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Developing a framework of simulation-based medical education curriculum for effective learning

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SUMMARY

Simulation-based medical education (SBME) is considered to improve cognitive, affective and psychomotor domains of the medical trainees. However, very few institutions use a structured high-fidelity SBME curriculum. This systematic review provides an insight into a framework for planning, implementing and evaluating a simulation-based curriculum along with its required infrastructure. Electronic databases of ScienceDirect, Wiley online library, Ovid, Medline, Cochrane library, CINAHL, and ISI Web of knowledge were searched for full-text English language articles using keywords; simulation OR medical education OR simulators AND clinical training AND simulation-based medical education. An initial search selected 1146 titles. Using a systematic algorithm of data selection, extraction and synthesis, a total of eight studies were selected for further review. Research has shown that a triad of academia (faculty and instructors), program (planning, implementing and evaluating), and resources (simulators and tools) is required for designing a simulation-based curriculum. Planning a SBME curriculum involves gaps of identification and needs analysis, defining specific learning objectives and teaching pedagogies. Implementing SBME leads to enhanced psychomotor skills to a greater extent than cognitive and affective learning. Practice, repetition and learning from errors with immediate and post-event feedback makes the simulation exercises a perfect learning tool. This study provides a framework of key elements of SBME that can be embedded into medical curricula. Pillars of SBME curriculum include academia, program development and resources. Though psychomotor domain is largely augmented, in general, all clinical skills are improved.

Key words: Simulation-based medical education – Fidelity – Medical curriculum – Feedback – Psychomotor skills

INTRODUCTION

The Accreditation Council for Graduate Medical Education and European Working Time Directive have enforced a decrease in training hours and limited exposure to the patients due to growing concerns about patient safety (Fitzgerald and Caesar, 2012; Vucicevic et al., 2015). Such interventions have necessitated the introduction of technology and innovation-based educational measures that have led to the development of SBME, defined as 'a central thread in the fabric of medical education' (McGaghie et al., 2010). SBME is a complex educational strategy that uses a person, simulator, trainer, or set of conditions that aim to deliver education and to evaluate trainees with feedback by a standard format. Thus, a real time yet well-controlled clinical training environment is created that closely resembles real-life situations. SBME creates an attractive homologue to experiential

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learning that is usually applied during real-life clinical encounters (Lopreiato and Sawyer, 2015).

In medical education, learning in context and practice enriches the entire learning environment as such approach helps the learners to recall and retrieve knowledge and skills (Barry Issenberg et al., 2005). SBME offers contextual education and training not only by providing a critical appraisal of delivery of curriculum, but also, by mapping learning objectives with course contents and teaching pedagogies (Motola et al., 2013). At the same time, incorporating SBME into existing curricula with a comprehensive course blueprint provides flexibility for a wider coverage of topics without endangering patient safety. A primary motive and unique feature of SBME is its characteristic utility in practicing skills, where trainees can practice over unlimited times and tend to learn from mistakes and errors (Ziv et al., 2005). This exercise fosters life-long learning with improved professional development (Bilal et al., 2019). At the same time, trainees from various disciplines can learn with, from and about each other in an interprofessional learning climate for better patient outcomes (Guraya and Barr, 2018). From a different perspective, SBME provides opportunities for mastering professional skills with less chances of lapses of medical professionalism such as violation of confidentiality, privacy, and data protection (Guraya et al., 2016a).

Despite great enthusiasm and perceived benefits of SBME, few institutions have adopted this innovative educational approach. Though the impact and educational effectiveness of SBME are being increasingly acknowledged, literature has not reported a seamless acceptability of SBME by a majority of medical institutions (Savoldelli et al., 2005). This low acceptability of SBME mostly springs from paying little attention to the deployment and incorporation of SBME curriculum, needs analysis, faculty training, resources, and to carefully balancing clinical training between real-time and SBME (Fisher et al., 2016). This study aims to provide a framework for developing and designing SBME in medical curricula that will facilitate educators for training tomorrow's doctors' in a safe and effective simulated clinical environment.

