Transfer of learning from simulated setting to the clinical setting: identifying instructional design features

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Abstract

**Background:** Transfer of learning (ToL) is the endpoint of simulation-based training (SBT). It is affected by numerous factors, which can be classified into 3 categories: learner characteristics, work environment, and training design. The first 2 have been identified to some extent in previous research. In this study, the aim was to identify the instructional design (ID) features affecting the ToL in SBT.

**Methods:** This qualitative study was conducted in 2 phases. Phase 1 covers thematic analysis of comparative studies in the field of SBT. A systematic search was performed on 6 databases of Ovid MEDLINE, EMBASE, PsycINFO, CENTRAL, Scopus, and Web of Science, and the references of related systematic reviews were also checked. In phase 2, semi-structured interviews were conducted with key informants (instructors and learners) and analyzed using directed content analysis. The results of the 2 phases were combined, and finally ID features of SBT were identified and categorized.

**Results:** In the first phase, 121 comparative studies were reviewed and in the second phase, 17 key informants were interviewed. After combining the results of the phases, the ID features affecting the ToL in SBT were classified into 3 broad categories and 15 subcategories as follows: (1) pre-simulation: preparation, briefing, and teaching cognitive base; (2) underlying theories: deliberate practice, mastery learning, and proficiency-based training; (3) and methods and techniques: distributed practice, variability, increasing complexity, opportunity for practice, repetitive practice, active learning, feedback/debriefing, simulator type, and simulator fidelity.

**Conclusion:** Although learning is transferred from the simulated setting to the clinical setting, this process is not automatic and straightforward. Numerous factors affect this transfer. The results of this research can be used in designing and evaluating the SBT programs.

**Keywords:** Simulation Training, Manikins, Transfer, Psychology, Education, Medical, Students, Medical

**Conflicts of Interest:** None declared

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Introduction

Simulation is “a technique that creates a situation or environment to allow persons to experience a representation..."
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of a real event for the purpose of practice, learning, evaluation, testing, or to gain understanding of systems or human actions.” (1). It facilitates any kind of learning, whether in the domain of cognitive, affective, and psychomotor, and allows learners to practice principles and skills in a controlled environment and learn to prepare themselves for safer patient care (2). Nowadays, instead of learning the skills on a patient in the clinical environment, students initially learn them on the simulator (3).

There are different methods and types of simulation, including full-body manikins, part-task trainers, screen-based simulators, virtual reality, and simulated patients (2). Learning objectives, level of fidelity needed, and learning level of trainees are 3 influential factors in choosing the method and type of simulation (4).

The efficacy of simulation-based training (SBT) has been reported in many published systematic reviews and meta-analyses (5-8). Kirkpatrick's 4-level model is frequently used in the evaluation of educational programs and includes reaction, learning, behavior, and results (9). In SBT, the trainee’s level of learning (a skill or knowledge) is evaluated in a simulated setting and on a simulator. However, SBT is effective when the learner is prepared to apply what s/he has learned in the simulated setting to real patients in the clinical setting. This is the third level of Kirkpatrick’s model, that is, “behavior change,” which is more specifically known as transfer of learning (10). As Norman et al expressed, 1 of the assumptions of SBT is that the skills learned through the simulator could be applied to the real patients (11). Nonetheless, the results of more than 30 years of research show that transfer of learning to the clinical setting is not an easy task (12).

Transfer of learning has a broad meaning and it has been supported by research for more than 120 years, especially in the literature of applied psychology and organizational learning (13). Contrary to the popular belief, transfer of learning has a complex and dynamic process, and it is affected by a set of factors (14). According to studies, the factors affecting transfer of learning are classified into 3 categories: learner characteristics, training design, and work environment (15). In the past, there was not much evidence regarding the transfer of learning; however, nowadays, it is strongly claimed that learning from the simulated setting can be transferred to the clinical setting (16-22). In fact, there have been debates over the utility of SBT for decades, that is, to understand whether or not simulation works. However, nowadays, the main question is how SBT works, and how we can design and implement it to maximize learning and facilitate transfer of learning (23). To this end, identifying the factors affecting transfer of learning is more important. As mentioned earlier, 3 categories of factors affect the transfer of learning; however, the purpose of this study is to find factors related to instructional design (ID), because the characteristics of the learners and factors related to the work environment have been identified and explained clearly in several previous studies (24-26).

Methods

This qualitative study was performed in 2 phases. The first phase included thematic analysis of comparative studies related to SBT, and the second was the directed content analysis of qualitative interviews with learners and instructors of SBT.

Phase 1: Thematic Analysis of Comparative Studies Related to SBT

Review Question: Based on comparative studies, which features of instructional design related to SBT can affect the transfer of learning in undergraduate and postgraduate medical trainees?

Information Sources and Search Strategy: A systematic search was performed on 6 databases, including Ovid MEDLINE, EMBASE, PsycINFO, Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, and Web of Science. Searching included free keywords and controlled terms. Terms and their derivatives were combined with appropriate Boolean operators. Wildcard and truncation operators were also used to increase search sensitivity. The search was conducted on August 12, 2019. Table 1 shows the search strategy developed for the Ovid MEDLINE database. This search strategy was adapted to other databases and modified as needed. In addition to searching the databases, the references of related systematic reviews were also examined. The Full search strategy for all databases is given in the Appendix S1.

Inclusion Criteria: All comparative studies (RCT, quasi-experimental, cohort, 1-group pretest-posttest studies) that met the following criteria were included in the study:

- Using SBT as the main intervention;
- Investigating undergraduate and postgraduate medical trainees;
- Assessing transfer of learning on the patients and in real clinical setting;
- Evaluating only technical skills and procedures;
- Comparative studies;
- Published only in English language.

Exclusion Criteria:

- Other health profession trainees;
- Qualitative, review, descriptive, and editorial studies;
- Nontechnical skills (such as leadership, teamwork, communication skills);
- Assessing learners’ skills on a simulator or an animal or a human cadaver;
- Lack of full text of articles; and
- Published in a language other than English.

Selection of Studies: All retrieved articles were imported into EndNote X9 software. After removing duplicate records, the studies were selected through 3 screening stages. In title screening, clearly irrelevant articles were excluded from the review. Then, title and abstract screening was performed according to the inclusion and exclusion criteria. When there was no agreement on the abstracts or there was insufficient information, the full-texts of the articles were reviewed. Conflicts were resolved through discussion.
Data Extraction and Analysis: Thematic analysis was used to find themes (instructional design features). The 5 stages of thematic analysis are familiarization with data, assigning the initial codes, searching for themes, reviewing the themes, and charting themes according to the objectives of the study (27). For this purpose, the Introduction and Methods sections of each article were carefully studied and the features related to the SBT instructional design were highlighted in the PDF file. Then, all the articles were imported into MAXQDA 2018 software. Previously identified instructional design features, such as feedback, repetitive practice, and fidelity, were used as a starting point of theme classification, and new themes were added. Finally, the obtained themes (factors) were reviewed several times and categorized based on similarities.

In addition, basic study characteristics, such as source, year, study design, topic, learners, and sample size were extracted for each article.

