The 100 most cited articles on healthcare simulation: a bibliometric review

The 100 Most Cited Papers on Healthcare Simulation: A Bibliometric Review

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Abstract

This article provides an overview and synthesis of the 100 most cited healthcare simulation publications to provide insight into the articles that have shaped current knowledge and practice.

Searches of the Scopus and Web of Science databases were conducted in July 2017. Most articles were concerned with medical education and training (86%), and were most often published in surgical journals (33%). Manikins (20%), standardized patients (16%), inanimate part-task trainers (16%), fully simulated environments (17%) and virtual reality part-task trainers (14%) were the most commonly featured types of simulators.

Healthcare simulation research has matured and grown during the preceding decades. There has been a move away from research questions focused on 'does simulation work?' to an assessment of the conditions under which simulation is most effective. It is hoped that providing an overview of highly cited works will help to identify topics for further research.

Introduction

Because the use of simulation has become more established within the delivery of healthcare education and training, the healthcare simulation research literature has experienced corresponding growth[1,2]. A trend in medical and healthcare literature has been to conduct citation analyses in order to identify the most cited works in a particular field[3,4]. To our knowledge, no such works have been conducted pertaining to the use of simulation in healthcare education and research. As such, with the increase in the use of simulation in healthcare education and the growth of healthcare simulation research over the past three to four decades, it seems that this is an appropriate time to take stock, and to examine the nature of those articless that have been cited the most within the field of healthcare simulation.

The number of citations received is often used as a measure of the impact an individual article, author, journal or institution has had on a field of research, with a basic assumption that high numbers of citations are indicative of high levels of impact[5,6]. Therefore, identifying the most cited articles can be useful in identifying "classic" works in a field and highlighting areas for future research[6]. Although a frequently used approach[7], there are a number of limitations to the use of citation analysis which must be taken into account, such as the potential for a risk of bias as a result of older publications having had longer time to accumulate citations, or the way in which the citation practices of individuals can affect citation rates[8]. Nevertheless, when appropriately applied, interpreted and analyzed, citation analysis can be a useful tool to provide some indication of which authors, articles and topics are influencing or motivating research in a field[9,10].

This paper aims to identify the 100 most highly cited articles in healthcare simulation education and research, and to report on the characteristics of these publications. The hope is that this analysis will: (1) provide insight into the history and development of the field of

simulation in healthcare education and research; and (2) provide an overview of research in the area and insight into the papers that have helped shape current knowledge and practice.

Methods

Study design

This paper describes a citation analysis of journal articles in the field of healthcare simulation education and research. The top 100 articles were chosen as this is consistent with other bibliometric reviews in the healthcare fields[3,4,11,12] and offers the reader more information as opposed to reporting just the top 10 or the top 50 papers in a field.

Search strategy and study selection

Searches were conducted in the Scopus and the Web of Science databases (Claruvate Analystics, Philadelphia, PA) in July 2017. Publications pertaining to "simulation-based education" or "simulation-based research" and "health care professionals" were identified. No time limits were imposed on the searches, although searches were limited to the English language due to resource limitations (see table, Supplemental Digital Content 1, for detailed search strategy). In both databases, the retrieved articles were sorted using the sorting option "Times cited – highest to lowest". The outputs from both databases were presented in a descending order, with the higher cited articles at the top of the list, and were exported to two separate Excel spreadsheets for further analysis. Two reviewers (CW & SF) independently applied the inclusion and exclusion criteria to each article within the two lists. The full texts were then screened, independently, until each reviewer had developed a list of 100 eligible articles. Cohen's Kappa indicated high inter-rater reliability (k=.83, Sensitivity=.94, specificity=.82). To resolve any disagreements, the research team would review the paper(s) in question, in detail, together, and discuss the issues at length until consensus was reached.

Eligibility criteria

Studies were eligible for inclusion if they were the following:

a) described the employment of simulation using virtual reality (VR) simulators, standardized or simulated patients (SPs), inanimate part-task trainers, high-fidelity and static manikins, live animals, inert animal products, cadavers and role-plays;
b) included healthcare personnel (e.g., doctors, nurses, health profession students, allied healthcare professionals);
c) were focused on the teaching and/or assessment of clinical or procedural skills, and;
d) were published in an English language, peer-reviewed journal.

Studies were ineligible for inclusion if they were the following:

a) described simulation-based education with individuals other than healthcare professionals or health profession students;
b) had a focus on computational simulation or mathematical modeling;
c) did not have healthcare simulation education or research as a key focus; or
d) featured written clinical vignettes alone. Due to the lack of interactive components, for the purpose of this review, these do not constitute simulation technology[13].

Data extraction

For both databases, data were extracted independently by two reviewers. For Scopus the data were extracted by CW and CM, and for Web of Science the data were extracted by CW and SF. Information was extracted on the following variables: 1) author and publication year; 2) number of citations; 3) country of publication (based on the first author's affiliation at the time of publication); 4) participants/population of focus; 5) type of simulator used; 6) type of targeted skill (i.e., technical or non-technical); 7) subject/discipline, and; 8) article type (e.g., intervention, systematic review). High percentage agreement between the raters

was found for both databases (Scopus percentage agreement=94%; Web of Science percentage agreement=96%; See table, Supplemental Digital Content 2, for data extraction table).

Top 100 list citations

The list of the top 100 cited articles was compiled and ranked according to the outputs from the Scopus database search. Scopus was selected as the primary database as it covers more journals (approximately 21,500 journals)[14] compared to Web of Science (approximately 18,200 journals)[15]. Furthermore, a number of key simulation journals such as Simulation in Healthcare, the Journal of Clinical Simulation in Nursing and the British Medical Journal of Simulation and Technology Enhanced Learning are indexed within Scopus but not Web of Science. In order to obtain the citation counts from Google Scholar and Web of Science, each article from the Scopus list was individually searched for in these other databases and reported alongside the Scopus outputs (see table, Supplemental Digital Content 3 for list of citations for all three databases). Publications with the same number of citations were ranked at the same position.

Self-citations

Using the "exclude self-citations" option in Scopus, the percentage of self-citations within the list of 100 most highly cited papers derived from Scopus was calculated.

Statistical analysis

The Pearson correlation coefficient (r) was calculated to determine whether number of years since publication was correlated with total number of citations among the included papers.

Publication trends

Additional searches using the terms "simulation in healthcare" and "simulation-based medical education" were conducted within Scopus. These searches, and the resultant data, provide a broad overview of the publication trends of papers using these terms.

Results

Study selection. Due to the differences in the outputs from each database, it was impossible to compile a single list of the top-cited papers. The flow diagram for the Scopus screening process is provided in Figure 1. The initial search in Scopus returned 479,216 results, of which the titles and abstracts of the 3,075 highest cited texts were screened against the eligibility criteria. The full texts of 381 articles were then examined until the 100 most cited articles remained. A table of the full list of the top 100 publications according to Scopus, along with the number of citations those articles received in Web of Science and Google Scholar, are provided in Supplemental Digital Content 3 (see table, Supplemental Digital Content 3, list of publications with citations). A full list of the 100 most cited publications returned from the Web of Science search is also provided (see table, Supplemental Digital Content 4, Web of Science list).

Self-citations. Self-citations were found to comprise 5.7% of the total number of citations in the Scopus top 100 list.

Publication trends. Figure 2 provides an overview of publication trends within Scopus under the search terms "healthcare simulation" and "simulation-based medical education". An increase in papers using these terms was observed from 1994 onwards. A substantial growth is evident from 2005 onwards. Figure 2 also indicates key events that have occurred in healthcare simulation in terms of establishing it as a discipline (e.g., founding of international societies and discipline specific journals). Figure 3 shows the publication trends for the articles in the included list between the years 1988-2011. A general increase in the number of publications was observed, which peaked in the years 2004 and 2006.