RESEARCH METHODOLOGY

Study design

In May 2019, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Guraya et al., 2016b) was used to determine key elements of designing and implementing SBME in modern medical education. The databases of ScienceDirect, Wiley online library, Ovid, Medline, Cochrane library, CINAHL, and ISI Web of knowledge were searched for full-text English language articles published between 2008 and 2019. Medical search headings (MeSH) used for this search were: simulation OR medical education OR simulators AND clinical training AND simulation-based medical education. The MeSH terms were manually inserted into the databases and then the search outcome were retrieved and further analysed. Only original articles that investigated various elements of SBME in all medical and health sciences disciplines were included in this systematic review. Studies outside the selected period and letters to editor, narrative reviews and systematic reviews, editorials, conference proceedings and commentaries were excluded from this search. In summary, we followed structured guidelines by PRISMA for initial search using pre-defined MeSH terms and then further analysis was done by removing the redundant and irrelevant articles from the initial list of publications. This process finally identified eight articles that specifically matched the inclusion criteria of this research. These articles were deeply analysed in the discussion section using their contents and salient features. However, we used other publications in the introduction section to enrich the background of SBME and to set a scene of research significance.

Data collection, extraction and synthesis

Following the initial search, 1146 titles were selected. Analysis of these titles showed 218 duplicate publications that were excluded from the records (Fig. 1). Duplicate titles were those where different databases showed similar titles and added inaccurate data in search results. Of the remaining 928 articles, 697 articles were excluded, as these publications included editorial, personal views and brief communications. During analysis of the remaining 231 articles, 201 studies were excluded during mutual discussion and general consensus, as researchers could not find scientific evidence for their inclusion in the final list of articles. A final round of reviews excluded another 22 articles due to incomplete data from publications. Finally, a total of eight original studies were included in this systematic review.

Quality assurance

During the search process, selection bias and blinding of participants and personnel (performance bias) were resolved using Cochrane Collaboration tool. Risk of bias was eliminated by frequent meetings and group discussions by the researchers. In addition, conflicts were resolved by consensus and by aligning selection criteria with the search design of this systematic review.

RESULTS

Literature review has shown substantial growth in the quality and rigour of research published on SBME over the years. The key characteristics from the selected eight articles, including complete reproducible citations, publication year, study type,