Phase 2: Directed Content Analysis of Qualitative Interviews

In order to emphasize the context and increase the strength of the study, in-person interviews were conducted with key informants. By “key informants” we mean all individuals who participated in the simulation sessions as learners or instructors. Instructors should have at least 2 years of teaching experience in SBT, and learners should have participated in at least 10 simulation sessions. Sampling was done completely purposefully. Participants of both genders, various disciplines, positions, and hospitals were selected for interview to maximize the variation of sampling. Individuals were called and invited to interview. If they accepted the invitation, the time and place of the interview were set. In the interview session, first, the purpose of the study was explained and a brief description was given about the concept of transfer of learning and the objectives of the session, the duration of the training, the role and techniques. Each of these categories have their own subcategories that are described below. Meanwhile, some open-ended questions were asked to identify other factors, especially with regard to the context. In the interview session, first, an open-ended question was asked. For example, the following questions were asked from the instructors and learners, respectively:

- “What factors affect the process of transferring technical skills learned in the simulated environment to the real patient?”
- “Have you experienced transfer of learning? If yes, what were the factors behind this transfer?”

This was followed by more detailed and exploratory questions using predefined codes and levels. After each interview, the data were implemented, and directed content analysis was performed on them, and subsequent interviews were conducted based on them. Interviews continued until data saturation.

The set of codes (factors) identified from the first phase of the research was used as a guide for coding the text of the interviews. Therefore, whenever a text was related to the previously identified factors, the same code was assigned to it. New codes were also emerged and stored separately in the MAXQDA software. The codes were reviewed several times, and after being summarized, they were placed in the preexisting categories or in the new category based on similarity and appropriateness.

Results

Phase 1

The process of study selection is presented in Figure 1. After removing duplicates, 14,620 records remained. Then, 10,773 articles in the title screening and 3,445 articles in the abstract screening were excluded. Next, 295 studies were excluded by full-text screening, leaving 107 studies for final review. After reviewing the reference list of systematic reviews, 14 new articles were obtained. Therefore, a total of 121 articles were reviewed.

The characteristics of the articles and their full reference lists have been presented in a table in the Appendix S2 and S3. The studies had been published between 1987 and 2019 in 74 different journals. In addition, journals of surgery and anesthesia played a major role in publishing these articles.

In total, 10 one-group pretest-posttest studies, 10 cohort studies, 10 quasi-experimental studies, and 91 (75%) true experimental (RCT) studies were included in the review. Most of the studies (46%) were 2-group pretest-posttest and 2-group posttest only (37%). Also, 81% (91) of study participants were postgraduate medical trainees (PGMT), 21% (18) undergraduate medical trainees (UGMT), and 3.3% (4) of the studies had a mix of PGMT and UGMT. Minimally invasive surgeries/procedures, Central Venous Catheter (CVC) insertion, and intubation were the most commonly taught clinical topics using simulation.

Table 1 (in the Appendix S4) shows the ID features that lead to the transfer of learning in SBT. In total, 3 broad categories of factors affecting learning transfer were identified: presimulation, underlying theories, and methods and techniques. Each of these categories have their own subcategories that are described below.

Presimulation

Briefing: In this session, the instructor explains the objectives of the session, the duration of the training, the role of the learners, and the teaching method. Defining the roles and tasks is especially important for group and scenario-based simulation sessions. Also, if there is a simulator or medical device that students are not familiar with, it should be introduced and described. The briefing takes place just before the simulation session (1, 28). Briefing sessions were reported in 23 (19%) studies.

Teaching Cognitive Base: Before starting the simulation, learners should be familiar with the theoretical and cognitive base of the procedure. Items, such as the importance and necessity of the procedure, anatomy, indications, contraindications, and steps to perform the procedure should be described. This section can be presented in locations, contraindications, and steps to perform the procedure should be described. This section can be presented in...
the form of text, videos, e-learning, lectures, et cetera (29). In 64 (52.8%) interventions, teaching the theoretical dimension of procedures was reported. In 42 (34.7%) interventions, the procedure technique was shown as a pre-prepared film before starting the simulation operation. The cognitive dimension could be presented several days before the simulation or in the simulation session or before the start of the simulation operation. No specific information was extracted from the reports.

**Underlying Theories**

**Deliberate Practice (DP):** This theory was developed by Ericsson et al. According to them, significant improvements in performance occur when the following cases are met: The objectives of the task are well defined, individuals are motivated to progress, they receive feedback and adequate opportunities for repetition, and gradual modification of their performance is provided (30).

Nine features or requirements of DP in simulation-based medical education are as follows: (1) learners with high motivation and good concentration; (2) engaging in a well-defined goal or task; (3) appropriate difficulty level of the tasks; (4) frequent and focused training; (5) accurate assessment; (6) informative feedback from educational resources (eg, simulator and teacher); (7) learners monitoring their own learning experiences and review and correct strategies, errors, and levels of learning, and reengage in DP if necessary; (8) learners are evaluated for competency; (9) learners are allowed to go to the next level/unit.

The effect of DP on learning and its transfer in simulation has been well documented. However, not all the above 9 features have been necessarily observed in all articles. Mostly, they included 3 phases of practice, informative feedback, and reinforcement. In total, this method was used in 11 (9%) studies to learn the skills. It is noteworthy that most of these articles merged mastery learning (ML) and DP.

**Mastery Learning (ML):** ML is not a new approach and it dates back to the 1950s and 1960s; it is the brainchild of John Carroll and Benjamin Bloom. According to this approach, if all learners are given ample opportunity, all of them can achieve all or most of the learning outcomes at the mastery level (31). ML is a rigorous type of compe-
virtual reality. Therefore, these levels have already been researched, the simulator used in this approach was mostly haptic feedback. This level is determined by the experts. In our point in this approach is to determine the level of proficiency. This level is determined by the experts. In our research, the simulator used in this approach was mostly virtual reality. Therefore, these levels have already been embedded as a program by simulator developers. In 49 (40.49%) studies, simulation interventions were performed with PBT approach. Considering the topics covered, we find that almost all of the interventions were about 1 of the minimally invasive surgeries/procedures (MIS). Therefore, we can conclude that MIS (skill), PBT (training approach), and virtual reality (simulator type) are completely interrelated. This means that combining them increases learning and transfer of learning.

**Methods and Techniques**

**Feedback and Debriefing:** In simulation, feedback refers to information given or dialogue between participants, facilitators (instructors), simulator, or peers to improve understanding of concepts or aspects of performance (28). Feedback is very important in simulation, and some scholars believe that if we remove feedback from the simulation, almost no learning will happen (36). Feedback was reported in 86 (71%) studies, but the sources of feedback were as follows:

- Instructor or facilitator (46; 38%);
- Simulator (66; 54.5%);
- Haptic feedback (40; 33%);
- Audiovisual feedback (23; 19%);
- Unknown (3; 2.47%).

Haptic feedback is particularly relevant to virtual reality simulators. This type of feedback can be used to simulate contact, touching a limb or part of the body, and cutting (1). A number of studies have reported more than 1 source of feedback, so the sum of the percentages of feedback sources is greater than the feedback itself. In simulation, there are generally 2 types of feedback: one is during-session feedback, which can occur immediately, and the other is end-of-session feedback (including debriefing). Immediate feedback is most effective in teaching individual procedural skills, and if final feedback is provided, it can help increase learning and transfer of learning (37). The term debriefing is specific to team simulation training, which is based on guidelines, such as ACLS, ATLS, PALS, etc. Some consider feedback and debriefing as completely separate concepts, but some simulation articles refer to group feedback at the end of a session as debriefing. Debriefing is essentially a reflection and 1 of the most important factors in the transfer of learning in studies related to resuscitation training. Feedback was provided in 68 (56.19%) papers during the simulation session and in 23 (19%) papers at the end of the simulation session. The procedures taught in these 121 articles were mostly of individual type; hence, the number of feedbacks during the sessions was higher than end-of-session ones.