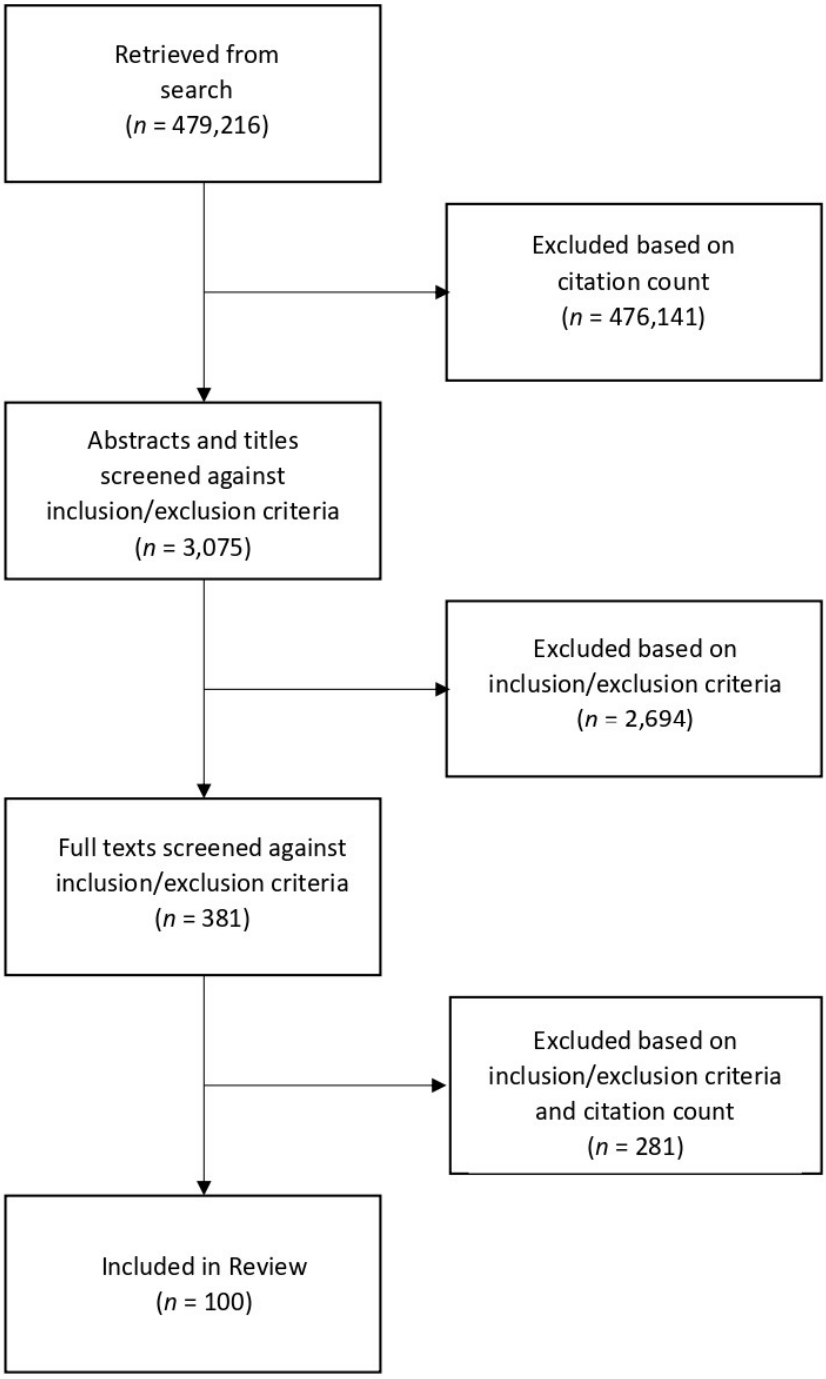

Fig 1. Flow diagram of study selection from outputs retrieved from Scopus.

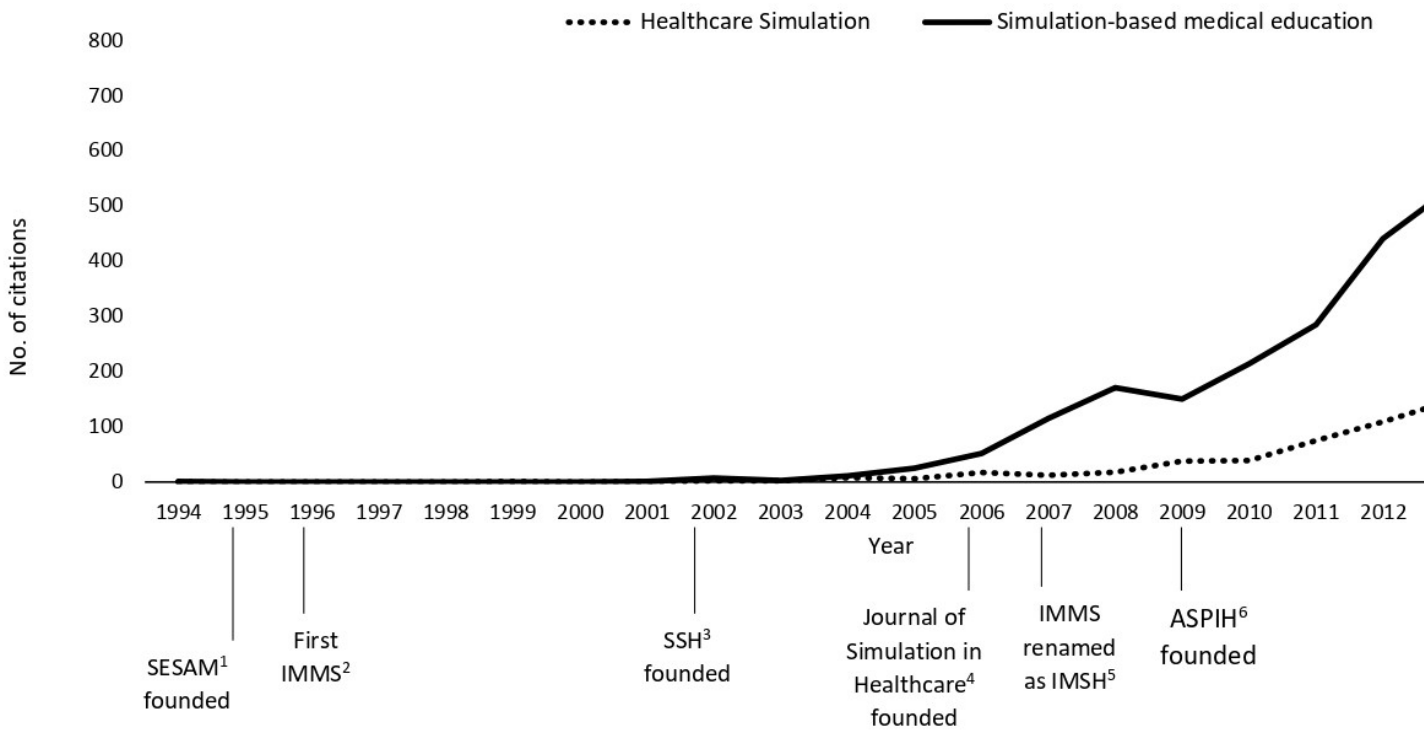

Fig 2. Citations per year coded in Scopus for the terms "healthcare simulation" and "simulation-based medical e
simulation history are also presented. No citations were present for these terms in the years preceding 1994.

[1] Society in Europe for Simulation Applied to Medical Education.
[2] International Meeting on Medical Simulation.
[3] Society for Simulation in Healthcare.
[4] Later in 2006, renamed as the Journal of the Society for Simulation in Healthcare.
[5] International Meeting for Simulation in Healthcare.
[6] Association for Simulated Practice in Healthcare

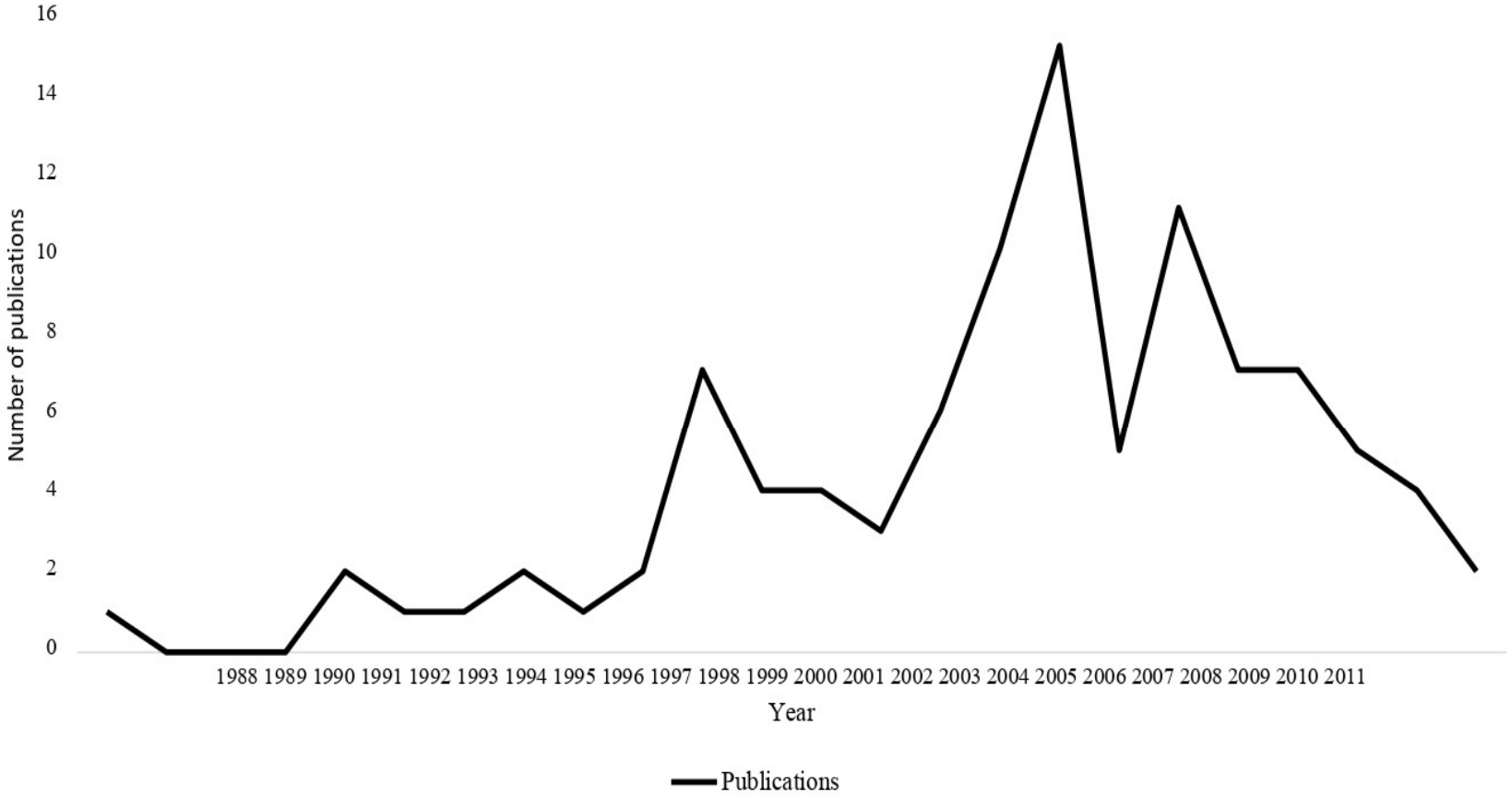

Fig.3. Number of publications per year for the top 100 articles in simulation in healthcare education and research retrieved from Scopus.