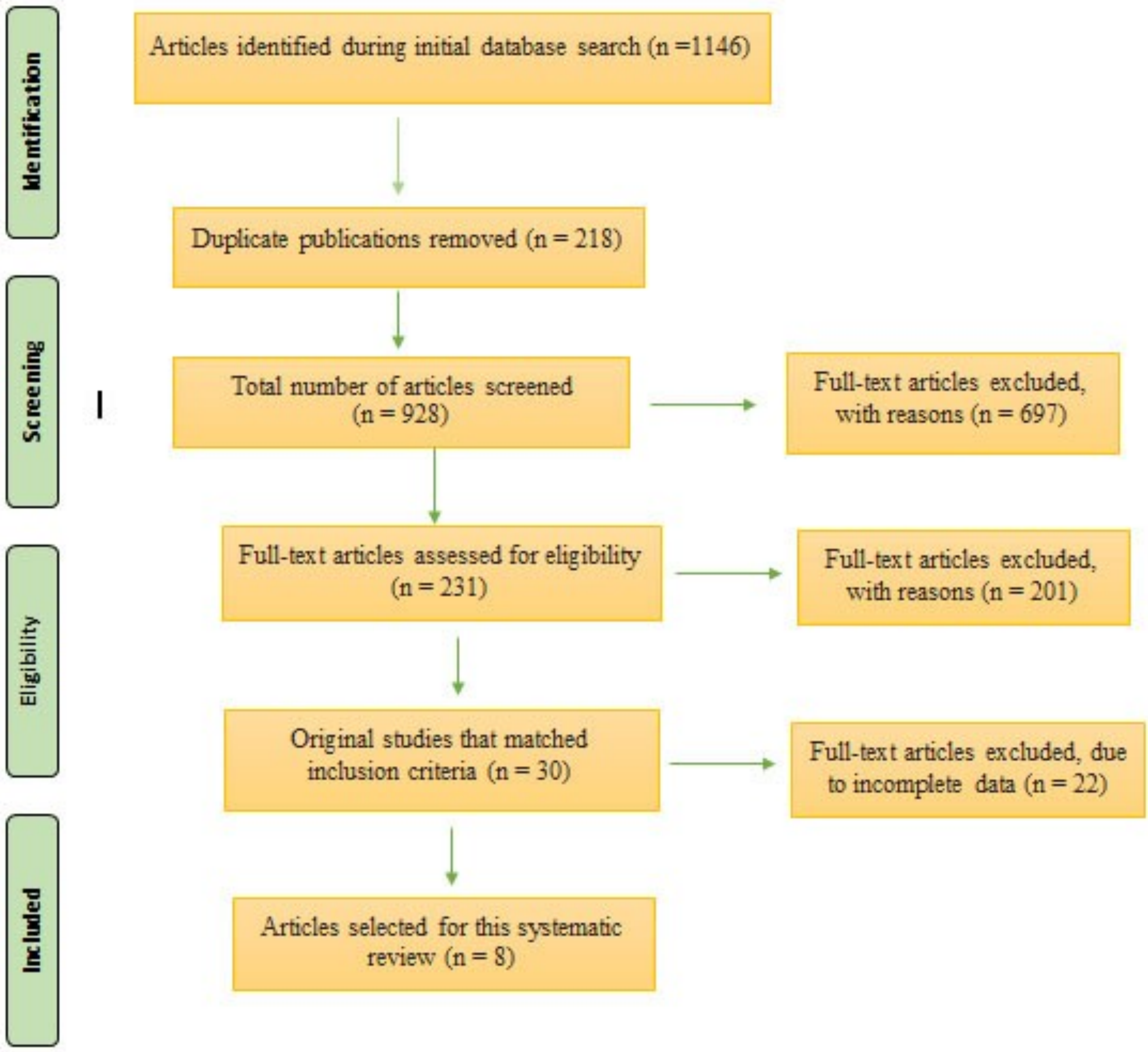

Fig 1. Flow diagram showing algorithm for selection of studies that investigated the role of simulation based medical education in this systematic review.

Fig 2. Key elements of academia, program and resources for simulation-based medical education.

and primary end-point outcomes are detailed in-Table 1.

DISCUSSION

A working framework for developing, implementing and evaluating SBME into a medical curriculum as well as its core components are illustrated in Fig. 2. The forthcoming sections of the article provide the salient features and recommended domains for designing and implementing SBME curriculum.

1. Academia

Educators and course instructors play vital roles in constructing simulation-based educational climate, where trainees learn from their mistakes in a safe learning environment. A standard 6-step framework for curriculum development includes problem identification, general and specific needs

Table 1. Major characteristics and key findings of the selected 8 original studies about simulation-based medical education in this systematic review

