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The use and effectiveness of high-fidelity simulation in health professions education: current update

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Abstract

Over the past 10 years, there has been an increase in the use of high-fidelity simulation (HFS) as a tool to support and enhance learning in health profession programs. In this article, we review the utilization of HFS in biomedical (basic science) courses for health professions students, and we compare its effectiveness to traditional teaching methods. Studies exploring the impact of HFS on students and residents were included in the review. The use of HFS is more prevalent in advanced clinical settings such as in training residents and nurses than in teaching students in preclinical years. When compared to traditional teaching methods, HFS is noted to be superior in delivering core biomedical concepts to stu-dents and healthcare professionals. However, a few studies showed no significant differences between HFS and traditional teaching methods when assessing clinical management skills. Overall, HFS is a valuable teaching tool which enhances knowledge retention and clinical skill acquisition in medical education.

Keywords
Simulation, high-fidelity, students, pharmacology, biomedical sciences, teaching, training

1. Introduction

Simulation is a supplemental tool that replaces or augments real experiences with guided scenarios that evoke or replicate substantial aspects of the real world in a fully interactive manner.[1] Simulation is a powerful tool to support teaching and learning which leverages and incorporates key principles of adult learning theory and evidence. Simulation environments allow for standardized training and evaluation and pose minimal risk to the patient in comparison with experiential learning conducted in the clinical setting.[2]

In this paper, simulation fidelity (low, medium, or high) describes the spectrum of how realistic a manikin is at mirroring a live patient.[3] Low-fidelity simulators mirror the actual action or scenario closely but are the least realistic to the learner in comparison with higher-fidelity simulators. An example of a low-fidelity simulator is the intravenous injection trainer which is used as an aid in venepuncture tutorials for medical, physician assistant, or nursing students.[3] In healthcare simulation, high-fidelity refers to simulation experiences that are extremely realistic and provide a high level of interactivity and realism for the learner.[4] The simulation environment used in high-fidelity simulation (HFS) is usually of high quality and constitutes a high level of idealization. Various training aids/modes can be used in HFS including humans, manikins, task trainers, or virtual reality.[3] HFS training supports the provision of a bridge between didactic and observational learning to clinical training through repetitive practice and mastery-based learning prior to, or in parallel with, traditional bedside training.[5]

Table 1. Cant and Cooper's proposed fidelity typology.

Simulation tools to increase the fidelity	Description of simulation activity
Partial task trainers	Replica models or manikins used to learn, practice, and gain competence in simple techniques and procedures
Peer-to-peer learning	Peer collaboration used to develop and master skills, such as basic health and physical assessment
Screen-based computer simulators	Programs used to acquire knowledge, to assess competency of knowledge attainment, and to provide feedback related to clinical knowledge and critical thinking skills.
Virtual reality	Combines a computer-generated environment with tactile, auditory, and visual stimuli provided through sophisticated partial trainers to promote increased authenticity
Haptic system	A simulator that combines real-world and virtual reality exercises into the environment
Standardized patients	Uses case studies and role-playing in the simulated learning experience; individuals, students, or paid actors are taught to portray a patient in a realistic and consistent manner
Full-scale simulation	Simulation that incorporates a computerized full-body manikin that can be programmed to provide realistic physiologic response to practitioner actions; these simulations require a realistic environment and the use of actual medical equipment and supplies

HFS is used toclinically complement the principal medical teaching for healthcare professionals by simulating diverse, realistic clinical scenarios.[6] For example, it has been employed in training radiology residents in the management of adverse reactions to contrast agents in hospital settings.[7–10]

The definition of HFS varies across the literature. Cant and Cooper defined HFS as a computerized manikin that physiologically responds accordingly to students' actions and proposed the fidelity typology shown in Table 1.[11]

The many advantages of HFS include the possibility of practice without the added risk of harming a patient or delaying emergency management, the opportunity to receive thorough feedback,[12] and enhancing teamwork to provide the highest quality of care to patients.[13] One of the reported disadvantages of HFS is that it has become so realistic with the technological advancement in our day that some students described their simulation experiences as overwhelming.[14] This could lead to distraction which may negatively impact meeting the educational objectives that the simulation was intended for. Assessing the criteria such as the simulation session's goals, students' level of experience, and the topic at hand all factor into the success of the simulation. HFS experience could be improved to optimize the benefits it provides. Designing an unexpected simulation, for example, could simulate a more realistic scenario in a hospital setting. That would in turn test the collegiality of the team and their coherence when working together in an emergency setting.[15] Overall, HFS is thought to be beneficial when operated and carried out appropriately, and its benefits are thought to outweigh the disadvantages mentioned in the literature.