TABLE 1. Study characteristics of top 100 published articles.

Study characteristics	Frequency (%)	*M* (no. of citations)	*SD* (no. of citations)	Range (no. of citations)
1. Country of origin				
USA	45	412.4	275.8	1141-186
UK	27	289	97.3	536-188
Canada	16	388.8	246.2	1084-202
Denmark	4	323.5	258.4	711-189
Australia	3	258.7	6.7	263-251
The Netherlands	2	217	35.5	240-194
Sweden	2	242.5	41.7	272-213
Israel	1	-	-	398
2. Focus of paper/type of study*				
Review (non-systematic)	35	378	201.1	1,201-186
Intervention	28	321.5	250.9	1,411-194
Tool evaluation/development	18	359.6	236.1	1,084-199
Systematic review/meta-analysis	7	447.3	404.5	1,342-188
Observational	6	289.8	87	443-220
Performance assessment	5	183	56.3	348-189
User evaluations	2	233	60.8	276-190
Curriculum development	1	-	-	189
Editorial	1	-	-	192
Invited address	1	-	-	1,066
3. Subject/discipline*				
Medical education/training	86	371.9	240.7	1141-186
Surgery	45	352.8	239.1	1,411-186
Laparoscopy/MIS	23	352	266.9	1,411-188
generic	21	352	217.6	1,084-106
endoscopy	1	-	-	287
Crisis/crew resource management	15	277.1	86.6	480-192
Doctor-patient communication	11	304.5	126.2	536-194
Anesthesiology	9	304.4	101.4	480-192
Assessing clinical competence/quality of care	6	585.8	344.4	1,201-211
Nursing education/training	5	263.2	103.9	445-190
Oncology	5	302.2	140.7	536-197
Primary care	4	430.5	192.4	656-211
Team training	4	242.6	39.5	291-100
Critical/emergency care	3	235.3	29.1	256-202
Obstetrics/gynecology/midwifery	2	226.5	44.6	258-295
Healthcare in general	1	-	-	562
Health professions education and training	1	-	-	461
4. Targeted skill				
Technical skills	41	358.8	247.4	1411-188
Both	34	422.2	280	1342-186
Non-technical skills	25	232.9	232	1342-194
5. Type of simulator*				
Various/non-specified	40	414.4	288.1	1,342-186
Manikins	20	274.5	76.9	480-190
Standardized/simulated patient	16	331.7	144.1	656-197
Inanimate part-task trainers/box trainers/bench models	16	320.4	129.1	622-203
Full simulated environment	17	264.5	73.7	480-190
Virtual reality (part-task trainers)	14	367.4	331.9	1,411-188
Live animals/animal parts	4	286.2	75.1	389-213
Role play	3	197	4.2	200-194
Cadaver	1	-	-	338
Computerized clinical vignette	1	-	-	350

*Many papers fit into more than one category and so column does not add to 100%.

Study characteristics. The characteristics of the top-cited articles retrieved from Scopus are shown in Table 1. The most commonly cited papers were published between 1988 and 2011 with a citation range from 1,411 to 186 (*M*=361.55, *SD*=237.27). No significant correlation was found between years since publication and number of citations (*p*=.48; see figure, Supplemental Digital Content 5, which illustrates the Pearson coefficient).

TABLE 1. Study characteristics of top 100 published articles.

Country of publication. As can be seen within Panel 1 of Table 1, almost half of the studies within the 100 most cited articles were published in the United States (45%)[1,13,16-58], with the UK as the next highest contributor (27%)[59-85], followed by Canada (16%)[86-101].

Type of Study. The distribution of the number of publications by type of study is shown in Panel 2 of Table 1. Non-systematic reviews (35%)[1,13. 20,23,24,28,29,31,32,35,37-39,42,44,48,50,51,58,,60,62,64-66,68,69,73,80,82,83,85,87,93,102,103] were the most common type of study within the 100 most cited articles, followed by interventions (28%)[18,25,26,30,36,41,43,45,49,53-55,63,75,-78,81,90,92,95,96,104-108] and studies focusing on tool evaluation/development (18%)[22,34,52,59,61,70,74,76,79,86,88,89,91,94,98-100,109]. Systematic reviews/meta-analyses (7%)[19,27,33,84,110-112], observational studies (6%)[16,46,4771,90,97], papers describing performance assessments (5%)[17,67,99,109,113], user evaluations (2%)[40,57], and curriculum development studies (1%)[113] were less commonly cited. The focus of a small number of papers (5%)[74,76,99,109,113] was deemed to fall across two or more categories.

Subject/Discipline. The breakdown by subject/discipline is presented in Panel 3 of Table 1. Many studies related to several subjects or disciplines and this is reflected in the results. For example, crisis resource management was often studied within anesthesiology[17,30,35,40,49,54,56,59,73,106] or surgical teams[30,53,95]. The majority of studies (86%)[1,13,16,18,-21,23-26,30-33,35-50,53-55,58-60,62-66,68-73,75-77,79-112] had a key focus of medical

education/training, defined as a "discipline covering the education, and the practice of, skills by students enrolled in medical schools/colleges to become doctors; residency training, continuing medical education; and specializing postgraduate training"[114(p.1148)]. Surgery accounted for 45% of papers[18,26,28,30,39,41,53,58,61,62,66-70,74-77,79,84,86-96,98,99,101-105,107-109,111-113]. This was followed by crisis/crew resource management (15%)[17,30,35,37,40,43,49,53,54,56,59,73,80,95,106], doctor-patient communication (11%)[25,36,45,48,55,63,72,81,82,85,97], and anesthesiology (9%)[17,30,35,40,54,56,59,73,106].

Targeted skills. It can be seen from Panel 4, Table 1 that of the 100 most cited papers the majority (41%)[16,18,26,28,39-41,46,47,61,62,63,67,69,70,75-77,84,86-96,98,99,101,130-105,107-109,111-113] were focused primarily on technical skills (i.e., the knowledge, skills, and ability to accomplish a specific medical task, such as suturing or performing a physical examination[115 (p.38)]. Papers focused specifically on non-technical skills (e.g., communication, decision making, history taking skills) were less common (25%)[25,30,36,37,43-45,48,50,51,53-55,59,63,66,72-74, 79-82,85,100]. Finally, 34% [1,1317,19-24,27,29,321-35,38,42,49,52,56-58,60,64,65,68,71,78,83,97,106,106,110] of papers focused on both technical and non-technical skills. For example, in full scale simulations, the focus was often directed at training/assessing communication skills as well as technical ability[78].

Type of simulator. Panel 5 of Table 1 shows the frequency of the different types of simulators used. Most articles (40%) [1,1319-21,23,24,27,29,32-34,38,41,44,50,56,58,62,64-66,68,74-78,80,83,86,87,92,93,95,102,103,107,111,112] discussed, or used, multiple types of simulators. For example, review papers sometimes provided an overview of, or comparisons between, various tools useful for a specific discipline (e.g., various tools available for training and assessment in laparoscopic surgery[69]); the history and development of the field (e.g., the development of simulation for medical education[64]); and future directions[13].

Manikins were the next most commonly used type of simulator (20%)[16,17,30,35,37,40,43,46,47,49,51,54,57,59,71,73,78,79,106,110] They were used to teach a variety of technical and non-technical skills within medical education and training (15% of all articles[16,30,35,37,40,43,46,47,49,54,59,71,73,79,106]; crisis/crew resource management (11% of all articles)[17,30,35,37,40,43,49,54,59,73,106]; anesthesiology (7% of all articles)[17,35,40,54,59,73,106]; nursing (4% of all articles)[51,57,78,110]; emergency medicine (3% of all articles)[43,46,47]; team training (2% of all articles)[37,43]; Surgery (2% of all articles)[30,79]; and obstetrics and gynecology (1% of all articles)[71].

Simulated patients were featured in 16%[22,25,34,36,42,45,48,52,60,72,81,82,85,97,100] of articles in the teaching/assessment of non-technical skills across a number of subject areas/disciplines e.g., medical education (13% of all articles)[25,36,42,45,48,60,63,72,81,82,85,97,100] , doctor-patient communication (10% of all articles)[25,36,45,48,63,72,81,82,85,97], oncology (5% of all articles)[36,63,72,81,82], and primary care (4% of all articles)[22,25,34,52].

Inanimate part-task trainers also featured in 16% of papers[26,41,70,75,76,88-92,94-96,98,99,101], all of which were surgical papers, in particular laparoscopic surgery (10% of all articles)[26,41,75,76,89,90,94,96,99,101].

Fully simulated environments were featured in 17% of articles[17,30,35,37,40,43,49-51,54,57,59,73,78,79,106,110]. These full scale simulations were often used in relation to crisis/crew resource management training (11% of all articles)[17,30,35,37,40,43,49,54,59,73,106] and in nursing (4% of all articles)[51,57,78,110].

Virtual reality (VR) part-task trainers featured in 14% of articles[18,28,39,67,69,75,76,84,104,105,107-109,113]and were used almost entirely in relation to laparoscopic (12% of all articles)[18,67,69,75,76,84,104,105,107-109,113] and minimally invasive surgery (MIS) (1% of all articles[28]. One study compared computerized clinical vignettes to SPs for the assessment of clinical competence[34].

Live animals/inert animal products (4%)[41,61,95,107], role-play (3%)[53,55,82]and cadavers (1%)[92], were less commonly featured as a key mode of simulation.