No.	Article citation	Publication year	Study format	Primary end-point outcome
1	KOSANAM et al. (2019) Exploring the learning experiences of neonatal nurses with in-situ and off-site simulation-based education: A qualitative study. J Neonatal Nurs, 25(1):41-45.	2019	Original qualitative study	- Compared the effect of neonatal simulation-based education in off-site or in-situ settings - In-situ simulation was found to be difficult to conduct due to staff prior commitments. - Off-site simulation was more demanding as staff was engaged outside the wards. - Overall, in-situ simulation provided high fidelity learning experience.
2	MAKRANSKY et al. (2016) Simulation based virtual learning environment in medical genetics counseling: an example of bridging the gap between theory and practice in medical education. BMC Med Educ, 16(1):98.	2016	Original study	- This pre- post test model investigated whether SBME enhances students' understanding, intrinsic motivation, and self-confidence during their learning process - All studies variable significantly increased after a 2-hour training session
3	KHAMIS et al. (2016) A stepwise model for simulation-based curriculum development for clinical skills, a modification of the six-step approach. Surg Endosc, 30(1):279-287.	2016	Original study	-A 7-step curricular model; problem identification and needs analysis, focused needs assessment, objectives, teaching pedagogies, feedback and program evaluation - This high quality simulation can be applied across all medical disciplines
4	DAGNONE et al. (2016) How we developed a comprehensive resuscitation-based simulation curriculum in emergency medicine. Med Teach, 38(1):30-35.	2016	Original study	- The authors studies difficulty level of each skill, repetitive practice, students' motivation, and feedback to develop a core model for emergency medicine - A comprehensive curriculum was developed that can be implemented with gradually increasing complexity throughout emergency care medicine.
5	WISE et al. (2016) Assessing student usage, perception, and the utility of a Web-based simulation in a third-year medical school clerkship. J Clin Anesth, 33:5-13.	2016	Original study	- An educational intervention of web-based learning was used to explore learning experience of undergraduate medical students - The preference rate for web-based simulation by the students was 4.1/5. - The study advocated the role of web-based simulation in medical education.
6	OH et al. (2015) The effects of simulation-based learning using standardized patients in nursing students: A meta-analysis. Nurse Educ Today, 35(5):e6-e15.	2015	Original study	- SBME using standardized patients poses positive impact on self efficacy and learning motivation - This effect enhances knowledge and clinical skill acquisition of learners
7	CHEN et al. (2018) Standardised simulation-based emergency and intensive care nursing curriculum to improve nursing students' performance during simulated resuscitation: a quasi-experimental study. Intensive Crit Care Nurs, 46:51-56.	2018	Original study	- This study used a standardised high-technology SBME model for intensive care nursing on the 3rd year nursing students. - A range of simulated scenarios for resuscitation were employed for acquisition of resuscitation skills. - The SBME curriculum resulted in improved skills and competence in resuscitation simulation.
8	MAERTENS et al. (2018) Endovascular training using a simulation based curriculum is less expensive than training in the hybrid angiosuite. Eur J Vasc Endovasc Surg, 56(4):583-590.	2018	Original study	- This prospective, randomised controlled trial determined the cost-effectiveness of simulation curriculum on surgical trainees in endovascular surgery. - The simulation model reduced cost of training in the angiosuites. - The effectiveness and impact of hybrid simulation in skills acquisition was also better than real patients due to feedback and grading arms of simulators.

analysis, goals and objectives, teaching strategies, implementation, and evaluation (Dagnone et al., 2016). Medical educators and senior faculty with vast experience in curricular interventions mostly undertake such educational reforms and tend to incorporate SBME in curriculum. An organized, well-rehearsed and systematic approach that holistically embraces community needs and institutional resources will lead to effective learning (Barsuk et al., 2016). Stakeholders from department, college, clinical skills center, simulators, community representatives and volunteers should constitute a steering committee for developing SBME curriculum.

2. SBME program

A brief schema for planning, implementation and evaluation of SBME curriculum is illustrated in Fig. 3. Planning and integrating SBME into medical curriculum is a multi-stage process, as it starts with a critical review of needs analysis. A coherent team of educators, course director, department head, subject expert, and simulation technician should review the curriculum and determine the need and magnitude of SBME. This review will identify which clinical skills are not sufficiently covered in the curriculum. Per se, high-risk and low-volume clinical scenarios fit within the scope of simulation, as skills taught in such scenarios cannot be essentially practiced on real patients due to threats to patient safety (Oh et al., 2015). Following the selection of clinical scenarios, educators need to develop and integrate specific, precise, and measurable learning outcomes of SBME in curriculum. Aligning SBME module with program objectives is of the utmost importance, as this task will ensure horizontal and vertical integration of the program (Thomas et al., 2016). Teaching same topic in a particular course during a given academic year is vital for initial introduction of the topic (horizontal integration). Additionally, for effective learning, revisiting a topic every year with gradually increasing breadth and depth is vital (vertical integration). Subsequent implementation of a new SBME module requires consultation with simulation personnel to customise tools and devices, and for selection of appropriate simulation models. Finally, an assessment arm is developed that should precisely be tagged with course learning objectives. Periodic evaluation of the SBME intervention using feedback from all stakeholders (students, faculty, and staff) and assessment grades will help