HFS has been noted in the literature to enhance knowledge delivery and retention in many fields. Interventional radiologists have used high-fidelity endovascular simulation to decrease the learning curve in the curriculum.[16] Dentistry and veterinary students who participated in HFS expressed their preference to it when compared to traditional teaching methods, stating that HFS improved their knowledge, as well as their clinical and teamwork skills.[17,18]

A study was conducted on the general public using HFS to assess the knowledge of drug administration in emergency settings. The participants were able to conclude that the nasal spray formulation of naloxone was the most successfully administered in an opioid overdose.[19] Crucial data obtained with the aid of HFS confirm the benefits of its utilization not only in teaching, but also in obtaining information to better advance emergency management and public health.

HFS is a valuable learning support tool, hence several biomedical programs have adopted or advocated to establish it as a core pillar in their curricula to enhance learning alongside traditional teaching methods such as lectures and tutorials.[20,21] There are limited studies that have compared the effectiveness of HFS to traditional methods in teaching clinical skills with most reporting positive outcomes including improved knowledge retention,[3,22,23] enhanced leadership skills,[24] and improved post-session test results.[25,26] Despite a large literature body reporting benefits of HFS in clinical teaching settings, there is limited number of available studies that explore whether HFS aids in improving the delivery of basic science disciplines such as physiology and pharmacology to health professions, students, and trainees. However, HFS has been increasingly used in supporting the teaching of basic science concepts.[27] Basic science concepts form the foundation of a health professional's education and pave the way to clinical competency. Therefore, it is crucial to review the effectiveness of the recently introduced use of HFS in basic science teaching delivery. In this review, we analyze the available literature on the use of HFS in teaching both basic science and clinical concepts, aiming to shed light on the level of utilization of HFS in undergraduate biomedical education, and its effectiveness in comparison with traditional teaching methods.

Table 2. Keywords searched on PubMed database, and the number of hits generated for each combination.

Keywords searched	Number of hits
"High-fidelity" AND "simulation" AND "Pharmacology"	164
"High-fidelity" AND "simulation" AND "students" AND "pharmacology"	35
"High-fidelity" AND "simulation" AND "students" AND "biomedical sciences"	15

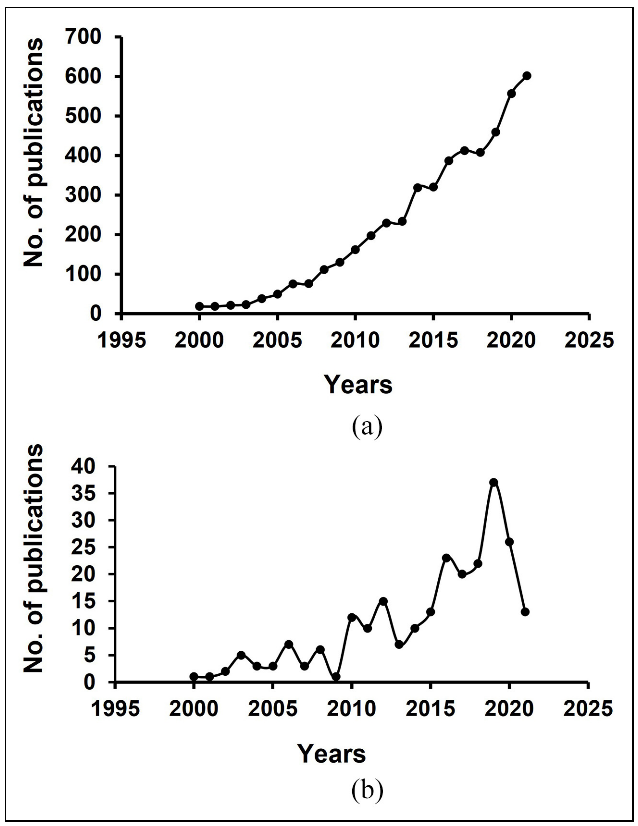

Figure 1. Number of publications generated over the past 21 years (a) in general education (searched terms "high fidelity" AND "simulation" AND "education"), and (b) in the field of pharmacology (searched terms "high-fidelity" AND "simulation" AND "pharmacology").