Journals. The journals which have published the top cited articles are presented in Table 2. Surgical journals have contributed the most articles (32%)[18,26,28,39,41,53,58,66,69,70,75,77,79,84,86,88-90,92-96,99,101,103-105,107,109,111-113] , followed by general medical journals (22%)[20,22-25,27,32,34,36,38,45,46,52,55,60,62,63,67,85,87,97,108] and medical education journals (15%)[1,19,21,33,42,48,64,65,68,74,83,91,98,100,102. Simulation specific journals have contributed 3% of the top cited articles[31,35,44]. Any journals which have contributed less than two articles to the top-cited list are grouped under the category of "Other" in Table 2.

TABLE 2. Journals which have published the highly cited papers in the list retrieved from Scopus.

Journal	Frequency (%)	*M* (no. of citations)	*SD* (no. of citations)	Range (no. of citations)
American Journal of Surgery	9	321.9	136	622-199
Annals of Surgery	8	438.5	408.2	1,141-189
Medical Education	7	304.6	100.1	507-196
Academic Medicine	7	414.9	300.7	1,066-202
JAMA	6	555.2	358.3	1,201-220
British Journal of Surgery	5	488.6	397.1	1,084-188
Surgical Endoscopy and Other Interventional Techniques	5	226.4	34.9	287-203
Quality and Safety in Healthcare	4	311	168.8	562-202
Archives of Internal Medicine	3	352	141.1	505-227
British Journal of Anesthesia	3	319.3	139.3	480-238
British Medical Journal (BMJ)	3	322	116.2	423-195
Journal of the American College of Surgeons	3	334.7	122.4	476-263
The Lancet	3	441.3	115.3	536-313
New England Journal of Medicine	3	581	183	740-381
Anesthesiology	3	272	78.1	348-192
Annals of Internal Medicine	2	272	110.3	350-194
Critical Care Medicine	2	243.5	6.4	248.239
Journal of Advanced Nursing	2	232.5	26.2	251-214
Journal of Nursing Education	2	203	18.4	216-190
Simulation in Healthcare	2	332	111.7	411-253
Other	18	340.1	263.1	1,342-186

The 10 Most Cited Articles

Table 3 presents a summary of the ten most highly cited articles. These articles include: two controlled interventions in which VR task trainers were used to improve laparoscopic surgery skills[18,104]; a systematic review investigating the features and uses of high-fidelity simulation associated with effective learning[19]; and three non-systematic reviews which discussed the use of various simulators in the assessment and training of both technical and non-technical skills[20,23,87]. Two studies evaluated the use of part-task trainers[88] or a combination of part-task trainers and live animals[86] to assess/train technical skills, while one study[22] compared the use of SPs to written clinical vignettes in the assessment of the quality of care provided by physicians. Finally, one of the top-cited articles was an invited address[21] in which the use of simulation is discussed in relation to deliberate practice in medical education/training.

Discussion

The aims of this study were to identify the 100 most cited articles in simulation in healthcare education and research, and to describe the characteristics of these papers. The top-cited papers, according to the Scopus database, were published between 1988 and 2011 and came mainly from the United Sates (45%). Non-systematic reviews (35%) and interventions (28%) were the most common type of publication and 40% of the papers used/discussed multiple simulators. Most articles focused on the education and/or training of medical professionals (86%) across domains but surgery was the most common specialty (45%). Furthermore, technical skills (41%) were more often featured than non-technical skills (25%) and surgery specific journals (33%) have contributed the largest number of highly-cited articles in the current list. The increasing trend of publications relating to healthcare

TABLE 3. The 10 highest-cited publications in healthcare simulation as listed in Scopus.

Rank	Author and year	Scopus citations	Description
1	Seymour et al., 2002[18]	1,141	A prospective randomized trial investigating whether virtual reality training transfers technical skills to the operating room to reduce error risk in laparoscopic surgery.
2	Issenberg, et al., 2005[19]	1,342	A BEME systematic review of 109 articles on the features and uses of high-fidelity medical simulations that lead to effective learning.
3	Epstein & Hundert, 2002[20]	1,201	A non-systematic review in which the authors discuss the assessment of clinical competence, including the use of standardized patients and OSCE examinations in the assessment of physical examination and technical and communication skills.
4	Martin et al., 1997[86]	1,084	Preliminary study to 1) compare the reliability of three scoring systems, 2) compare live animals and bench models and 3) assess the construct validity of the Objective Structured Assessment of Technical Skills (OSATS). Surgical residents' performance was graded using checklists, global rating forms and pass/fail judgements.
5	Ericsson 2004[21]	1,066	An invited address in which Ericsson discusses the use of simulation for deliberate practice in medical education/training.
6	Reznick & McRae, 2006[87]	740	A non-systematic review in which the authors discuss the use of simulation in surgical training.
7	Grantcharov et al., 2004[104]	711	A randomized controlled trial. Surgical trainees were randomised to either receive virtual reality training on the MIST-VR or to receive no training.
8	Peabody et al., 2000[22]	656	A prospective trial compared three methods for measuring quality of care: 1) structured reports by standardised patients, 2) abstraction of medical records and 3) physicians' responses to clinical vignettes.
9	Epstein, 2007[23]	622	A non-systematic review in which Epstein also discusses the various methods of assessment in medical education, including clinical simulations.
9	Reznick et al., 1997[88]	622	An assessment of the reliability and construct validity of the Objective Structured Assessment of Technical Skills (OSATS). 48 general surgery residents completed a 2 hour, 8 station OSATS and were assessed at each via two methods of scoring.

simulation education and research suggests that it has become a widespread and accepted methodology in the education of healthcare professionals.

The specialty of surgery dominated the top 100 most cited papers; more specifically, laparoscopic surgery. It is well recognized that basic laparoscopic skills are well suited to practice on a simulator[58]. This finding may also be partly attributable to the fact that the rise in simulation has occurred concurrently with the growth of minimally invasive surgery. Assessing the acquisition of laparoscopic skills fits well within the 'scientific method' with clear, measurable performance metrics (e.g., time, instrument motion).

The high representation of interventions (28%) in the 100 most cited papers may suggest that there has been a 'burden of proof' to demonstrate that healthcare simulation is an effective training and education tool. In the past decade however, systematic reviews and meta-analyses have been conducted and are attaining high citation counts, despite only being published in recent years[19,27,33,84,110-112]. Such studies are useful for advancing research, directing practice and facilitating decision-making, so the increasing appearance of these types of studies is unsurprising and provides further evidence of the maturation of the field[116-118].

A general increase in the amount of publications per year was observed for the time period covered (1988-2011) by this review, which reflects the growth of the field. Similar findings have been observed elsewhere; in a systematic review spanning 34 years (1969-2003), Issenberg and colleagues[19] also illustrated the rapid increase in journal articles on high-fidelity simulation in medical education with 57% of the included studies published in the latter years of the review (2000-2003). Although there is a subsequent decline in publications after the peak years of 2004/2006, this can be expected as a consequence of the impact of a time of publication bias that exists within citation analyses whereby older publications have had more time to accrue more citations than recent studies[119].

Strengths and limitations

Strengths of the study include: the use of an accepted and frequently used technical method[119,120]; stringent, transparent inclusion and exclusion criteria; a comprehensive systematic search process across two key electronic databases; and the presentation of a novel overview and synthesis within the field.

There were also some limitations that should be noted. First, the search was limited to the English language, and so articles in other languages, which may have global impact, were potentially excluded. Second, the citation counts provided by Scopus, Web of Science and Google Scholar, and the records returned by Scopus and Web of Science, vary considerably, making it impossible to produce a single comprehensive list of the 100 most cited articles. There are various arguments in favor of, and against, both Scopus and Web of Science so it is unlikely that one database is superior to the other[7]. For example, Web of Science's coverage spans as far back as 1900, whereas coverage of articles before 1996 is more limited in Scopus[7,121]. However, Scopus covers more journals[14], including many key simulation journals which Web of Science does not. For this reason, the list of the top 100 articles is based on Scopus. A further limitation is that the methodological rigor of the included studies was not examined. An assessment of study quality would have allowed for the examination of the association between citation count and study quality, and the determination of whether high quality studies receive more citations. This is something that future research may wish to address.

Finally, there are limitations to the assumption that highly cited papers are highly influential. First, different disciplines/domains often have different rates of citations which makes cross comparison difficult. For example, even within the same specialties, different citation rates can be found in different countries[122]. Second, the size and type of specialty also influences citation rates whereby larger fields, with more journals, tend to have higher

citation rates due to the increased opportunity to gather citations[123]. Likewise, there is a risk of bias in relation to the time of publication, whereby older publications have had longer to accumulate citations. Citation practices of individuals can also affect citation rates. For example, formal citations are not always correctly cited and informal citations, such as grey literature or conference presentations do not get routinely cited[114]. Biased citing can also occur due to Halo and Mathew effects or self/in-house citing and can affect overall couts[8,124,125]. However, within our dataset, the rates of self-citations were relatively low (<6%). Finally, there are considerable variations in the items retrieved from different databases, as observed in the present study, and at different time points[126]. It should also be noted that there are alternative methods of conducting bibliometric analyses to the method employed in the current study[127]. For example, impact may be measured based on the mean citations per year or via OVID article views. Nevertheless, citation analysis is a key methodology used across many disciplines[127]; and despite the above mentioned limitations, when applied appropriately, citation analysis can be a useful approach to identify which authors, articles and topics are influencing or motivating research in a field[9,10].

Implications for future research

This review has provided an historical overview of the highly-cited publications within the field of healthcare simulation education and research, as opposed to looking to the future of the field. Nevertheless, based upon our findings, it is possible to provide some thoughts on what we may see as the field of simulation continues to advance. Healthcare simulation research has clearly matured over the last three decades, with the top 10 papers all being published within the last 20 years. There is now sufficient evidence that healthcare simulation is an effective educational intervention when it is used under the right conditions[128]. Therefore, there will be a move away from research questions focused on 'does

healthcare simulation work?' to an assessment of the conditions when simulation is most effective- i.e., 'why, how and with whom does healthcare simulation work?'