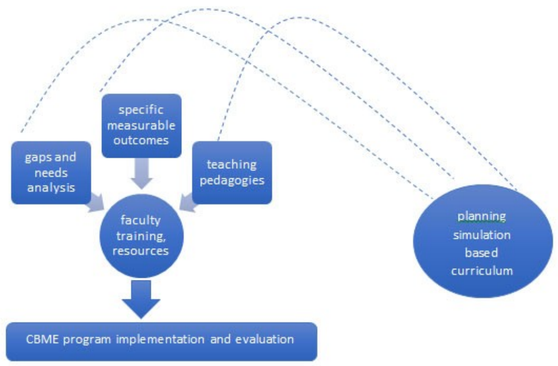

Fig 3. A schematic illustration of simulation based medical education curriculum planning, implementation and evaluation.

maintain the quality and effectiveness of the learning environment (Barsuk et al., 2016).

McGaghie et al. (2010) have argued that simulation-based education is most effective when this strategy embraces the core curriculum and is not used as an additional component. The authors have concluded that a simulation-based course should be carefully planned, implemented and evaluated in the context of a larger core curriculum, which can be embedded at a course level or on a broader level of the entire program. In another study, the authors developed a core resuscitation curriculum for SBME using four variables; difficulty of skill, repetitive practice, motivation, and immediate feedback (Dagnone et al., 2016). The course contents were aligned with the guidelines by the Royal College of Physicians and Surgeons of Canada. Consequently, a comprehensive longitudinal curriculum was developed that could potentially cater for all junior and senior trainees of their residency programs. This study reflects the importance of using specific domains for constructing simulation-based specialty curricula.

Web-based simulation (WBS) is another teaching strategy that carries great promise in modern medical education. From this perspective, Wise et al. conducted an observational study to determine the students' opinions about WBS in anaesthesiology (Wise et al., 2016). The participants preferred WBS over textbooks, and have proposed that such educational strategy can potentially fill gaps in clinical education, without overburdening the students and faculty.

3. Mastery learning

In mastery learning, trainees practice a technical or behavioral skill until they are able to independently perform the skill without supervision (McGaghie et al., 2011a). Achievement of mastery learning embraces five stages; formal structured instruction, deliberate practice, precision, precise feedback, and post-testing (McGaghie et al., 2011b). During mastery learning session, instructors demonstrate and elaborate clinical skill or behavior to the trainees, which is then followed by practice by trainees till they are able to perform independently. SBME has an extra-ordinary feature of allowing trainees to practice a skill or behavior until a mastery learning level is achieved. In addition to the repetitive nature of SBME, an assessment arm of mastery learning provides performance score and points out mistakes. This fosters learning experience, as trainees learn from mistakes and practice till perfection.

Kosanam et al. (2019) have compared the impact of SBME in off-site and in-situ settings in neonatal simulation-based education, and have found that in-situ simulation offered a significantly more realistic simulation climate. However, the authors have found some challenges of participants' distraction and limited resources. Another study by

Makransky et al. (2016) used a pre-post-test model, and has shown that a 2-hour SBME session significantly enhanced knowledge and self-motivation of undergraduate students. In a study by Sawyer et al. (2011), a selected cohort of residents was gradually engaged in a series of simulation-based scenarios, and showed progressive improvements in technical skills, despite escalating level of clinical difficulty in various resuscitations models. Similarly, Eich et al.(2007) have reported significant association between difficulty of simulation scenarios in pediatric anesthesia and candidates' opinions about their learning experience. Thus, by gradual incorporation of difficult clinical scenarios into SBME model, learners were challenged and pushed to accomplish their desired level of competence.

Mastery learning has been shown to progress through several phases from novice, competent, proficient and finally from expert to master (Khamis et al., 2016). Transfer-to-practice is the ultimate destination of SBME philosophy when shift of simulation training is materialized into real-time clinical practice, and this should be included as an integral component of program evaluation and validation.