**Distributed Practice:** This method is in contrast to massed practice. According to this method, to teach a skill, it is better to divide the practice into shorter sessions over a longer period of time (38). For example, if we have 8 hours to teach a skill, instead of an 8-hour session, we can hold it in the form of four 2-hour sessions. This method is widely used in the approaches of DB, ML, and PBT. In this study, we considered simulation interventions as a distributed practice when they were held in more than 1 session/day. Thus, the distributed practice method was

| Table 1: Search Strategy for Ovid MEDLINE |
|-------------------------------------------|
| Row | Syntax | N |
|-----|--------|---|
| 1   | simulation.ab,ti. | 175122 |
| 2   | simulator?.ab,ti. | 18054 |
| 3   | manikin?.ab,ti. | 2711 |
| 4   | mannikin?.ab,ti. | 62 |
| 5   | mannequin?.ab,ti. | 1610 |
| 6   | exp Simulation Training/ | 7701 |
| 7   | Patient Simulation/ | 4738 |
| 8   | High Fidelity Simulation Training/ | 185 |
| 9   | exp Computer Simulation/ | 223787 |
| 10  | virtual reality.ab,ti. | 8250 |
| 11  | Virtual Reality/ | 1044 |
| 12  | augmented reality.ab,ti. | 1529 |
| 13  | exp Education, Medical/ | 158221 |
| 14  | educat5.ti,ab. | 546268 |
| 15  | train5.ti,ab. | 493886 |
| 16  | learn5.ti,ab. | 359073 |
| 17  | instruct5.ti,ab. | 89094 |
| 18  | teach6.ti,ab. | 178995 |
| 19  | currucul5.ti,ab. | 51461 |
| 20  | 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 | 367730 |
| 21  | 13 or 14 or 15 or 16 or 17 or 18 or 19 | 1436455 |
| 22  | 20 and 21 | 38476 |
| 23  | exp Clinical Study/ or comparative study/ | 2527306 |
| 24  | 22 and 23 | 5046 |
| 25  | limit 24 to english language | 4941 |
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used in most (71%) of the interventions.

Repetitive Practice: Repetitive practice is a basic principle in learning any technical skill. In fact, repetitive practice quickly automates skills, and the key is to transfer skills from the simulator to the real patient (39). It should also be noted that, if it is embedded in DP, it would be more effective than unstructured and thoughtless practice. Nevertheless, repetitive practice helps learn the skills, especially in novices. Once the learning curve reaches the plateau level, the routine repetition of a skill no longer improves one's performance, in which case the principles of DP should be used (40, 41). Repetitive practice was reported in 72 (56.19%) papers. Our criterion for the repetitive practice was performing a task on the simulator for more than 1 time.

Increasing Complexity: If we break down the steps of a procedure or task from simple to complex and gradually increase its difficulty, the learning of skills will be easier for learners, especially novices (39). Although this approach could be implemented in the scenario-based simulations, it was observed that, in the reviewed studies, MIS procedures had been mainly taught with virtual reality simulators. In total, 42 (34.7%) cases of the interventions used the technique of gradually increasing complexity to teach skills.

Variability: Variability simply refers to the use of a variety of practices to teach a particular concept or skill. For example, instead of executing and practicing a specific scenario for 5 times, it is better to have a different scenario each time, but the task is the same. In other words, this diversity is about the surface features of a task. For example, when describing a particular clinical symptoms, we can give examples of patients of different ages, genders, races, and medical histories (42). In scenario-based simulation training, this variety of practices can be considered in the scenario itself. Moreover, in advanced simulators, such as full-body manikins and virtual reality, this practice may be embedded as a program in the simulator itself. In the present study, most of the studies that received the variability code used virtual reality simulators for training. Overall, 26 (21.48%) studies used the variability technique.

Simulator Fidelity: Simulator fidelity is one of the challenging topics. It is usually divided into 3 categories: low, medium, and high fidelity. It simply means the realism level of the simulator, and how similar it is to the real world (1). High-fidelity simulators have long been thought to improve transfer of learning, but various studies have shown that transfer of learning does not depend solely on the level of fidelity. In general, educational goals, type of procedure, and level of learners determine the fidelity of a simulator (11). By simulator fidelity, we actually mean physical fidelity. Nowadays, this term is used to mean simulation itself, in which case the simulator is only one of its components. In this view, in addition to the simulator fidelity, there are at least 2 other kinds of fidelity: environmental fidelity and psychological fidelity.

Environmental Fidelity: To what extent does the simulated environment (simulator, room, tools, equipment, moulage, and sensory prop) represent the reality and appearance of the real environment?

Psychological Fidelity: To what extent does the simulated environment stimulate the underlying psychological processes required in the real environment? In fact, it is the level of realism perceived by learners (11).

No specific information was extracted from environmental and psychological fidelity of the experimental studies. Regarding the physical fidelity of the simulator, although most of the educational interventions (68 cases; 56.19%) used high-fidelity simulators, in 26 (21.48%) cases they used low-fidelity simulators, such as task trainers; they also showed transfer of learning. A combination of them was used in 5 (4.13%) studies. The remaining studies did not report the type of fidelity.

Simulator Type: Virtual reality simulators were used in 65 (53.71%) interventions; task trainer simulators in 23 (19%); full-body manikins in 6 (4.95%), and box trainers in 6 (4.95%). Finally, in 8 (6.61%) interventions, a combination of simulators was used. Also, some studies did not report the type of simulator.

Phase 2

A total of 17 participants were interviewed. The minimum and maximum interview durations were 25 minutes and 65 minutes (average duration = 41 minutes). Demographic information of participants is presented in the Appendix S5. Through directed content analysis, a total of 98 initial and open codes (including codes obtained from phase 1) were identified. One of the aims of qualitative directed content analysis is to see whether the findings show evidence of support or nonsupport for a phenomenon. Thus, the following question was raised:

- From the interviewees’ point of view, do the existing factors influence the transfer of learning meaningful to them?

In phase 1 of the study, a total of 12 factors related to instructional design in transfer of learning were extracted. Two of these factors were also confirmed in interviews (feedback and teaching cognitive base). Since there was no experience for some factors, practically no specific information was obtained. For example, there was no teaching or learning experience by ML, PBT, or DP. However, 3 categories and several subcategories were extracted from the interviews in addition to the previous 12 factors.

Feedback Source

In the interviews, in addition to the instructor and the simulator, peer feedback was extracted as one of the main sources of feedback in the simulation sessions. In this regard, 1 student said:

"If I know, for example, that my peer knows the content very well, and the teacher is very busy, I may ask my peer to help me learn a skill. Then, I can practice it in front of the instructor and get his/her feedback. Overall, I personally get a lot of feedback from my peers."

Preparation

It includes items such as choosing the appropriate time and location for training, scenario design, et cetera.
Appropriate Time
"The time of the class is also important. For example, when our simulation sessions are scheduled at 4 PM or 5 PM, then it seems as if it is not part of our curriculum...."

Appropriate Location
"... I do not think it is a good idea to hold our classes in the stressful situation of the hospital."

Predesigned Scenario
"Depending on the year of the residency, we run 3 different scenarios. For example, if we are going to teach resuscitation. There is a simple resuscitation practice for PGY1 residents and a more complicated one for PGY3 ones (like infants’ resuscitation).

Opportunity for Practice
"But at the end, I came to the conclusion that a simulation workshop would not be complete unless every single person sitting there would eventually run the procedure once."

Active Learning
"The teacher should involve the learners and constantly ask them questions. Sometimes, our simulation classes are not different from the theory classes; they are spiritless. I attended a simulation class at a hospital. It was very good; there were few learners and the teacher gave us a complete feedback."

Similarities Between Learning Environment and Transfer Environment
"The more the environment or simulator is similar to the clinical environment, the better. Of course, the instructor can also play a major role. That means s/he can help get closer to the real environment."