We anticipate an increasing number of systematic reviews and meta-analyses within specific areas of healthcare simulation such as those by McGaghie et al.[33] and Sturm et al.[112]. Until recently, there may not have been a sufficient number of journal articles to allow for these types of reviews. However, as the body of research increases, these types of reviews will become more commonplace in the healthcare simulation literature.

It is likely that surgery will continue to be a dominant specialty in the most cited healthcare simulation research, with a growing role for simulation across surgical specialties[28]. Simulation is a potentially effective training and education tool to support the continued growth in minimally invasive surgery, and other new surgical methods (e.g., robot assisted surgery) are also techniques that can be taught and practiced using simulators[129].

With further advances in healthcare simulation technology (e.g., improved haptics) it is also likely that there will be a 'blurring' of the categories of simulators and increases in the use of hybrid simulation (i.e., the combination of two or more simulation modalities in order to create a more realistic experience[115] such as those used by Kneebone et al.[129] and Crofts et al.[130]), and VR simulator technologies such as the MIST-VR for surgical training (e.g., Aggarwal et al.[69]; Grantcharov et al.[109]).

Conclusion

The use of healthcare simulation is no longer an exception, but has become a key component of modern health profession education and training[13,131]. This review has demonstrated that healthcare simulation is a vibrant and growing field of research. As the use of healthcare simulation has become more commonplace in healthcare education, there has been an exponential rise in the number of research articles published, and a corresponding

increase in the outlets that publish this research. Healthcare simulation will always be changing and developing[128]. However, it is hoped that identifying those papers that have had the most influence over the last decades will help inform the healthcare simulation research that will be carried out in the future.

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Ethical approval

Ethical approval was not sought for this manuscript as we were not collecting data from any individuals but reviewing existing research studies.

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130. Crofts JF, Bartlett C, Ellis D, Hunt LP, Fox R, Draycott TJ. Training for shoulder dystocia - A trial of simulation using low-fidelity and high-fidelity mannequins. *Obstet Gynecol* 2006; **108**(6): 1477-85.

131. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. Effect of practice on standardised learning outcomes in simulation-based medical education. *Med Educ* 2006; **40**(8): 792-7.

Supplemental Digital Content 1.

Example Search Strategy for articles pertaining to healthcare simulation education and research, run in Scopus on 03/07/2017. Searches were limited to English language. No time limits were imposed.

	Search strategy in Scopus	Results
1	Title-abs-key (simulat*)	3,630,017
2	Title-abs-key (manikin*)	6,904
3	Title-abs-key (“task trainer”)	220
4	Title-abs-key (“virtual patient”)	1,147
5	Title-abs-key (“virtual reality”)	90,045
6	Title-abs-key (“Standarised patient*”)	2,880
7	Title-abs-key (team*)	380,045
8	Title-abs-key (“problem based learning”)	12,530
9	Title-abs-key (Master*)	165,232
10	Title-abs-key (“Deliberate practice”)	637
11	Title-abs-key (“crisis resource management”)	219
12	Title-abs-key (“crew resource management”)	559
13	Title-abs-key (communicat*)	1,730,497
14	Title-abs-key (“non-technical skill*”)	813
15	Title-abs-key (“technical skill*”)	8,131
16	Title-abs-key (“procedural skill*”)	1,148
17	#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9	4,213,725
18	#10 OR #11 OR #12 OR #14 OR #15 OR #16	1,739171
19	#17 OR #18	5,658,908
20	Title-abs-key (doctor*)	262,641
21	Title-abs-key (Health* W/2 personnel*)	224,179
22	Title-abs-key (“emergency med*”)	81,113
23	Title-abs-key (paramedic*)	25,363
24	Title-abs-key (Nurs*)	777,758
25	Title-abs-key (“operating room technician*”)	671
26	Title-abs-key (physician*)	641,025
27	Title-abs-key (midwi*)	40,682
28	Title-abs-key (anesthe*)	532,964
29	Title-abs-key (hospital*W/2 personnel)	33,767
30	Title-abs-key (“junior doctor*”)	2,854
31	Title-abs-key (“student*”)	867,646
32	Title-abs-key (hospital* W/5 intern*)	10,516
33	Title-abs-key (“general pract*”)	171,769
34	Title-abs-key (hospital*)	1,874,518
35	Title-abs-key (surg* AND NOT storm)	2,814585
36	Title-abs-key (“primary care”)	110,964
37	Title-abs-key (“health* professional*”)	74,937
38	Title-abs-key (“Medical educat*)	226,694
39	Title-abs-key (“medical train*”)	6,566
40	#20 OR #21 OR #22 OR #23 OR #24 OR #25 OR #26	1,688,369
41	#27 OR #28 OR #29 R #30 OR #31 OR #32 OR #33 OR #34	2,598,163
42	#35 OR #36 OR #37 OR #38 OR #39	4,054,568
43	#40 OR #41 OR #42	6,857,255
44	#19 AND #43	479,216

Supplemental Digital Content 2.

Data extraction table for variables extracted from the top 100 articles retrieved from Scopus under search terms relating to healthcare simulation education and research, and healthcare professionals and trainees. Articles with the same number of citations were given the exact same rank.

Rank	Author and year	Total number of citations	Type of paper	Type of simulator	Skill	Clinical topic	Participants/ population	Journal	Country of publication
1	Seymour et al., 2002[18]	1411	Intervention	VR (part-task trainer)	Technical skills	Surgery (laparoscopy); Medical education and training;	Surgical residents (*n*=16)	Annals of Surgery	USA
2	Issenberg et al., 2005[19]	1342	Systematic review	Various	Both	Medical education and training;	Medical trainees and professionals	Medical Teacher	USA
3	Epstein & Hundert, 2002[20]	1201	Review (non-systematic)	Various	Both	Assessing clinical/professional competence; medical education and training;	Medical trainees and professionals	Journal of the American Medical Association (JAMA)	USA
4	Martin et al., 1997[86]	1084	Tool evaluation	Various	Technical skills	Surgery (generic); medical education and training;	Surgical residents, PGY1, 3, 5 (*n*=20)	British Journal of Surgery	Canada
5	Ericsson, 2004[21]	1066	Invited address	Various	Both	Medical education and training;	Medical trainees and professionals	Academic Medicine	USA
6	Reznick & McRae, 2006[87]	740	Review (non-systematic)	Various	Technical skills	Surgery (generic); Medical education and training;	Surgeons and trainees	New England Journal of Medicine	Canada
7	Grantcharov et al., 2004[104]	711	Intervention	VR (part-task trainer)	Technical skills	Surgery (laparoscopy); medical education and training;	16 surgical trainees	British Journal of Surgery	Denmark
8	Peabody et al., 2000[22]	656	Tool evaluation	SPs	Both	Primary care; assessing	20 primary care physicians	JAMA	USA

						clinical/professional competence;			
9	Epstein, 2007[23]	622	Review (non-systematic)	Various	Both	Assessing clinical/professional competence; medical education and training;	Medical trainees and professionals	New England Journal of Medicine	USA
9	Reznick et al., 1997[88]	622	Tool evaluation	Inanimate part-task trainer	Technical skills	Surgery (generic); medical education and training;	48 general surgery residents	American Journal of Surgery	Canada
11	Gaba, 2004[13]	562	Review (non-systematic)	Various	Both	Healthcare in general; medical education and training;	Healthcare trainees and professionals	Quality and Safety in Healthcare	USA
12	Issenberg et al., 1999[24]	543	Review (non-systematic)	Various	Both	Medical education and training;	Medical trainees and professionals.	JAMA	USA
13	Fallowfield et al., 2002[63]	536	Intervention	SPs	Non-technical skills	Doctor-patient communication; Oncology; medical education and training;	160 oncologists.	The Lancet	UK
14	McGaghie et al 2010[1]	507	Review (non-systematic)	Various	Both	Medical education and training;	Medical trainees and professionals	Medical Education	USA
15	Roter et al., 1995[25]	505	Intervention	SPs	Non-technical skills	Medical education and training; primary care; Doctor-patient communication;	Primary care physicians	Archives of Internal Medicine	USA
16	Fried et al., 2004[89]	484	Tool evaluation	Inanimate part-task trainer	Technical skill	Surgery (laparoscopy); Medical education and training;	215 surgeons and trainees.	Annals of Surgery	Canada
17	Fletcher et al., 2003[59]	480	Tool evaluation	Manikin; full simulated environment	Non-technical skills	Anesthesiology; CRM; Medical	50 consultant anesthetists	British Journal of Anesthesia	UK

						education and training;			
18	Scott et al., 2000[26]	476	Intervention	Inanimate part-task trainer	Technical skills	Surgery (laparoscopy); medical education and training;	22 second and third year residents.	Journal of the American College of Surgeons	USA
19	Wass et al., 2001[66]	475	Review (non-systematic)	SPs	Both	Assessing clinical/professional competence; medical education and training;	Medical trainees/students	The Lancet	UK
20	Cook et al, 2011[27]	461	Systematic review and meta-analysis	Various	Both	Health professions education/training;	Health professions trainees	JAMA	USA
21	Gallagher et al., 2005[28]	456	Review (non-systematic)	VR (part-task trainers)	Technical skills	Surgery (MIS); medical education and training;	Surgical trainees	Annals of Surgery	USA
22	Jeffries, 2005[29]	445	Review (non-systematic)	Various	Both	Nursing education and training;	Nursing students	Nursing Education Perspectives	USA
23	Derossis et al., 1998[101]	443	Observational	Inanimate part-task trainers	Technical skills	Surgery (laparoscopy); medical education and training;	N=42; 6 general surgery residents from each of the 5 years (n=30); 6 laparoscopic surgeons; 6, non-laparoscopic, attending surgeons	American Journal of Surgery	Canada
24	Howard et al., 1992[30]	424	Intervention	Manikin; full simulated environment	Non-technical skills	Anesthesiology; CRM; surgery (laparoscopy); medical education and training;	12 anesthesia residents	Aviation, Space and Environmental Science.	USA

