learning, collaboration (The Educational Practices Questionnaire)
(Wang and Xu, 2020) (China)	Quasi-experiment	141 (71)	HFS	SP	Knowledge (theoretical examination score) Skill (practical examination score) Collaboration, caring, interest in learning, self-confidence (self-designed questionnaire)
(Wei, Zhang, Qiu, & Wu, 2018) (China)	Quasi-experimen	93 (48)	Lecture + HFS	Lecture + LFS	Knowledge (theoretical examination score) Skill (practical examination Collaboration (self-designed questionnaire) Critical thinking (self-designed questionnaire)
(Wei, Li, & Tao, 2020) (China)	RCT	60 (30)	HFS	LFS	Interest in learning (self-learning ability questionnaire)
(Wu, 2017) (China)	RCT	46 (23)	HFS	LFS	Knowledge (self-designed questionnaire) Skill (practical examination score) Satisfaction (self-designed questionnaire)
(Yang & Zhang, 2020) (China)	RCT	144 (72)	HFS	case study	Skill (practical examination score) Satisfaction (self-designed questionnaire)
(Zhang, Xu, Wang, & Zhang, 2016) (China)	Quasi-experiment	80 (40)	HFS	LFS	Skill (practical examination score)
(Zhao, Guo, Zhang, Shi, & Zhang, (China)	Quasi-experiment	78 (40)	HFS	LFS	Knowledge (theoretical examination score) Skill (practical examination score)

Table 1 (*continued*)

Note. LFS: low-fidelity simulation; MFS: medium-fidelity simulation; HFS: high-fidelity simulation; SP: standard patient.

Table 2
Quality appraisal of studies with NICE Quality Appraisal Checklist.

Studies	Questions																												
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	3.1	3.2	3.3	3.4	3.5	3.6	4.1	4.2	4.3	4.4	4.5	4.6	EV
IV (Ahn and Kim, 2015)	+	+		+	+	+		+		++	NR	++	++	+		+	+	+	NA	NA	++		++	+	+	++	+
(Gharaibeh, & Alostaz, 2013)	+	+	++	+	+	+		+	++	++	NR	++	++	+	+	+	+	++	++	+	++		NR		+	++	+
+ (Aqel & Ahmad, 2014)	+	+	+	+	+	+		+	++	++	++	++	++	+	+	+	+	++	++	+	++				+	++	+
+ (Ayed et al., 2021)	+		+	+	+	+		+	+	++	NR	++	++	+		++	+	+	++	+	++		++	++	+	++	+
+ (Baptista et al., 2016)	+	+	+	+	++	++		+	++	++	++		++	+			+	+	NA	NA	++			+	+	++	+
+ (Bian & Guo, 2016)	+	NR			+			+	++	++	++	++	++	+		++	++	+	++	NA	NA	++	++	NR	+	+	++	+
(Brannan, White, & Bezanson, 2008)	+		+		+			+	++	++	++	++	++	+		++	++	+	++	NA	NA	++	++	NR	+	+	++	+
(Deng & Wang, 2014)	+	+	+	+	+	+		+		++	NR	++	++	+		++	+	+	++	+	++	++	NR	+	+	+	+
(Deng et al., 2017)	+	NR	NR	+	+	+		+		++	++	++	++	++	++	++	+	+	NA	NA	++	++	NR	+	+	+	NR
(Fang, Yang, Wang, Guo, & Zeng, 2015)	+	NR			+			+	++	++	++	++	++	+	+	++	+	+	NA	NA	++	++	NR	+	+	++	
(Fong et al., 2021)	+	+	+	+	+	+		+	++	++	NR	++	++	+		+	+	++	++	+	++		NR	++	+	++	+
+ (Gao & Zhao, 2008)	+				+	+	+		+		++	++	++	++	+	+	++	+	+	NA	NA	++	++	NR	+	+	
+ (Huang et al., 2015)	+					+		+	++	++	++	++	++	+	+	+	++	+	+	NA	NA	++	++	NR	+	+	+
(Kang, Kim, Lee, Kim, & Kim, 2020)	+	+	+		+			+	++	++	++	++	++	+	++	+	+	++	++	+	++		NR	++	+	++	+
(Levett-Jones, Lapkin, Hoffman, Arthur, & Roche, 2011)	+	+	+	+	+	+		+	++	++	NR	NR	++	NR	+	NR	+	+	++	+	++	NR	NR	NR	+	+	+
(Li, 2013)	+			+	+	+		+	++	++	NR	++	++	+	+	++	+	+	NA	NA	++	++	NR	+	+	+	
+ (Li and Li, 2019)	+	NR	+		+			+	++	++	++	++	++	+	++	++	+	+	NA	NA	++	++	NR	+	+	++	+
+ (Li et al., 2020)	+		+		+			+	++	++	NR	++	++	+	++	++	+	+	NA	NA	++	++	NR	+	+	+	+
+ (Liu, 2009)	+	NR		+	+	+		+		++	NR	++	++	+	+	++	+	+	NA	NA	++	++	NR	+	+	++	
+ (Liu & Tan, 2014)	+	NR	+	+	+	+		+		++	++	++	++	+	++	++	+	++	NA	NA	NR	++	NR	+	+	+	
+ (Liu et al., 2015)	+	+	+	+	+	+		+	++	++	NR	++	++	+		++	+	+	NA	NA	++	++	NR	+	+	++	+
+ (Liu et al., 2016)	+		+	+	+	+		+		++	++	++	++	+	++	++	+	++	NA	NA	++	++	NR	+	+	++	+
+ (Liu et al., 2017)	+	NR			+			+	++	++	++	++	++	+	+	++	+	+	NA	NA	++	NR	NR		+	++	
+ (Liu et al., 2020)	+	+	+	+	+	+		+		++	NR	NR	++	++		NR	+	+	NA	NA	++	++	NR		+	++	+
(Niu, Sun, Wu, Yang, & Song, 2014)	+	+	+	+	+	+		+		++	++	NR	++	++	+	NR	+	+	NA	NA	++	NR	NR		+	+	+
(Oldenburg, Maney, & Plonczynski, 2013)	+	+			+			+		++	NR		++	NR			+	+	++	+	++		NR	+	+	+	+
(Pan, Zhao, Yuan, Zheng, & Yuan, 2016)	+				+			+		++	++	++	++	+	++	++	+	+	NA	NA	++	++	NR	+	+	++	
(Salameh et al., 2021)	+	++	++	+	+	+		+	++	++	++	++	++	+		++	+	++	NA	NA	++		++	++	+	++	++

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