Integration of the Results of the 2 Phases of the Study
As mentioned earlier, fidelity is divided into 3 categories: physical, environmental, and psychological. Thus, the category “similarity between learning environment and transfer environment” was merged with environmental fidelity. In Phase 1, the instructor and the simulator were identified as 2 sources of feedback, and in the interviews, a peer was added. Preparation was placed under the general category of presimulation, and the opportunity for practice and active learning was included in the category of methods and techniques. Therefore, in 2 phases of the study, 15 features of instructional design that are effective in transferring learning from the simulated setting to the clinical environment were extracted. These 15 features were classified into 3 general categories (Table 2).

Discussion
Many factors are influencing the transfer of learning from the simulated environment to the clinical environment. In previous studies, these factors were not clearly and comprehensively identified. As a result, in this study, we identified these factors using a 2-phase study. These factors, which are the characteristics of ID, were classified into 3 general categories: presimulation, underlying theories, and methods and techniques. Some of the above factors overlap, which means that if we use one approach, it automatically covers some other factors as well. For example, if we use the ML approach, factors such as feedback, repetitive practice, and increasing complexity are embedded in it. However, this does not mean that these factors can be used only with these approaches. There are many studies that have used only repetitive practice or feedback without performing all the steps of ML. In general, the above factors have a positive effect on learning and transfer of learning. However, if they are utilized in the form of a coherent approach, such as ML and PBT, they can be more effective. If we consider the transfer of learning as the end point and measure of the effectiveness of any educational intervention, SBT meets this criterion; and the review of 121 comparative studies (75% were RCTs) confirmed this issue.

It was reconfirmed that a wide range of skills and procedures can be taught using simulation techniques. This can include complex procedures like laparoscopy cholecystectomy (43) and simple procedures, such as injections. The important point is to identify and use the factors affecting learning and transfer of learning in SBT (23).

Although the transfer of learning has been extensively studied by cognitive psychologists and educational specialists for more than a century, it has rarely been considered by medical educators (44). According to Dyre and Tolsgaard, there are many articles in medical education confirming that transfer of learning can occur, but few studies explore when, why, and how the transfer can be optimized theoretically and conceptually (45). In other words, the transfer of learning in medical education is taken for granted, while various studies in the field of medical education have repeatedly shown that this field is a challenging task for both students and teachers (46).

| Table 2. ID Features That Lead to the Transfer of Learning in SBT |
|---------------------------------------------------------------|
| **Presimulation**                                            |
| Preparation                                                   |
| Briefing                                                      |
| Teaching cognitive base                                       |
| **Underlying theories**                                       |
| Deliberate practice                                           |
| Mastery learning                                              |
| Proficiency-based training                                    |
| **Methods & Techniques**                                      |
| Distributed practice                                          |
| Variability                                                   |
| Increasing complexity                                         |
| Opportunity for practice                                      |
| Repetitive practice                                           |
| Active learning                                               |
| Feedback/debriefing                                          |
| Simulator type                                               |
| Simulator fidelity                                           |

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When most lessons are taught outside the clinical setting, instructors need to devise a method to design the curriculum so that the learning can be transferred to the real environment (47).

A number of factors affecting the transfer of learning that were obtained in this study were similar to those reported in previous studies (39, 48, 49). However, the present study was different from them in 4 major aspects:

1. Only studies that really measured the transfer of learning were examined;
2. The strength of evidence was relatively high (75% were RCTs [randomized controlled trials]);
3. The number of factors extracted was higher than the previous studies and were classified into 3 categories;
4. By conducting a qualitative interview, issues related to context were also considered.

In this study, all simulation modalities (patient simulations, VR, etc.) and all medical trainees’ levels (undergraduate and postgraduate) were included, which may have ignored their particular conditions and requirements.

Conclusion

Although transfer of learning from a simulated environment to a clinical setting is done regularly, this process does not occur automatically and directly. In general, 3 categories of factors, including learner-related factors, factors related to educational design, and factors related to clinical environment have an impact on transfer of learning. In this study, only factors related to educational design were extracted from comparative studies and qualitative interviews. Each of these 16 factors can be explored in more depth in future studies. Experimental studies as well as systematic reviews are recommended. The results of this research can be used in designing simulation-based medical education programs as well as evaluating these programs.

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Conflict of Interests

The authors declare that they have no competing interests.

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## Appendix S1. Full Search Strategy for Six Databases

### 1- Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Daily and Versions (R) 1946 to August 09, 2019

**Search date:** 12 August 2019

| Row | Syntax | N   |
|-----|--------|-----|
| 1   | simulation.ab,ti. | 175122 |
| 2   | simulator?:ab,ti. | 18054 |
| 3   | manikin?:ab,ti. | 2711 |
| 4   | mannequin?:ab,ti. | 62 |
| 5   | exp Simulation Training/ | 1610 |
| 6   | Patient Simulation/ | 7701 |
| 7   | High Fidelity Simulation Training/ | 4738 |
| 8   | exp Computer Simulation/ | 185 |
| 9   | virtual reality.ab,ti. | 223787 |
| 10  | Virtual Reality/ | 8250 |
| 11  | augmented reality.ab,ti. | 1044 |
| 12  | exp Education, Medical/ | 1529 |
| 13  | educat$.ti,ab. | 158221 |
| 14  | train$.ti,ab. | 546268 |
| 15  | learn$.ti,ab. | 493886 |
| 16  | instruct$.ti,ab. | 359073 |
| 17  | teach$.ti,ab. | 89094 |
| 18  | curricul$.ti,ab. | 178995 |
| 19  | 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 | 367730 |
| 20  | 13 or 14 or 15 or 16 or 17 or 18 or 19 | 1436455 |
| 21  | 20 and 21 | 38476 |
| 22  | exp Clinical Study/ or comparative study/ | 55340 |
| 23  | 22 and 23 | 2527306 |
| 24  | limit 24 to english language | 5046 |
| 25  | limit 24 to english language and embase and journal | 4941 |

### 2- Embase 1974 to 2019 Week 32 (OvidSP)

**Search date:** 12 August 2019

| Row | Syntax | N   |
|-----|--------|-----|
| 1   | simulation.ab,ti. | 187436 |
| 2   | simulator?:ab,ti. | 23800 |
| 3   | manikin?:ab,ti. | 3949 |
| 4   | mannequin?:ab,ti. | 83 |
| 5   | exp Simulation Training/ | 2491 |
| 6   | Patient Simulation/ | 3916 |
| 7   | High Fidelity Simulation Training/ | 756 |
| 8   | exp Computer Simulation/ | 265 |
| 9   | virtual reality.ab,ti. | 278975 |
| 10  | exp medical education/ | 112145 |
| 11  | train$.ti,ab. | 10979 |
| 12  | learn$.ti,ab. | 15315 |
| 13  | instruc$.ti,ab. | 1852 |
| 14  | augmented reality.ab,ti. | 395646 |
| 15  | exp comparative study/ or exp controlled study/ | 300492 |
| 16  | educat$.ti,ab. | 716976 |
| 17  | train$.ti,ab. | 654469 |
| 18  | learn$.ti,ab. | 467062 |
| 19  | instruc$.ti,ab. | 121097 |
| 20  | teach$.ti,ab. | 229201 |
| 21  | curricul$.ti,ab. | 65579 |
| 22  | 15 or 16 or 17 or 18 or 19 or 20 or 21 | 1914304 |
| 23  | 14 and 22 | 55340 |
| 24  | exp comparative study/ or exp controlled study/ | 7869395 |
| 25  | 23 and 24 | 13595 |
| 26  | limit 25 to (english language and embase and journal) | 7849 |
3- PsycINFO 1967 to August Week 1 2019 (OvidSP)