25	Maguire & Pitceanthly, 2002[85]	423	Review (non-systematic)	SPs	Non-technical skills	Doctor-patient communication; medical education and training;	Medical professionals	British Medical Journal (BMJ)	UK
26	Regehr et al., 1998[91]	418	Tool evaluation	Inanimate part-task trainers	Technical skills	Surgery (generic); medical education and training;	53 general surgery residents (PGY1-PGY6)	Academic Medicine	Canada
27	Fanning & Gaba, 2007[31]	411	Review (non-systematic)	General/non specified	Both	Medical education and training;	Medical professionals	Simulation in Healthcare	USA
28	Ziv et al., 2003[102]	398	Review (non-systematic)	Various	Both	Surgery (generic); medical education and training;		Academic Medicine	Israel
29	Appleyard et al., 2000[61]	389	Tool evaluation	Live animals	Technical skills	Surgery (endoscopy);	Surgeons	Gastroenterology	UK
30	Cooke et al., 2006[32]	381	Review (non-systematic)	Various	Both	Medical education and training;	Medical professionals.	New England Journal of Medicine	USA
31	McGaghie et al., 2011[33]	364	Meta-analysis	Various	Both	Medical education and training;	Medical trainees	Academic Medicine	USA
32	Peabody et al., 2004[34]	350	Tool evaluation	SPs; computerized clinical vignettes	Both	Primary care; assessing clinical competence/quality of care;	Primary care physicians (*n*=116)	Annals of Internal Medicine	USA
33	Moorthy et al., 2003[62]	348	Review (non-systematic)	Various	Technical skills	Surgery (generic); medical education and training.	Surgical trainees	BMJ	UK
33	Gaba et al., 1998[17]	348	Performance assessment	Manikins; full simulated environment	Both	Anesthesiology; CRM;	Anesthetists	Anesthesiology	USA
35	Gaba et al., 2001[35]	345	Review (non-systematic)	Manikins; Full simulated environment	Both	CRM; Anesthesiology; Medical education and training;	Anesthetists and trainees.	Simulation and Gaming	USA
36	Wayne et al., 2008[16]	343	Observational	Manikin	Technical skills	Medical education/training;	Internal medical residents	Chest	USA

37	Anastakis et al., 1999[92]	338	Intervention	Various	Technical skills	Surgery(generic); Medical education and training;	PGY1 surgical residents (*n*=23)	American Journal of Surgery	Canada
38	Bradley, 2006[64]	327	Review (non-systematic)	Various	Both	Medical education and training;	Medical trainees	Medical Education	UK
39	Maran & Glavin, 2003[65]	326	Review (non-systematic)	Various	Both	Medical education and training;	Medical trainees	Medical Education	UK
40	Back et al., 2007[36]	324	Intervention	SPs	Non-technical skills	Oncology; Doctor-patient communication; medical education and training;	115 medical oncology fellows	Archives of Internal Medicine	USA
41	Yule et al., 2006[66]	322	Review (non-systematic)	Various	Non-technical skills	Surgery (generic); medical education and training;	Trainees or consultant surgeons	Surgery	UK
42	Taffinder et al., 1998[67]	313	Performance assessment	VR (Part-task trainer);	Technical skills	Surgery (laparoscopy);	6 trainee surgeons	The Lancet	UK
43	Vassiliou et al., 2006[94]	303	Tool evaluation	Inanimate part-task trainers	Technical skills	Surgery (Laparoscopy); medical education and training;	General surgery residents PGY1- 5 (*n*=17); attending surgeons (*n*=4)	American Journal of Surgery	Canada
44	Reznick, 1993[93]	296	Review (non-systematic)	Various	Technical skills	Surgery (generic); medical education and training;	Surgeons	American Journal of Surgery	Canada
45	Baker et al., 2006[37]	291	Review (non-systematic)	Manikins; full simulated environment	Non-technical skills	Team training; CRM; medical education and training;	Medical professionals	Health Services Research	USA
46	Okuda et al., 2009[38]	288	Review (non-systematic)	Various	Both	Medical education and training;	Undergraduate and graduate medical trainees	Mount Sinai Journal of Medicine	USA
47	Satava, 1993[39]	287	Review (non-systematic)	VR (part-task trainer)	Technical skills	Surgery (generic); medical education and training;	Surgical residents and trainees	Surgical Endoscopy	USA

48	Kneebone et al., 2003[68]	283	Review (non-systematic)	Various	Both	Surgery (generic); medical education and training;	Healthcare trainees and professionals	Medical Education	UK
49	Gaba & De Anda, 1988[40]	276	User evaluations	Manikin; Full simulated environment	Technical skills	Anesthesiology; CRM; medical education and training;	First and second year residents; medical students (*n*=17)	Anesthesiology	USA
50	Ahlberg et al., 2007[105]	272	Intervention	VR (part-task trainer)	Technical skills	Surgery (laparoscopy); medical education and training;	13 surgical residents	American Journal of Surgery	Sweden
51	Aggarwal et al., 2004[69]	266	Review (non-systematic)	VR (Part-task trainers)	Technical skills	Surgery (laparoscopy); medical education and training;	Surgeons and surgical trainees	British Journal of Surgery	UK
52	Datta et al., 2001[70]	265	Tool evaluation	Inanimate part-task trainers	Technical skills	Surgery (generic); medical education;	Basic surgical trainees (*n*=12); junior specialist registrars (*n*=13); senior specialist registrars (*n*=13); consultants (*n*=13).	Journal of the American College of Surgeons	UK
53	Sutherland et al., 2006[111]	263	Systematic review	Various	Technical skills	Surgery (generic); medical education and training;	Surgeons; surgical trainees/residents; medical students	Annals of Surgery	Australia
53	Korndorffer et al., 2005[41]	263	Intervention	Inert animal products; Inanimate part-task trainer;	Technical skills	Surgery (laparoscopy); Medical education and training;	Surgical residents (PGY1-PGY5; *n*=17)	Journal of the American College of Surgeons	USA

55	Sturm et al., 2008[112]	262	Systematic review	Various	Technical skills	Surgery (generic); Medical education and training;	Surgeons and trainees.	Annals of Surgery	Australia
56	Draycott et al., 2008[71]	258	Observational	Manikins	Both	Medical education and training; Obstetrics/midwifery /gynecology;	Midwifery and obstetric staff	Obstetrics and Gynecology	UK
56	Downing, 2004[42]	258	Review (non-systematic)	SPs	Both	Medical education and training;	Undergraduate medical trainees	Medical Education	USA
58	Shapiro et al., 2004[43]	256	Intervention	Manikins; full simulated environment	Non-technical skills	Emergency medicine; team training; CRM; medical education and training;	Teams of ED physicians and nurses.	Quality and Safety in Healthcare	USA
58	Fallowfield et al., 1998[68]	256	Intervention	SPs	Non-technical skills	Doctor-patient communication; medical education and training; oncology;	Senior oncologists (attendings; *n*=127); senior registrars (*n*=51	Journal of Clinical Oncology	UK
60	Rudolph et al., 2006[44]	253	Review (non-systematic)	Non-specified (simulation in general)	Non-Technical skills	Medical education and training;	Medical professionals and trainees.	Simulation in Healthcare	USA
61	Cant & Cooper., 2010[110]	251	Systematic review	Manikins; Full simulated environments.	Both	Nursing education and training;	Nursing students and registered nurses.	Journal of Advanced Nursing	Australia
62	Yedidia et al., 2003[45]	250	Intervention	SPs	Non-technical skills	Medical education and training; Doctor-patient communication;	Medical students (*n*=293)	JAMA	USA
63	Barsuk et al., 2009[46]	248	Observational	Manikin	Technical skills	Medical education and training; Critical care;	Postgraduate trainees: 2nd & 3rd year internal medicine and emergency medicine (*n*=103)	Critical Care Medicine	USA

64	Duffy et al., 2004[48]	246	Review (non-systematic)	SPs	Non-technical skills	Doctor-patient communication; medical education and training;	Physicians	Academic Medicine	USA
65	Chopra et al., 1994[106]	240	Intervention	Manikin; full simulated environment	Both	Anesthesiology; CRM; medical education and training;	Anesthetists and anesthesiology trainees (*n*=28)	British Journal of Anesthesia	The Netherlands
66	Steadman et al., 2006[49]	239	Intervention	Manikin; full simulated environment	Both	Medical education and training; CRM;	4th year medical students (*n*=31)	Critical Care Medicine	USA
67	Fletcher et al., 2002[73]	238	Review (non-systematic)	Manikins; Full simulated environments.	Non-technical skills	Anesthesiology; medical education and training; CRM;	Anesthetists and anesthetic trainees.	British Journal of Anesthesia	UK
68	Yule et al., 2006[74]	235	Qualitative; Tool evaluation/ development	Various	Non-technical skills	Surgery (generic);	Trainees or consultant surgeons	Medical Education	UK
69	Grober et al., 2004[95]	228	Intervention	Inanimate part-task trainers & live animals	Technical skills	Medical education and training; Surgery (generic); CRM;	Junior Surgical residents (PGY 1 &3; *N*=50)	Annals of Surgery	Canada
70	Barsuk et al., 2009[47]	227	Observational	Manikin	Technical skills	Medical education and training;	Internal and emergency medicine residents (*n*=92)	Archives of Internal Medicine	USA
71	Sroka et al., 2010[96]	224	Intervention	Inanimate part-task trainer	Technical skills	Surgery (laparoscopy); Medical education and training;	Junior surgical residents (*n*=16)	American Journal of Surgery	Canada
71	Beaubien & Baker, 2004[50]	224	Review (non-systematic)	Various	Non-technical skills	Medical education and training; Team training;	Healthcare professionals	Quality and Safety in Healthcare	USA
71	Munz et al., 2004[75]	224	Intervention	VR (part-task trainer); Inanimate part-task trainers	Technical skills	Surgery (Laparoscopy); medical education and training;	Medical students (*n*=24)	Surgical Endoscopy	UK