4. Feedback

Providing effective and immediate feedback to trainees is a crucial part of SBME that serves to enhance effective learning in the medical field. Feedback can spring from a host of sources such as simulator, instructor, trainee, and supervisor (Eppich et al., 2015). At the same time, feedback can be provided at various stages during simulation encounters including immediate, live, or post-event. Educators should determine the timing and nature of feedback that should be consistent with learning objectives of SBME sessions. Feedback during simulation session by the instructor or simulator in the form of verbal response, non-verbal cues or haptic feedback tend to coach the trainees while they learn specific clinical skills (Levett-Jones and Lapkin, 2014). However, for effective feedback during a simulation exercise, a structured script of feedback should be used in debriefing sessions. This will enable learners to provide their reactions throughout simulation exercise.

The most common feedback modality is a well-structured debriefing session that follows simulation sessions, often referred as post-event debriefing (Couper et al., 2015). This implies a structured process after an event that analyses the actions taken. Such debriefing sessions include reaction from the participants, in-depth analysis, and, finally, brief consolidation and take-home message from the learning experience. The overarching purpose of post-event debriefing sessions is to ensure that learners go beyond the phase of reaction, and this will help them develop experiential and lifelong learning skills. The students are mentored for developing the debriefing skills, and then they are given the opportunity to conduct debriefing sessions under supervision. This exercise not only provides guided reflections by the students but also the process of active learning is enriched. In their study on 3rd year nursing students for determining the impact of SBME in resuscitation, Chen et al. (2018) have shown that, during debriefing, the learners could better reflect on the given scenarios. This, in turn, provided an opportunity to all learners to actively participate and to listen to peers. Such exercise helps staged development of professional competence and communication skills.

5. Resources

As evident from the published literature, simulation training is resource-intensive, demanding, time -consuming and expensive (Ryall et al., 2016). At the same time, SBME requires carefully designed educational interventions in the existing curricula without duplication and with high fidelity. Currently, technological innovations, expert academia, simulators and budget are minimum requirements to run a SBME program in medical schools.

<u>Simulators</u>

Literature has shown several kinds of simulators. Virtual reality simulators (VR) employ a computer screen or a graphic-user interface that has the ability to create simulated patients and patient management scenarios (Lopreiato and Sawyer, 2015). The trainees interact with simulator-generated patients through an electronic interface on computers. In VR simulators, the degree of fidelity is exceptionally high, as it recreates a real-time learning atmosphere using novel biotechnology (Forgione and Guraya, 2017). The program is more clinically oriented with more focus on case-based scenarios and problem-solving skills. In task trainer simulators, learners repeatedly practice certain procedural skills until desired competency is accomplished, such as intravenous catheter placement or endotracheal intubation. This focused training permits trainers to set up a series of specific procedural skills where trainees can rotate through work stations till they achieve desired proficiency (Demirel et al., 2016). Task trainer simulators are cheaper than other high-tech simulators, as they contain engineered programs for high psychological fidelity that can provide immediate feedback and authentication of successful completion of task. This system is particularly valuable for the trainees who want to practice a certain procedure over a range of training sessions at their own pace. Hybrid simulators (HS) embrace simultaneous application of two or more modalities of simulation that may include use of mannequins, task trainers, VR simulators, standardized patients and some actors (Taylor et al., 2016). This intense multi-modal and integrated simulation model thrives to enrich learning experience of a range of complex clinical scenarios. However, using HS is a challenge for maintaining realism across several simulation tools, as the entire scenario represents a single clinical situation (Freschi et al., 2015).

In brief, the virtual reality simulators are mostly used in pre-clinical teachings, particularly Anatomy and Physiology. These simulators are also used in minimally invasive surgery, as well as robotic surgery and tele-mentoring. The task trainer simulators are used in management of difficult airways, advanced venepuncture and arterial punctures, and ultra-sound compatible central vein models. Mostly, HS demonstrates a staged but fragmented breakdown of a series of clinical applications. Ultimately, a complex procedure or clinical skill is practiced over a range of simulated models.