| Row | Syntax | N  |
|-----|--------|----|
| 1   | simulation.ab,ti. | 27376 |
| 2   | simulator?.ab,ti. | 4290 |
| 3   | manikin?.ab,ti. | 354 |
| 4   | mannikin?.ab,ti. | 22 |
| 5   | mannequin?.ab,ti. | 174 |
| 6   | exp Simulation/ | 59868 |
| 7   | exp Computer Simulation/ | 15149 |
| 8   | exp Virtual Reality/ | 7920 |
| 9   | exp Augmented Reality/ | 398 |
| 10  | virtual reality.ab,ti. | 4648 |
| 11  | augmented reality.ab,ti. | 587 |
| 12  | 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 | 78768 |
| 13  | exp Medical Education/ | 23000 |
| 14  | educat$.ti,ab. | 431270 |
| 15  | train$.ti,ab. | 282152 |
| 16  | learn$.ti,ab. | 413163 |
| 17  | instruct$.ti,ab. | 124043 |
| 18  | teach$.ti,ab. | 246927 |
| 19  | curricul$.ti,ab. | 56215 |
| 20  | 13 or 14 or 15 or 16 or 17 or 18 or 19 | 1062791 |
| 21  | 12 and 20 | 22287 |
| 22  | medical.ab,ti. | 177550 |
| 23  | medicine.ab,ti. | 51166 |
| 24  | healthcare.ab,ti. | 38430 |
| 25  | physician?.ab,ti. | 57399 |
| 26  | health profession?.ab,ti. | 3042 |
| 27  | 22 or 23 or 24 or 25 or 26 | 271975 |
| 28  | 21 and 27 | 1626 |
| 29  | limit 28 to ("0300 clinical trial" or "0400 empirical study") | 1035 |
| 30  | limit 29 to (peer reviewed journal and english language) | 765 |

4- EBM Reviews - Cochrane Central Register of Controlled Trials July 2019 (OvidSP)

| Row | Syntax | N  |
|-----|--------|----|
| 1   | simulation.ab,ti. | 6052 |
| 2   | simulator?.ab,ti. | 2315 |
| 3   | manikin?.ab,ti. | 1178 |
| 4   | mannikin?.ab,ti. | 11 |
| 5   | mannequin?.ab,ti. | 366 |
| 6   | Patient Simulation/ | 450 |
| 7   | exp Computer Simulation/ | 1511 |
| 8   | virtual reality.ab,ti. | 2315 |
| 9   | augmented reality.ab,ti. | 128 |
| 10  | 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 | 11404 |
| 11  | exp Education, Medical/ | 3074 |
| 12  | educat$.ti,ab. | 54046 |
| 13  | train$.ti,ab. | 86835 |
| 14  | learn$.ti,ab. | 25476 |
| 15  | instruct$.ti,ab. | 21877 |
| 16  | teach$.ti,ab. | 17313 |
| 17  | curricul$.ti,ab. | 3893 |
| 18  | 11 or 12 or 13 or 14 or 15 or 16 or 17 | 164977 |
| 19  | 10 and 18 | 5258 |
| 20  | limit 19 to english language | 4250 |
## Transfer of learning in simulation-based training

### 5. Scopus

Search date: 12 August 2019

( TITLE-ABS (simulation OR simulator? OR manikin? OR mannequin? OR "virtual reality" OR "augmented reality") AND INDEXTERMS ("Simulation Training" OR "Patient Simulation" OR "High Fidelity Simulation Training" OR "Computer Simulation" OR "Virtual Reality") AND INDEXTERMS ("medical education" OR "education, medical") OR TITLE-ABS (educat* OR learn* OR train* OR teach* OR instuct* OR curricul*) ) AND ( INDEXTERMS ("clinical trials" OR "clinical trials as a topic" OR "randomized controlled trial" OR "Randomized Controlled Trials as Topic" OR "controlled clinical trial" OR "Controlled Clinical Trials" OR "random allocation" OR "Double-Blind Method" OR "Single-Blind Method" OR "Cross-Over Studies" OR "Placebos" OR "multicenter study" OR "double blind procedure" OR "single blind procedure" OR "crossover procedure" OR "clinical trial" OR "controlled study" OR "randomization" OR "placebo") ) OR TITLE-ABS-KEY ("clinical trials" OR "clinical trials as a topic" OR "randomized controlled trial" OR "Randomized Controlled Trials as Topic" OR "random allocation" OR "allocated randomly" OR "Double-Blind Method" OR "Single-Blind Method" OR "Cross-Over Studies" OR "Placebos" OR "cross-over trial" OR "single blind" OR "double blind" OR "factorial design" OR "factorial trial") AND ( LIMIT-TO (LANGUAGE, "English") ) AND ( LIMIT-TO (SRCTYPE, "j") )

### 6. Web of Science core collection

1983-2019

- Science Citation Index Expanded (SCI-EXPANDED) --1983-present
- Social Sciences Citation Index (SSCI) --1983-present
- Emerging Sources Citation Index (ESCI) --2015-present

Search date: 12 August 2019

TS=(simulation OR simulator? OR manikin? OR mannequin? OR "virtual reality" OR "augmented reality") AND TS=(medical education OR educat* OR learn* OR train* OR teach* OR instuct* OR curricul*) AND TS=(clinical trial OR comparative study OR controlled trial)

Indexes=SCI-EXPANDED, SSCI, ESCI Timespan=All years

### Appendix S2: Study Characteristics of Included Papers

| Source | Journal | Study Design | Is RCT? | Topics | Trainees | N  |
|--------|---------|--------------|---------|--------|----------|----|
| 1- (Ewy GA, et al.,1987) | Academic Medicine | 2PP | No | Physical examination | UGME | 116,92 |
| 2- (Ovassapian A, et al.,1988) | British journal of anaesthesia | 2PP | Yes | Intubation | PGME | 16,16 |
| 3- (From RP, et al.,1994) | Anesthesia and analgesia | 2PP | Yes | Airway Management | UGME | 49,48 |
| 4- (Peugnet F, et al.,1998) | Computer Aided Surgery | 2PP | Yes | Laser coagulation | PGME | 5,3 |
| 5- (Tuggy ML,1998) | The journal of the American board of family practice | 2PO | Yes | Flexible sigmoidoscopy | PGME | 5,5 |
| 6- (Scott DJ, et al.,2000) | Journal of the American College of Surgeons | 2PP | Yes | Laparoscopic cholecystectomy | PGME | 9,13 |
| 7- (Hamilton EC, et al.,2001) | American journal of surgery | 2PP | Yes | Laparoscopic hernia repair | PGME | 10,11 |
| 8- (Naik VN, et al.,2001) | Anesthesiology | 2PP | Yes | Intubation | PGME | 12,12 |
| 9- (Ost D, et al.,2001) | American journal of respiratory and critical-care medicine | 2PO | Yes | Bronchoscopy | PGME | 3,3 |
| 10- (Edmond CV, Jr.,2002) | Laryngoscope | 2PO | NO | Endoscopic sinus surgery | PGME | 2,2 |
| 11- (Hamilton EC, et al.,2002) | Surgical Endoscopy and Other Interventional Techniques | 1PP | NO | Laparoscopic cholecystectomy | PGME | 19 |
| 12- (Rowe R, et al.,2002) | Anesthesia & Analgesia | 2PP | Yes | Intubation | PGME | 12,8 |
| 13- (Seymour NE, et al.,2002) | Annals of surgery | 2PO | Yes | Laparoscopic cholecystectomy | PGME | 8,8 |
| 14- (Gerson LB, et al.,2003) | Endoscopy | 2PP | Yes | Sigmoidoscopy | PGME | 9,7 |
| 15- (Gormley GI, et al.,2003) | Annals of the rheumatic diseases | 2PP | Yes | Shoulder injection | UGME | 20,20 |
| 16- (Lee SK, et al.,2003) | Journal of trauma | 2PP | Yes | Trauma assessment | PGME | 30,30 |
| 17- (Abrahamsson S, et al.,2004) | Quality & Safety in Health Care | 2PO | Yes | Intubation | PGME | 5,5 |
| 18- (Blum MG, et al.,2004) | Annals of thoracic surgery | 2PO | Yes | Bronchoscopy | PGME | 5,5 |
| 19- (Di Giulio E, et al.,2004) | Gastrointestinal endoscopy | 2PO | Yes | Upper gastrointestinal endoscopy | PGME | 11,11 |
| 20- (Grantcharov TP, et al.,2004) | British journal of surgery | 2PP | Yes | Laparoscopic cholecystectomy | PGME | 8,8 |
### Appendix S2. Study Characteristics of Included Papers