74	Tamblyn et al., 2007[97]	220	Observational	SPs	Both	Doctor-patient communication; medical education and training	Medical trainees and professionals.	JAMA	Canada
74	Taffinder et al., 1998[76]	220	Tool evaluation; intervention;	VR (part-task trainer); Inanimate part-task trainers;	Technical skills	Surgery (laparoscopy); medical education and training;	Expert (n=10) and novice (*n*=10) surgeons.	Conference proceedings – Studies in Health Technology and Informatics.	UK
76	Lasater, 2007[51]	216	Review (non-systematic)	Manikins; Full simulated environments;	Non-technical skills	Nursing education and training;	Nursing students	Journal of Nursing Education	USA
77	Aggarwal et al., 2007[77]	215	Intervention	Various	Technical skills	Surgery (laparoscopy); medical education and training;	Experienced LC surgeons (*n*=10); Novice LC surgeons (*n*=20)	Annals of Surgery	UK
78	Alinier et al., 2006[78]	214	Intervention	Manikin; Full simulated environment;	Both	Nursing education and training;	Nursing students	Journal of Advanced Nursing	UK
79	Hyltander et al., 2002[107]	213	Intervention	VR (part-task trainer); Inert animal products;	Technical skills	Surgery (laparoscopy); medical education and training;	24 medical students (surgical rotation)	Surgical Endoscopy	Sweden
80	Luck et al., 2000[52]	211	Tool evaluation	SPs	Both	Primary care; assessing clinical competence;	Faculty physicians, 2nd & 3rd year residents (*n*=20)	The American Journal of Medicine.	USA
81	Faulkner et al., 1996[98]	210	Tool evaluation	Inanimate part-task trainers	Technical skills	Surgery (generic); medical education and training;	Surgical residents (3rd & 5th year; *n*=12)	Academic Medicine	Canada
82	Yule et al., 2008[79]	209	Tool evaluation	Manikin; full simulated environment	Non-technical skills	Surgery (generic); medical education and training;	Consultant surgeons (*n*=44)	World Journal of Surgery	UK

83	Fraser et al., 2003[99]	205	Tool evaluation; performance assessment	Inanimate part-task trainer.	Technical skills	Surgery (laparoscopy); Medical education and training;	Medical students and junior surgical residents (*n*=83); Chief senior surgical residents (*n*=82)	Surgical Endoscopy	Canada
84	Derossis et al., 1998[90]	203	Intervention;	Inanimate part-task trainer.	Technical skills	Surgery (laparoscopy); Medical education and training;	Surgical residents (PGY3; *n*=12)	Surgical Endoscopy	Canada
85	Flin & Maran, 2004[80]	202	Review (non-systematic)	Various	Non-technical skills	Emergency medicine; medical education and training; CRM;	Emergency medical staff; anesthetists; surgeons.	Quality and Safety in Healthcare	UK
85	Hodges et al., 1999[100]	202	Tool evaluation	SPs	Non-technical skills	Medical education and training;	Clinical clerks (psychiatry; *n*=14); family practice residents (*n*=14); practicing family physicians (*n*=14).	Academic Medicine	Canada
87	Awad et al., 2005[53]	200	Intervention	Role-play	Non-technical skills	Team training; medical education and training; surgery (generic); CRM;	Operating room teams	American Journal of Surgery	USA
88	Grantcharov et al., 2003[109]	199	Performance assessment; tool evaluation.	VR (part-task trainer);	Technical skills	Surgery (laparoscopy); medical education and training;	Surgeons (*n*=41)	American Journal of Surgery	Denmark
89	Fallowfield et al., 2003[81]	198	Intervention follow up	SPs	Non-technical skills	Doctor-patient communication; Oncology; medical	Oncologists (*n*=74): of whom: consultants	British Journal of Cancer	UK

						education and training;	(*n*=48); Senior SPRs in training (*n*=26);		
90	Parle et al., 1997[82]	197	Review (non-systematic)	SPs; role-play	Non-technical skills	Doctor-patient communication; oncology; medical education and training;	Healthcare professionals	Social Science & Medicine	UK
90	Holzman et al., 1995[54]	197	Intervention	Manikin; full simulated environment	Non-technical skills	Anesthesiology; CRM; medical education and training;	Anesthesiologists (*n*=68); anesthesia nurses (*n*=4)	Journal of Clinical Anesthesia	USA
92	Kneebone et al., 2004[83]	196	Review (non-systematic)	Various	Both	Medical education and training;	Medical trainees and professionals.	Medical Education	UK
93	Larsen et al., 2009[108]	195	Intervention	VR (part-task trainer);	Technical skills	Surgery (laparoscopy); Gynecology and obstetrics; medical education and training;	First and second year registrars specializing in gynecology and obstetrics (*n*=24)	BMJ	Denmark
94	Van Hove et al., 2010[103]	194	Review (non-systematic)	Various	Technical skills	Surgery (generic); medical education and training;	Surgeons; surgical trainees.	British Journal of Surgery	The Netherlands
94	Brown et al.,1999[55]	194	Intervention	Role-play	Non-technical skills	Doctor-patient communication; medical education and training;	Primary care physicians; surgeons; medical subspecialists; nurse practitioners; physician assistants (*n*=69)	Annals of Internal Medicine	USA
96	Gaba, 1992[56]	192	Editorial	Various	Both	Anesthesiology; CRM;	Anesthesiologists	Anesthesiology	USA

97	Feingold et al., 2004[57]	190	User evaluations	Manikin; Full simulated environment.	Both	Nursing education and training;	Nursing students (*n*=65); faculty (*n*=4)	Journal of Nursing Education	USA
98	Aggarwal et al., 2006[113]	189	Curriculum development; performance assessment	VR (part-task trainer)	Technical skills	Surgery (laparoscopy); medical education and training;	Experienced surgeons (*n*=20); novice surgeons (*n*=20)	Annals of Surgery	Denmark
99	Gurusamy et al., 2008[84]	188	Systematic review	VR (part-task trainers)	Technical skills	Surgery (laparoscopy); medical education and training;	Surgical trainees; medical students; surgical residents.	British Journal of Surgery	UK
100	Scott & Dunnington, 2008[56]	186	Review (non-systematic)	Various	Both	Surgery (generic); Medical education and training;	Surgeons/ surgical trainees	Journal of Gastrointestinal Surgery	USA

Supplemental Digital Content 3.

The 100 most cited articles in simulation in healthcare education and research retrieved from, and ranked according to, Scopus. Each listed article was also individually searched for in Web of Science and Google Scholar. The citations received by each article within these two additional databases are provided where applicable.

		Total number of citations		
Rank	**Author and year**	**Scopus**	**Web of Science**	**Google Scholar**
1	Seymour et al., 2002[18]	1,411	1,223	1,994
2	Issenberg et al., 2005[19]	1,342	1,108	2,353
3	Epstein & Hundert, 2002[20]	1,201	999	2,664
4	Martin et al., 1997[86]	1,084	1,003	1,460
5	Ericsson, 2004[21]	1,066	833	1,683
6	Reznick & McRae, 2006[76]	740	660	1,089
7	Grantcharov et al., 2004[104]	711	611	998
8	Peabody et al., 2000[22]	656	621	874
9	Epstein, 2007[23]	622	0	1,302
9	Reznick et al., 1997[88]	622	543	827
11	Gaba, 2004[13]	562	279	1,237
12	Issenberg et al., 1999[24]	543	444	847
13	Fallowfield et al., 2002[63]	536	443	789
14	McGaghie et al 2010[1]	507	380	968
15	Roter et al., 1995[25]	505	460	771
16	Fried et al., 2004[89]	484	443	678
17	Fletcher et al., 2003[59]	480	389	698
18	Scott et al., 2000[26]	476	Not listed	604
19	Wass et al., 2001[66]	475	383	905
20	Cook et al, 2011[27]	461	410	768
21	Gallagher et al., 2005[28]	456	412	657
22	Jeffries, 2005[29]	445	Not listed	1,101

23	Derossis et al., 1998[101]	443	383	627
24	Howard et al., 1992[30]	424	307	690
25	Maguire & Pitceanthly, 2002[85]	423	314	835
26	Regehr et al., 1998[91]	418	376	599
27	Fanning & Gaba, 2007[31]	411	Not listed	839
28	Ziv et al., 2003[102]	398	326	844
29	Appleyard et al., 2000[61]	389	290	562
30	Cooke et al., 2006[32]	381	333	801
31	McGaghie et al., 2011[33]	364	327	589
32	Peabody et al., 2004[34]	350	324	496
33	Moorthy et al., 2003[62]	348	304	517
33	Gaba et al., 1998[17]	348	275	497
35	Gaba et al., 2001[35]	345	Not listed	591
36	Wayne et al., 2008[16]	343	291	553
37	Anastakis et al., 1999[92]	338	304	420
38	Bradley, 2006[64]	327	262	764
39	Maran & Glavin, 2003[65]	326	229	649
40	Back et al., 2007[36]	324	295	503
41	Yule et al., 2006[66]	322	263	486
42	Taffinder et al., 1998[67]	313	268	409
43	Vassiliou et al., 2006[94]	303	288	432
44	Reznick, 1993[93]	296	303	471
45	Baker et al., 2006[37]	291	228	665
46	Okuda et al., 2009[38]	288	247	599
47	Satava, 1993[39]	287	3	184
48	Kneebone et al., 2003[68]	283	229	501
49	Gaba & De Anda, 1988[40]	276	228	509
50	Ahlberg et al., 2007[105]	272	266	396