3. Results and discussion

3.1 HFS in teaching biomedical sciences: student acceptability

Traditional teaching methods, such as didactic lectures and in-person tutorials, overwhelm the science and medical curricula worldwide. The searched literature is not extensive in providing a suggestive impact to influence the use of HFS. Advanced medical residency and nursing programs provide access to HFS integrated with clinical training and pharmacology programs have been slowly adopting HFS to deliver content more effectively to medical students in preclinical years. Over the past 21 years, there has been an obvious increase in the acceptance and the use of HFS to deliver concepts in general education (Figure 1(a)), and more specifically in the field of pharmacology (Figure 1(b)).

For example, via et al.[28] showed that medical students studied anesthetic drugs' physiologic effects using high-fidelity simulators. A post-simulation survey revealed that 83% of the students preferred the clinically simulated integrated experience, compared to traditional didactic lectures. More recently, HFS studies assess student knowledge retention using pre-simulation and post-simulation tests and comparing their scores. Meyer et al.25 evaluated pharmacology students through a survey to determine their ability to apply pharmacology knowledge post-simulation and found that over 90% of surveyed students stated that HFS improved their skills. HFS has been used in exposing to aid in exposing medical students to drug toxicity and management scenarios, for example, lithium and salicylate toxicity. Students completed a 5-point Likert-type scale survey in both studies, which demonstrated high acceptability and engagement with the case simulations.29,30 Since student satisfaction and exam performance are significantly and positively correlated with one another,[31–34] it is valid to consider student preference when choosing teaching methods. Several papers conducted quantitative studies to assess the impact of HFS on the application of theoretical knowledge in pharmacy students using the pre-simulation and post-simulation test intervention method. Results demonstrated a statistically significant increase in post-simulation test scores that are conducted immediately and 9 months post-simulation when compared to pre-test scores ($p < 0.05$).[26,35]

The utilization of HFS in teaching cardiology has been more evident in the literature over the past two decades, considering the simulation's efficacy in conveying more complex clinical scenarios and core principles. Simulation for medical students is often used for teaching clinical management to clerkship students, such as congestive heart failure,[36] acute illness,[37] anesthesia scenarios,[26] or acute myocardial infarction.[38] Basic science education using small group simulation has been described for shock physiology[39] and cardiovascular physiology.[38,40,41] In 2016, Morgan and colleagues assessed 299 students' knowledge retention in the management of unstable cardiac arrhythmias. The study used a pre-simulation and post-simulation test method, with a significant rise in scores post-simulation. The use of HFSs and the improved retention of basic science knowledge witnessed in students solidify the correlation between the two.[26] The pharmacological management of other cardiac episodes such as ventricular fibrillation and pulseless ventricular tachycardia has been noted and aided by HFSs in the literature.[42] Simulators allowed pharmacy and medical students to apply their learned didactic lecture theories to practice, further cementing it in implicit rather than explicit memory.[23] HFS has also successfully reduced anxiety and increased self-confidence in healthcare professionals.[43] Anxiety has been extensively studied for its adverse cognitive side effects such as inhibition and decreased attention.[44] Decreasing anxiety with the utilization of HFS would accelerate reaction time when administering a drug in an emergency setting, therefore, improving patient care. When using simulators to appraise students' clinical responses, they are required to retrieve basic science concepts that necessitate plain recollection, such as which drug class should be administered and at what dosage. The active recall of medical concepts further supports the assertion as to how practical it is to use simulators to ingrain the basic science concepts, which in turn refines patient healthcare. Another study yielded a significant increase in post-simulation test scores by 22% following HFSs to assist in learning cardiovascular function curves in first-year medical students.[45] More recently, Yu et al.[46] demonstrated that medical students have a significantly lower level of anxiety and higher level of confidence after attending a simulation session in comparison with before, as measured by the State-Trait Anxiety Inventory (STAI).

3.2. Effectiveness of HFS in teaching biomedical sciences compared with traditional teaching methods

Many studies using HFS in biomedical students suggest a significant increase from pre-simulation to post-simulation test scores. Arcoraci and colleagues noted that the medical students' immediate and long-term retention on positive ionotropic agents was significantly higher when compared to students in the traditional teaching groups.[3] Konieczny and colleagues demonstrated a notable increase in nursing students' knowledge of drug administration skills following HFS compared to low fidelity. The increase in knowledge post-HFS indicates that students are better equipped to tackle challenging clinical scenarios.[47] These results favor the utilization of high-fidelity patient simulations in delivering core concepts such as pharmacotherapy in comparison with traditional teaching methods. Students in their preclinical years could benefit from HFS by reinforcing basic concepts, increasing confidence and critical thinking when applying theoretical concepts.[11]