Standardized patients (SPs)

The use of SPs in simulation is being increasingly acknowledged as an effective teaching assessment tool as it provides high fidelity in real-time educational environment (Rutherford-Hemming et al., 2019). In a meta-analysis and systematic review by Oh et al. (2015), the authors analyzed the impact of SBME using SPs on three domains of Bloom's learning outcomes: cognitive, affective, and psychomotor. The authors have deduced that simulation-based learning using SPs showed excellent cognitive, affective, and psychomotor competencies. In particular, SBME using SPs was found to be more effective in acquisition of psychomotor competence. Unfortunately, the characteristics of cognitive and affective domains as measured by the trainees' learning motivation and learning satisfaction did not show significant improvement.

Several studies have shown effectiveness of SPs in enhancing communication skills of the medical and allied health sciences students (Bosse et al., 2012; Lin et al., 2013; Guraya et al., 2015). The study by Schwartz et al. (2015) has reported equal effectiveness of teaching strategies using real patients and SPs for communication skills and behavioral change domain (Zabar et al., 2018). Since learners encounter SPs in a range of clinical encounters, they are urged to observe professional codes of conduct, academic integrity and confidentiality of data (Al-Qahtani and Guraya, 2016). In contrast, Schwartz et al. have reported insignificant difference in scores given by the students for communication skills of SPs and real dietetic patients (Schwartz et al., 2015). The authors have argued that SPs need intense training and supervision before they are deemed ready for use in assessment. At the same time, selection of the right patient for a specific skill also plays vital role in achieving desired outcome of teaching or assessment task. Unfortunately, concrete scientific evidence for effective use of SPs in medical education is still lacking and more evidence-based studies are warranted to endorse the available data.

Space and budget

By and large, a specific part of college or hospital is dedicated for simulation-based education and assessment. The organizing team reviews current and future needs, curricular requirements, nature of SBME pedagogies, and physical space (Tann and Bates, 2019). Furthermore, availability of specific space for simulation-based education provides a platform for smooth development, rehearsal, and execution of SBME tasks. Research has proven that investing in technology-based medical education ultimately leads to improved delivery of healthcare to the community (Cook et al., 2011).

A wealth of literature has compared cost effectiveness of SBME using high-fidelity and low-fidelity simulation models (Iglesias-Vazquez et al., 2007; Chandra et al., 2008), and has shown that low-fidelity simulators were effective, but less expensive than high-fidelity models (Zendejas et al., 2013). Maertens et al. (2018) have argued that endovascular surgical training necessitates high-tech equipment, resources and a costly training climate. Their study has shown that simulation in endovascular surgery had reduced the annual training cost of €5001 to €3806 per trainee. Interestingly, the researchers have claimed that better fidelity does not always cost more than low fidelity simulation models, as pricing of tools may change over the passage of time. In conclusion, program development for SBME and allocation of resources, space, staff and faculty should be critically evaluated in terms of investment against its outright benefits.

Conclusion

This systematic review provides an insightful overview of educational aspects of SBME, including designing and implementing SBME curriculum, core principles of effective learning in SBME and some popular models of simulators. The thread of technology-enriched simulation is being gradually instilled into the fabric of all specialties of medical education. Designing simulation-based curriculum requires academia (faculty and instructors), program (planning, implementing and evaluating), and resources (simulators and tools). A careful analysis of gaps in the existing curriculum and needs analysis would be the first step in planning SBME curriculum. Then specific learning objectives and teaching pedagogies should be carefully designed and embedded within the medical curricula. Low-cost simulation models accomplish learning objectives outcomes similar to high-cost simulators Implementing SBME potentially enhances psychomotor skills to a greater extent than cognitive and affective learning. On a broader perspective, SBME would certainly benefit the society by improving patient safety and the quality of health-care.

AUTHORS' CONTRIBUTIONS

SYG conceived the idea and performed initial and final search, data analysis and synthesis, and significantly contributed in write-up of initial and final drafts. MFA and SSG had significant contributions in reviewing the literature and selecting the articles, and approved the final draft.

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