| Source | Journal                                           | Study Design | Is RCT? | Topics                                      | Trainees        | N   |
|--------|---------------------------------------------------|--------------|---------|---------------------------------------------|-----------------|-----|
| 21-    | (Sedlack RE, et al.,2004)                         | 2PO          | Yes     | colonoscopy                                 | PGME 4,4        |     |
| 22-    | (Sedlack RE, et al.,2004)                         | 2PO          | Yes     | flexible sigmoidoscopy                      | PGME 19,19      |     |
| 23-    | (Ahlberg G, et al.,2005)                          | 2PO          | Yes     | Colonoscopy                                 | PGME 6,6        |     |
| 24-    | (Hochberger J, et al.,2005)                       | 2PP          | Yes     | upper gastrointestinal endoscopy           | PGME 9,5        |     |
| 25-    | (Schijven MP, et al.,2005)                         | CO           | -       | laparoscopic cholecystectomy                | PGME 12,12      |     |
| 26-    | (Stitik TP, et al.,2005)                          | 2PP          | Yes     | injection skills                            | PGME 15,15      |     |
| 27-    | (Banks E, et al.,2006)                            | 2PP          | Yes     | episiotomy repair                           | PGME 12,12      |     |
| 28-    | (Cher RA, et al.,2006)                            | 2PO          | Yes     | Peripheral catheterization                  | PGME 10,10      |     |
| 29-    | (Cohen J, et al.,2006)                            | 2PO          | Yes     | Colonoscopy                                 | PGME 23,22      |     |
| 30-    | (Scherbo MW, et al.,2006)                         | 2PP          | Yes     | intravenous (IV) procedures                 | UGME 12,14      |     |
| 31-    | (Ahlberg G, et al.,2007)                          | 2PP          | Yes     | laparoscopic cholecystectomy                | PGME 7,6        |     |
| 32-    | (Banks EH, et al.,2007)                           | 2PP          | Yes     | laparoscopic tubal ligation                 | PGME 10,10      |     |
| 33-    | (Cosman PH, et al.,2007)                          | 2PO          | Yes     | Laparoscopic skills                         | PGME 5,5        |     |
| 34-    | (Miranda JA, et al.,2007)                         | 2PO          | No      | central venous catheter (CVC) insertion     | PGME 16,38      |     |
| 35-    | (Park J, et al.,2007)                             | 2PP          | Yes     | colonoscopy                                 | PGME 12,12      |     |
| 36-    | (Shavit I, et al.,2007)                           | 2PO          | No      | Procedural sedation                         | PGME 16,16      |     |
| 37-    | (Thomas-Gibson S, et al.,2007)                    | 1PP          | No      | colonoscopy                                 | PGME 21         |     |
| 38-    | (Draycott TJ, et al.,2008)                        | 1PP          | NO      | Shoulder dystocia                           | Both 254        |     |
| 39-    | (Howells NR, et al.,2008)                         | 2PO          | Yes     | arthroscopic skills                         | PGME 10,10      |     |
| 40-    | (Ossowski KL, et al.,2008)                        | 2PO          | Yes     | Laryngoscopy                                | UGME 10,10      |     |
| 41-    | (Van Sickle KR, et al.,2008)                      | 2PP          | Yes     | Laparoscopic skills                         | PGME 11,11      |     |
| 42-    | (Wayne DB, et al.,2008)                           | 2PO          | No      | Advanced Cardiac Life Support               | PGME 38,40      |     |
| 43-    | (Yi SY, et al.,2008)                              | 2PO          | No      | coloscopy                                   | PGME 5,6        |     |
| 44-    | (Barsuk JH, et al.,2009)                          | CO           | No      | central venous catheter (CVC) insertion     | PGME 92,92      |     |
| 45-    | (Barsuk JH, et al.,2009)                          | CO           | No      | central venous catheter (CVC) insertion     | PGME 28,13      |     |
| 46-    | (Barsuk JH, et al.,2009)                          | CO           | No      | central venous catheter (CVC) insertion     | PGME 76,27      |     |
| 47-    | (Britt RC, et al.,2009)                           | 2PO          | Yes     | central venous catheter (CVC) insertion     | PGME 13,21      |     |
| 48-    | (Domuracki KJ, et al.,2009)                       | 2PO          | Yes     | cricoid pressure                            | UGME 53,48      |     |
| 49-    | (Friedman Z, et al.,2009)                         | 2PP          | Yes     | Epidural anesthesia                         | PGME 12,12      |     |
| 50-    | (Gaies MG, et al.,2009)                           | 2PO          | Yes     | BMV, CVC, LP                                | PGME 18,18      |     |
| 51-    | (Hopley NJ, et al.,2009)                          | 2PO          | Yes     | laparoscopic cholecystectomy                | PGME 6,6        |     |
| 52-    | (Hansen CR, et al.,2009)                          | 2PP          | Yes     | laparoscopic skills                         | PGME 11,10      |     |
| 53-    | (Mohan PVR, et al.,2009)                          | 2PP          | Yes     | laparoscopic cholecystectomy                | PGME 12,12      |     |
| 54-    | (Sotto JA, et al.,2009)                           | 2PP          | Yes     | Peripheral venous cannulation               | UGME 20,20      |     |
| 55-    | (Steppacher HR, et al.,2010)                      | 2PP          | Yes     | weaning from bypass                         | PGME 10,10      |     |
| 56-    | (Burger J, et al.,2010)                           | 2PP          | No      | Cardiac auscultation (Physical exam)        | UGME 77,31      |     |
### Appendix S2. Study Characteristics of Included Papers