Pharmacy students in a pilot study were assessed for their knowledge retention after their interaction with HFSs and didactic lectures. Pharmacy students who received supplemental simulations scored 20% higher in their post-simulation tests and maintained the scores 1 month later. Students who only received didactic lectures showed a progressive decline in immediate and delayed post-simulation test scores.[22] HFS demonstrated strong knowledge retention abilities, thus utilizing it in basic science courses is critical for building a solid biomedical foundation. A limited number of published studies discussed the benefits, costs, and outcomes of using HFS. Nevertheless, most of those studies show promising results in knowledge retention and the understanding of basic science concepts as outlined in Table 3.

3.3. Effectiveness of HFS in teaching clinical management skills compared with traditional teaching methods

Several studies in the literature have explored the use of HFSs for teaching essential clinical and management skills to medical residents in a hospital setting. However, compared to traditional or low-fidelity teaching methods, HFS did not result in a better management outcome. Wang and colleagues compared test score differences between residents completing a computer-based and an HFS course for teaching contrast reaction management. The results were not significant and showed improved post-simulation test scores in both groups.[53] Other studies aiming to teach and refresh contrast reaction management to radiology residents were placed into either a traditional or HFS teaching group. There was no significant difference in performance between the two groups post sessions.[54,55] However, residents in the HFS group did perform better in severe contrast reactions and reported more comfort in managing them.[55] Emergency medicine residents in a comparative study also reported more satisfaction when their knowledge was evaluated using a high-fidelity simulator compared to a written examination on drug overdose management.[56]

Table 3. List of studies that compared the impact of HFS on knowledge retention (pre-simulation and post-simulation) to traditional teaching methods with delayed post-simulation test (0–9 months).

Reference	Time delay at conduct of post-simulation test	Results of comparison between didactic vs HFS groups	Student population—discipline
Wheeler et al.[35]	9 months	Students that viewed the online module and attended HFS scored significantly higher ($p = 0.002$) in post-simulation tests when compared to students who attended a formal lecture only. There may have been some inherent bias introduced by the participant selection process which was not random and limited in number. However, the more intense the teaching modalities became, more knowledge retention was noted in the students which supports the superiority of HFS when compared to didactic lectures.	Medical students—Drug administration skills
Alluri et al.[23]	5 weeks	In the simulation group, there was a significant increase in delayed post-simulation test scores ($p < 0.001$) when compared to immediate post-simulation test scores. However, the delayed post-simulation test was administered online where additional reference material could have been used by the students, and shortly after the mandatory final exam where the same topics were tested. These factors could have contributed to the increase in the delayed test scores. In contrast, there was no increase in delayed post-lecture test scores in the lecture group when compared to immediate post-lecture test scores ($p = 0.882$).	Medical students—Cardiology
Arcoraci et al.[3]	3 months	HFS group scored higher on the post-simulation test and did not decrease in score 3 months after the simulation when compared to sham ($p < 0.001$) and low-fidelity ($p < 0.001$) groups	Medical students—Pharmacology
Gisriel et al.[22]	1 month	Didactic lecture group vs HFS group had similar pre-test score. Post-test in Didactic group: Scored 1% lower compared to pre-test scores (15% lower 1 month later). Post-simulation test in Simulation group: Scored 20% higher compared to pre-test scores (maintained 1 month later)	Nursing students—Pharmacology
Ray et al.[48]	25 days	Students in the simulated patient case did not result in greater knowledge retention or comfort level than students in the written patient case. The post hoc analyses showed a significant difference between comfort levels at baseline and post-simulation test ($p < 0.001$), but there was no difference in comfort levels between the immediate and delayed post-simulation test	PharmD students—Pharmacy
Morgan et al.[26]	Same day of simulation	There was a significant improvement between individuals' pre-simulation vs post-simulation pharmacology test answer scores ($p < 0.0001$)	Medical student—Cardiology
Meyer et al.[25]	Same day of simulation	Toward Health Care Teams scale (ATHCT) scores improved from 4.55 to 4.72 on a scale of 1–6 ($p = 0.005$). Almost all (over 90%) of the students stated their pharmacology knowledge and their ability to apply that knowledge improved following the simulation	Nursing and pharmacy students—Pharmacology
Harris et al.[45]	Same day of simulation	Pre-simulation and post-simulation tests, along with student surveys, were used to determine student knowledge and perception of learning in two first-year medical school classes. There was an increase of 21% and 22% in the percentage of students achieving correct answers on a post-simulation test compared with their pre-test score. The median number of correct questions increased from pre-test scores of 2 and 2.5 to post-simulation test scores of 4 and 5 of a possible total of 6 in each respective year.	Medical student—Cardiology