| Source | Journal | Study Design | Is RCT? | Topics | Trainees | N |
|--------|---------|--------------|---------|--------|----------|---|
| 57- (Evans LV, et al., 2010) | Academic Medicine | 2PO | Yes | central venous catheter (CVC) insertion | PGME | 90,95 |
| 58- (Ferlitsch A, et al., 2010) | Endoscopy | 2PO | Yes | upper gastrointestinal endoscopy insertion | PGME | 14,14 |
| 59- (Fried MP, et al., 2010) | Otolaryngology—head and neck surgery | 2PO | Yes | Endoscopic sinus surgery | PGME | 12,13 |
| 60- (Gauger PG, et al., 2010) | American Journal of Surgery | 2PO | Yes | laparoscopic skills | PGME | 7,7 |
| 61- (Haycock A, et al., 2010) | Gastrointestinal Endoscopy | 2PO | Yes | colonoscopy | Both | 18,18 |
| 62- (Kallstrom R, et al., 2010) | Journal of Endourology | 1PP | No | Transurethral Resection of Prostate | PGME | 24 |
| 63- (Lenchus JD, 2010) | Journal of the American Osteopathic Association | 1PP | No | CVC, LP, paracentesis, thoracentesis | Both | 60 |
| 64- (Schout BM, et al., 2010) | BJU International | 2PO | Yes | cystourethroscopy | UGME | 50,50 |
| 65- (Sloka G, et al., 2010) | American Journal of Surgery | 2PP | Yes | Laparoscopic Cholecystectomy | UGME | 8,8 |
| 66- (Tongrasert F, et al., 2010) | Prenatal Diagnosis | CO | No | Cordocentesis | UGME | 5,5 |
| 67- (Wahidi MM, et al., 2010) | Chest | CO | No | bronchoscopy | PGME | 22,22 |
| 68- (De Ponti R, et al., 2011) | Journal of the American College of Cardiology | 2PO | Yes | transseptal catheterization | PGME | 7,7 |
| 69- (Ghaderi I, et al., 2011) | American Journal of Surgery | 1PP | No | laparoscopic incisional hernia repair (LIHR) | PGME | 14 |
| 70- (Johnson SJ, et al., 2011) | Human Factors | 2PO | Yes | Interventional Radiology procedures | PGME | 7,7 |
| 71- (Khouli H, et al., 2011) | Annals of Surgery | 2PP | Yes | Central venous catheter (CVC) | PGME | 24,23 |
| 72- (Palter VN, et al., 2011) | Annals of Surgery | 2PP | Yes | Abdominal fascial closure | PGME | 9,9 |
| 73- (Zendejas B, et al., 2011) | Annals of Surgery | 2PP | Yes | Laparoscopic inguinal hernia repair | PGME | 26,24 |
| 74- (Ahya SN, et al., 2012) | Seminars in Dialysis | 1PP | No | Hemodialysis catheter insertion | PGME | 12 |
| 75- (Bagai A, et al., 2012) | Circulation Cardiovascular Interventions | 2PP | Yes | Cardiac Catheterization | PGME | 11,15 |
| 76- (Ende A, et al., 2012) | Gastrointestinal Endoscopy | 2PP | Yes | diagnostic upper endoscopy | PGME | 10,9,9 |
| 77- (Franzek FM, et al., 2012) | Surgical Endoscopy | 2PP | Yes | laparoscopic camera navigation | UGME | 12,12 |
| 78- (Fried MP, et al., 2012) | Archives of Otolaryngology—Head & Neck Surgery | 2PP | No | Endoscopic sinus surgery | PGME | 8,6 |
| 79- (Haseo H, et al., 2012) | Simulation in Healthcare | 2PO | Yes | endovascular skills | PGME | 5,5 |
| 80- (Orzech N, et al., 2012) | Annals of Surgery | 2PO | Yes | laparoscopic suturing skills | PGME | 10,10 |
| 81- (Palter VN, et al., 2012) | Annals of Surgery | 2PO | Yes | laparoscopic colorectal surgery | PGME | 9,9 |
| 82- (Sarther DR, et al., 2012) | Respirology | CO | No | Bronchoscopy | PGME | 4,4 |
| 83- (White ML, et al., 2012) | Pediatric Emergency Care | 1PP | No | Lumbar puncture | PGME | 21 |
| 84- (Daly MK, et al., 2013) | Journal of Cataract and Refractive Surgery | 2PO | Yes | Cataract Extraction | PGME | 11,10 |
| 85- (Kalet A, et al., 2013) | Obstetrics and Gynecology | 2PP | Yes | laparoscopic skills | PGME | 48,54 |
| 86- (Palter VN, et al., 2013) | Annals of Surgery | 2PP | Yes | Laparoscopic Cholecystectomy | PGME | 10,10 |
| 87- (Pokroy R, et al., 2013) | Graefes Archive for Clinical and Experimental Ophthalmology | 2PP | No | Cataract surgery | PGME | 10,10 |
| 88- (Todsen T, et al., 2013) | BMC Medical Education | 2PO | Yes | Urethral catheterization | UGME | 17,14 |
| 89- (Balci MBC, et al., 2014) | Nobel Medicus | 2PO | Yes | Laparoscopic Skills | PGME | 8,8 |
| 90- (Bansal RK, et al., 2014) | Journal of Surgical Education | 2PP | Yes | Laparoscopic cholecystectomy | PGME | 9,8 |
| 91- (Cannon WD, et al., 2014) | Journal of Bone and Joint Surgery | 2PP | Yes | Arthroscopic knee surgery | PGME | 6,21 |
| 92- (Edrich T, et al., 2014) | Journal of Cardiothoracic and Vascular Anesthesia | 2PP | Yes | Echocardiography | PGME | 23,23 |
| 93- (Ferrero NA, et al., 2014) | Anesthesiology | 2PP | Yes | Transesophageal Echocardiography | PGME | 21,2 |
| 94- (Hendry P, et al., 2014) | International Journal of Pediatric Otorhinolaryngology | 2PP | Yes | Myringotomy and tympanostomy tube insertion (MT) | UGME | 13,11 |
| 95- (McIntosh KS, et al., 2014) | Canadian Journal of Gastroenterology & Hepatology | 2PP | No | Colonoscopy | PGME | 10,8 |
| Source   | Journal                                                                 | Study Design | Is RCT? | Topics                                                                 | Trainees | N  |
|----------|-------------------------------------------------------------------------|--------------|---------|------------------------------------------------------------------------|----------|----|
| 96-      | (Minai F, et al., 2014) Journal of Anaesthesiology, Clinical Pharmacology | 2PO          | Yes     | intubation                                                             | UGME     | 28,29 |
| 97-      | (Palter VN, et al., 2014) Annals of Surgery                             | 2PP          | Yes     | Laparoscopic Cholecystectomy                                           | PGME     | 8  |
| 98-      | (Udani AD, et al., 2014) Anesthesiology Research and Practice          | 2PP          | Yes     | subarachnoid blocks (SAB)                                              | PGME     | 11,10 |
| 99-      | (Grover SC, et al., 2015) Gastrointestinal Endoscopy                   | 2PP          | Yes     | colonoscopy                                                            | PGME     | 16,17 |
| 100-     | (Koch AD, et al., 2015) Gastrointestinal Endoscopy                      | 2PP          | Yes     | colonoscopy                                                            | PGME     | 8  |
| 101-     | (Felten ID, et al., 2015) Simulation in healthcare                     | 2PP          | Yes     | Central Venous Catheter (CVC) Insertion                               | PGME     | 36,37 |
| 102-     | (Tolsgaard MG, et al., 2015) Medical Education                         | 2PP          | Yes     | Ultrasonography                                                       | UGME     | 16,14 |
| 103-     | (Aloosh M, et al., 2016) Journal of Endourology                        | 1PP          | No      | Ureteroscopy                                                          | PGME     | 5  |
| 104-     | (Arias T, et al., 2016) International Journal of Gynaecology and Obstetrics | 2PO        | Yes     | vaginal examination                                                   | UGME     | 66,21 |
| 105-     | (Asoglu MR, et al., 2016) Journal of the Turkish-German Gynecological Association | CO        | No      | hysterectomy                                                           | PGME     | 75,98 |
| 106-     | (Jaffer U, et al., 2016) Journal of Surgical Education                | 1PP          | No      | Ultrasonography                                                       | UGME     | 24  |
| 107-     | (Thawani JP, et al., 2016) Journal of Clinical Neuroscience           | 2PO          | Yes     | Endoscopy                                                              | PGME     | 3,3 |
| 108-     | (Waterman BR, et al., 2016) Orthopedics                               | 2PP          | Yes     | Diagnostic Shoulder Arthroscopy                                       | PGME     | 12,10 |
| 109-     | (Bloch A, et al., 2017) Anesthesia and Analgesia                      | 2PP          | Yes     | Echocardiography                                                      | PGME     | 22,21 |
| 110-     | (Boza C, et al., 2017) Surgical Endoscopy                             | 2PP          | No      | advanced laparoscopy                                                  | Both     | 10,12,5 |
| 111-     | (Crochet P, et al., 2017) Journal of Surgical Education              | 2PP          | Yes     | Laparoscopic Suturing                                                 | PGME     | 12,6 |
| 112-     | (Dyde L, et al., 2017) Medical Education                              | 2PP          | Yes     | Ultrasonics                                                           | UGME     | 30,26 |
| 113-     | (Lofly M, et al., 2017) Egyptian Journal of Surgery                   | 2PP          | Yes     | laparoscopic appendectomy                                              | PGME     | 15,15 |
| 114-     | (Rosen H, et al., 2017) Journal of Obstetrics and Gynaecology Canada | 2PP          | Yes     | Ultrasonography                                                       | PGME     | 9,9 |
| 115-     | (Tolsgaard MG, et al., 2017) Annals of Surgery                        | 2PO          | Yes     | Ultrasonography                                                       | PGME     | 26,26 |
| 116-     | (Maertens H, et al., 2017) European Journal of Vascular and Endovascular Surgery | 2PP            | Yes     | Endovascular skills                                                  | PGME     | 9,10,10 |
| 117-     | (Kallidaikurichi Srinivasan K, et al., 2018) BMJ open                 | 2PO          | Yes     | Epidural Analgesia                                                   | PGME     | 13,9 |
| 118-     | (Garfjeld Roberts P, et al., 2019) Arthroscopy - journal of arthroscopic and related surgery | 2PP            | Yes     | diagnostic knee arthroscopy                                           | PGME     | 15,13 |
| 119-     | (Ostergaard ML, et al., 2019) European Radiology                      | 2PP          | Yes     | Ultrasonography                                                       | PGME     | 11,9 |
| 120-     | (Popovic B, et al., 2019) American Journal of Cardiology             | 2PO          | Yes     | Cardiac Catheterization                                               | PGME     | 10,10 |
| 121-     | (Wong DT, et al., 2019) European Journal of Anaesthesiology          | 2PP          | Yes     | bronchoscopic-guided intubation                                       | Both     | 16,15 |
Transfer of learning in simulation-based training

Appendix S2: Included papers for the review

1. Ewy GA, Felner JM, Juul D, Mayer JW, Sajid AW, Waugh RA. Test of a cardiology patient simulator with students in fourth-year electives. Journal of Medical Education. 1987;62(9):738-43.
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### Appendix S4. Effective ID factors influencing transfer of learning in SBT (Study ID refers to references listed in appendix)

| ID Features | Study ID |
|-------------|----------|
| Feedback    | Study ID |
| During      | 1,4,5,6,7,8,9,10,11,12,13,14,15,16,18,19,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121 |
| After (with debriefing) | 14,23,24,27,30,31,42,44,52,55,56,60,63,68,73,77,79,99,102,111,115,116,117,119 |
| Instructor | 4,7,8,13,14,15,16,23,24,27,28,31,34,39,41,42,44,45,46,52,55,56,60,63,68,70,72,73,74,76,77,82,83,86,90,91,92,93,95,97,98,99,101,102,106,110,111,115,116,117,120 |
| Feedback Source | Study ID |
| Simulator (force/haptic) | 6,9,10,11,12,13,14,19,21,22,25,28,29,30,35,37,39,41,52,54,55,56,60,62,68,71,72,77,78,80,84,89,91,92,93,95,99,99,100,101,102,107,108,112,115 |
| Simulator (Audio visual) | 1,10,18,23,26,35,41,42,54,55,56,75,78,80,81,84,95,97,99,101,112 |
| Simulator (no type stated) | 4,5,31 |
| Mastery Learning | 33,41,43,44,45,46,56,57,74,98,101 |
| Proficiency based training | 3,4,11,12,13,14,17,19,23,24,25,28,31,33,41,47,48,51,52,54,58,60,62,65,68,72,75,78,79,80,81,84,86,89,91,95,97,98,105,107,108,110,111,115,116,117,119 |
| Deliberate practice | 6,44,45,46,56,63,74,82,97,101,108 |
| Increasing complexity | 5,10,11,15,19,20,21,22,25,28,29,30,33,35,37,41,43,51,53,54,58,64,70 |
| Repeated Practice | 2,4,6,7,9,11,12,13,14,17,19,20,23,24,25,28,29,31,34,41,43,44,45,46,47,48,5 |
| Variability | 1,9,12,15,18,19,21,22,28,29,30,37,42,49,54,55,56,61,62,82,93,95,100,101,103 |
| Distributed Practice | 12,3,5,6,7,9,10,11,12,14,17,18,19,20,21,23,24,25,26,28,29,30,31,33,34,37,39,41,42,43,44,45,46,49,50,51,52,53,54,55,57,58,59,60,61,62,63,64,65,66,67,71,72,73,75,76,77,79,80,81,82,84,85,86,89,90,91,93,95,96,98,99,10,101,105,107,110,111,113,116,117,118,119 |
| Teaching cognitive base | 2,3,8,9,10,11,15,16,19,23,24,25,27,28,29,32,33,34,37,40,42,43,44,44,45,47,49, |
| Demonstration of procedures (Film) | 7,8,9,14,16,18,21,22,23,25,26,30,35,37,40,42,44,46,54,57,58,59,60,63,64,68,69,71,73,76,79,80,81,83,89,90,91,92,93,95,99,101,106,108,110,111,120,121 |
| briefing | 3,19,27,29,30,52,55,69,79,80,81,84,91,94,95,97,98,102,112,115,117,117,120 |
| High Fidelity | 1,4,5,9,10,11,12,13,14,16,18,19,20,21,22,23,24,25,28,29,30,31,33,35,37,42, |
| Low Fidelity | 7,8,15,27,34,38,40,45,46,47,53,67,69,74,73,74,88,94,96,98,101,104,111 |
| Mixed | 41,50,76,86,115 |
| Virtual Reality | 4,5,9,10,11,12,13,14,19,20,21,22,23,25,28,29,30,31,33,35,37,43,49,51,52, |
| Part-task trainer | 7,8,15,18,27,34,38,40,45,46,47,53,67,69,73,74,88,94,96,98,101,104,117 |
| Full body Manikin | 1,16,42,55,67 |
| Box Trainer | 6,65,69,90,113 |
| Mixed | 3,4,50,76,86,105,115,118 |

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### Appendix S5. Demographic information of participants

| Demographic variables | N |
|-----------------------|---|
| Level                 |    |
| Faculty Member        | 9 |
| Medical Student       | 3 |
| Resident              | 5 |
| Age                   |    |
| Min                   | 22|
| Max                   | 54|
| Average               | 37.4|
| Sex                   |    |
| Female                | 7 |
| Male                  | 10|
| Specialty             |    |
| Emergency Medicine    | 4 |
| General Surgery       | 2 |
| Orthopedics           | 2 |
| Obstetrics and Gynecology | 2  |
| Anesthesiology        | 1 |
| Internal Medicine     | 2 |
| Pediatrics            | 1 |
| Medical Students      | 3 |