(continued)

Table 3. Continued

Reference	Time delay at conduct of post-simulation test	Results of comparison between didactic vs HFS groups	Student population—discipline
Craig et al.[49]	Same day of simulation	Post-simulation test knowledge scores increased in both groups (Medication Safety Knowledge Assessment and Medication Safety Critical Element Checklist), but results were not statistically significant ($\alpha = 0.05$). Students who received the medication safety enhancement intervention performed significantly better in a subsequent simulation than students who did not have prior simulation experience ($p < 0.001$)	Nursing students—Drug administration practices
Sperling et al.[50]	Same day of simulation	Post-simulation test scores were higher in students who attended a simulation session compared to those who did not ($p < 0.001$). Students who participated in a simulation session were more comfortable in their overall approach to treating altered mental status patients (AMS) ($p = 0.05$). Students who participated in a simulation session were more likely to find the overall AMS curriculum useful ($p < 0.001$).	Medical student—Clerkship
Ali et al.[51]	Same day of simulation	Radiology trainees viewed the didactic lectures, attended a simulation session, and completed the pre-simulation and post-simulation quizzes and questionnaires. Mean scores increased from 69% to 82% ($p < 0.001$) and from 3.1 to 4.5 out of 5 ($p < 0.001$) on the objective and subjective tests, respectively.	Medical student—Radiology
Brown et al.[52]	Same day of simulation	Post-simulation test scores were significantly higher than pre-simulation test scores in Pediatric Cardiac Critical Care Nurse Practitioners (56.0% and 36.8%, respectively ($p < 0.001$)). The course improved overall knowledge, and the pediatric nurse practitioners reported satisfaction and confidence in the simulation experience.	Nursing students—Pediatric cardiac care

HFS: high-fidelity simulation.

3.4. HFS to assess knowledge gaps in healthcare workers

When HFS and traditional teaching methods are combined for training residents, the results improved significantly as noted in the literature. In a recent study, 96 radiology trainees attended two didactic lectures followed by a simulation, which resulted in a mean score increase from 69% on the pre-simulation test to 82% on the post-simulation test.[51] In 2015, Picard and colleagues reported similar results for combined didactic and HFS training for radiology residents. There was a significant increase in knowledge retention compared to baseline scores following the combined interventions.[54] Rehabilitation residents' knowledge on urgent care improved from the baseline mean score of 57.8% to 85% after the educational course consisting of didactic lecture and HFS.[57] A larger number of studies investigate the effects of HFSs independently and demonstrate substantial score improvement from pre-simulation to post-simulation tests. This has been proven in diverse clinical disciplines, where simulations improved test scores in paramedic seizure management by 26%,[58] increased medical students' competencies in managing neurological emergencies after simulations,[59] and enhanced safe drug administration in nursing students.[49] Sperling also concluded a strong relationship between HFS and improved knowledge-based test scores in the students' clinical approach, comfort and competence to patients with altered mental status.[50] These results are consistent and demonstrate the capability of HFS to advance clinical skills and enhance critical thinking when applying theoretical concepts.

Interestingly, pharmacology students who participated in a simulated patient case demonstrated no significant increase in long-term knowledge retention compared to those who were exposed to the conventional written patient case scenario.[48] A possible explanation for this surprising outcome could be that the participating students were in their fourth year of the program. By that point, having conducted a year of clinical practice may have aided the students in the written patient case group to achieve comparable results to students in the simulation group. Other factors that could have contributed to the insignificant findings in this study was the smaller group of participants of 26 students compared to other simulation studies and the shorter period of 25 days to assess the long-term retention of knowledge. Confounding variables should be considered when assessing the benefits HFS has on long-term knowledge retention to maximize the accu-racy of data interpretation.[48]

HFS has been used and studied extensively in training healthcare workers to improve practical skills and has helped in revealing significant areas of improvement in clinical skills. For example, seizures are commonly encountered by paramedics, and HFS helped uncover important knowledge gaps for paramedics in their management of the route and dosing of midazolam in children experiencing seizures.[58] HFS also uncovered that pediatric respiratory therapists lacked a uniform care algorithm in implementing lifesaving airway maneuverers to achieve effective ventilation in children.[60] The nursing field also has utilized HFS for teaching and training purposes. For example, a simulation ''boot camp'' for pediatric nurse practitioners in congenital heart diseases resulted in a significant increase in knowledge and proportion of time-sensitive tasks completed within 5 min, as well as an increase in performance confidence and overall satisfaction post-simulation compared to pre-simulation.[52] Nurses' confidence in completing a Clinical Opiate Withdrawal Scale also increased after conducting HFS.[61] Intensive care unit nurses participated in cardiopulmonary resuscitation simulation that concluded that more frequent training session conducted every 3 months would improve the timely manner of initiating chest compressions on patients and increase clinical skill retention.[62] HFS can be useful for achieving a standardized level of care that would prevent disease sequalae without jeopardizing patient health. It can be used to identify and bridge gaps in knowledge, clinical skills, and confidence in healthcare workers, which would proactively prevent detrimental consequences to patients in a healthcare setting. HFS could also be utilized to assess the appropriate time periods to conduct evaluations on the standards of clinical skills and care provided by nurses to patients.

4. Limitations

Most relevant papers investigating the use of HFS predominantly target residents and nurses to assess and improve emergency management and critical care skill gaps.[51,52,63,64] HFS allows researchers to uncover areas for reinforcing patient care and safety. There is a lack of studies investigating HFS to teach basic sciences, limiting the review's conclusions. The high-cost equipment used and the enormous time and effort required for meticulous planning and execution of HFS could restrict their use in teaching organizations.

The limited papers that studied the long-term knowledge retention following HFS conducted the delayed test from 0 to 9 months post simulation.[3,22,23,35] The long-term effect of HFS on knowledge retention and patient quality of care in comparison with traditional teaching methods in biomedical science programs remains unknown. Also, it is challenging to isolate a cost–benefit ratio for the utilization of HFS. To justify the high cost of HFS, a full economic analysis is necessary, which many healthcare professionals and doctors are not qualified to perform.[65] A cost–benefit analysis coupled with a cost–benefit ratio may be required to estimate the return of investment for simulators. However, the literature is scarce in concluding a definitive answer as to whether a simulator cost is justified, and that could be due to the subjective nature of the issue. Many factors contribute to costs, such as trained staff, location, proctors, and the physical simulator's price, to name a few. In the past few years, more papers were published to tackle the cost issue of high-fidelity simulators. These included developing models with less expensive commercially available material without compromising the quality of the fidelity and using biomedical calibration machines to turn low-fidelity models into high-fidelity simulators at a fraction of the cost.[66–68] The documented benefits of simulators include increased immediate and long-term knowledge retention, improved clinical skills, training, and confidence. However, clinically meaningful benefits are challenging to assess due to the lack of data on the impact of HFS in the biomedical science field on the patient quality of care and safety. Therefore, future studies are encouraged to establish a cost–benefit ratio for HFS use in teaching. This will help make solid recommendations on the value of HFS as a teaching method in the biomedical sciences taught within health professions programs.

5. Conclusion

The use of simulations is more evident in clinical training with medical residents and nurses, when compared to undergraduate health professions students. The optimization of HFS in teaching fundamental sciences such as pharmacology and clinical sciences is limited, despite providing promising results in knowledge retention and student satisfaction. There is an inadequate number of papers that mention the use of HFS to teach other basic biomedical sciences, such as cardiology and neuroscience. Providing a solid foundation in core disciplines inherently leads to acquiring a superior clinical skill set that translates into enhanced patient healthcare. Further research on establishing the uniform use of HFS to teach core concepts in undergraduate programs is encouraged. The adjustments of curriculums to abide by the pandemic's social distancing regulations could be feasible using HFS. They offer a safe opportunity to limit student–patient exposure but provide the experience needed to reinforce clinical skills and knowledge. The integration of HFS in healthcare's diverse clinical fields suggests a strong association with improved post-simulation test scores. Based on the trend of increas-ing number of HFS publications over the past 20 years, it can be concluded that there has been a clear rise of interest and acceptance for HFS. The direction that HFS has led is promising and the increased number of studies that attempt to tackle some of the limitations HFS carries further solidifies its growing influence in teaching and knowledge retention. We recommend incorporating simulations in preclinical stages to allow students to be sub-merged into a more holistic experience, developing their theoretical and clinical skills concurrently. This also will demonstrate a shift toward a more experientially based class grounded in the acquisition and demonstration of clinical competencies.

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