51	Aggarwal et al., 2004[69]	266	242	422
52	Datta et al., 2001[70]	265	227	349
53	Sutherland et al., 2006[111]	263	227	379
53	Korndorffer et al., 2005[41]	263	239	361
55	Sturm et al., 2008[112]	262	249	375
56	Draycott et al., 2008[71]	258	208	391
56	Downing, 2004[42]	258	228	500
58	Shapiro et al., 2004[43]	256	Not listed	402
58	Fallowfield et al., 1998[68]	256	222	374
60	Rudolph et al., 2006[44]	253	Not listed	457
61	Cant & Cooper., 2010[110]	251	178	645
62	Yedidia et al., 2003[45]	250	210	493
63	Barsuk et al., 2009[46]	248	222	374
63	Duffy et al., 2004[48]	246	222	445
64	Chopra et al., 1994[106]	240	188	339
66	Steadman et al., 2006[49]	239	180	426
67	Fletcher et al., 2002[73]	238	190	342
68	Yule et al., 2006[74]	235	200	318
68	Grober et al., 2004[95]	228	214	308
70	Barsuk et al., 2009$_{47}$	227	196	382
71	Sroka et al., 2010[96]	224	211	312
71	Beaubien & Baker, 2004[50]	224	98	451
71	Munz et al., 2004[75]	224	203	316
74	Tamblyn et al., 2007[97]	220	200	364
74	Taffinder et al., 1998[76]	220	188	297
76	Lasater, 2007[51]	216	148	591
77	Aggarwal et al., 2007[77]	215	205	295
78	Alinier et al., 2006[78]	214	157	532

79	Hyltander et al., 2002[107]	213	184	301
80	Luck et al., 2000[52]	211	191	283
81	Faulkner et al., 1996[98]	210	196	265
82	Yule et al., 2008[79]	209	173	279
83	Fraser et al., 2003[99]	205	191	264
84	Derossis et al., 1998[90]	203	180	278
85	Flin & Maran, 2004[80]	202	89	365
85	Hodges et al., 1999[100]	202	178	305
87	Awad et al., 2005[53]	200	150	315
88	Grantcharov et al., 2003[109]	199	169	286
89	Fallowfield et al., 2003[81]	198	164	306
90	Parle et al., 1997[82]	197	168	291
90	Holzman et al., 1995[54]	197	138	299
92	Kneebone et al., 2004[83]	196	334	155
93	Larsen et al., 2009[108]	195	191	339
94	Van Hove et al., 2010[103]	194	174	283
94	Brown et al.,1999[55]	194	159	299
96	Gaba et al., 1992[56]	192	151	300
97	Feingold et al., 2004[57]	190	111	441
98	Aggarwal et al., 2006[113]	189	177	278
99	Gurusamy et al., 2008[84]	188	176	288
100	Scott & Dunnington, 2008[56]	186	177	223

Supplemental Digital Content 4.

A list of the top 100 cited articles, and their associated numbers of citations, relating to simulation in healthcare education and research and healthcare professionals, retrieved from ISI Web of Science on 03/07/17. Articles with the same number of citations were given the exact same rank.

Rank	Author and year	Total no. of citations
1	Seymour NE, Gallagher AG, Roman SA, O'Brien MK, Bansal VK, Andersen DK, Satava RM. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Ann Surg* 2002 Oct;236(4):458.	1188
2	Issenberg SB, Mcgaghie WC, Petrusa ER, Lee Gordon D, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach* 2005 Jan 1;27(1):10-28.	1022
3	Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative "bench station" examination. *Am J Surg* 1997 Mar 1;173(3):226-30.	982
4	Epstein RM, Hundert EM. Defining and assessing professional competence. Jama. 2002 Jan 9;287(2):226-35.	958
5	Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med* 2004 Oct 1;79(10):S70-81.	796
6	Reznick RK, MacRae H. Teaching surgical skills—changes in the wind. *New Engl J Med* 2006 Dec 21;355(25):2664-9.	635
7	Peabody JW, Luck J, Glassman P, Dresselhaus TR, Lee M. Comparison of vignettes, standardized patients, and chart abstraction: a prospective validation study of 3 methods for measuring quality. *JAMA*. 2000 Apr 5;283(13):1715-22.	605
8	Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J, Funch-Jensen P. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *Brit J Surg* 2004 Feb 1;91(2):146-50.	591
9	Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative "bench station" examination. *Am J Surg* 1997 Mar 1;173(3):226-30.	537
10	Epstein RM. Assessment in medical education. *New Engl J Med.* 2007 Jan 25;356(4):387-96.	474
11	Roter DL, Hall JA, Kern DE, Barker LR, Cole KA, Roca RP. Improving physicians' interviewing skills and reducing patients' emotional distress: a randomized clinical trial. *Arch Iintern Med* 1995 Sep 25;155(17):1877-84.	455
12	Issenberg SB, McGaghie WC, Hart IR, Mayer JW, Felner JM, Petrusa ER, Waugh RA, Brown DD, Safford RR, Gessner IH, Gordon DL. Simulation technology for health care professional skills training and assessment. *JAMA* 1999 Sep 1;282(9):861-6.	430

13	Fallowfield L, Jenkins V, Farewell V, Saul J, Duffy A, Eves R. Efficacy of a Cancer Research UK communication skills training model for oncologists: a randomised controlled trial. *Lancet* 2002 Feb 23;359(9307):650-6.	429
14	Fried GM, Feldman LS, Vassiliou MC, Fraser SA, Stanbridge D, Ghitulescu G, Andrew CG. Proving the value of simulation in laparoscopic surgery. *Ann Surg* 2004 Sep;240(3):518.	421
15	Scott DJ, Bergen PC, Rege RV, Laycock R, Tesfay ST, Valentine RJ, Euhus DM, Jeyarajah DR, Thompson WM, Jones DB. Laparoscopic training on bench models: better and more cost effective than operating room experience?.*J Am Coll Surgeons* 2000 Sep 30;191(3):272-83.	412
16	Gallagher AG, Ritter EM, Champion H, Higgins G, Fried MP, Moses G, Smith CD, Satava RM. Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. *Ann Surg*. 2005 Feb;241(2):364.	393
17	Van Der Vleuten CP, Schuwirth LW. Assessing professional competence: from methods to programmes. *Med Educ* 2005 Mar 1;39(3):309-17.	380
18	Cook DA, Hamstra SJ, Brydges R, Zendejas B, Szostek JH, Wang AT, Erwin PJ, Hatala R. Comparative effectiveness of instructional design features in simulation-based education: systematic review and meta-analysis. *Med Teach* 2013 Jan 1;35(1):e867-98.	374
19	Derossis AM, Fried GM, Abrahamowicz M, Sigman HH, Barkun JS, Meakins JL. Development of a model for training and evaluation of laparoscopic skills. *Am J Surg* 1998 Jun 30;175(6):482-7.	371
20	Wass V, Van der Vleuten C, Shatzer J, Jones R. Assessment of clinical competence. *Lancet* 2001 Mar 24;357(9260):945-9.	369
21	Fletcher G, Flin R, McGeorge P, Glavin R, Maran N, Patey R. Anaesthetists' Non- Technical Skills (ANTS): evaluation of a behavioural marker system. *Brit J Anaesth* 2003 May 1;90(5):580-8.	364
22	Regehr, G., MacRae, H. , Reznick, R. K., Szalay, D. Comparing the psychometric properties of checklists and global rating scales for assessing performance on an OSCE-format examination. *Acad Med 1*998 Sep;73(9):993-997.	362
23	McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. *Med Educ* 2010 Jan 1;44(1):50-63.	351
24	Barrows HS. An overview of the uses of standardized patients for teaching and evaluating clinical skills. AAMC. *Acad Med* 1993 Jun 1;68(6):443-51.	341
25	Peabody JW, Luck J, Glassman P, Jain S, Hansen J, Spell M, Lee M. Measuring the quality of physician practice by using clinical vignettes: a prospective validation study. *Ann Intern Med* 2004 Nov 16;141(10):771-80.	315
26	McGaghie WC, Issenberg SB, Cohen ME, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. Academic medicine: *J Assoc Am Med Coll* 2011 Jun;86(6):706.	305
26	Ziv A, Wolpe PR, Small SD, Glick S. Simulation-based medical education: an ethical imperative. *Acad Med* 2003 Aug 1;78(8):783-8.	305

28	Moorthy K, Munz Y, Sarker SK, Darzi A. Objective assessment of technical skills in surgery. *BMJ* 2003 Nov 1;327(7422):1032.	298
28	Howard SK, Gaba DM, Fish KJ, Yang G, Sarnquist FH. Anesthesia crisis resource management training: teaching anesthesiologists to handle critical incidents. *Aviat Space Envir Med* 1992 Sep;63(9):763-70.	298
30	Anastakis DJ, Regehr G, Reznick RK, Cusimano M, Murnaghan J, Brown M, Hutchison C. Assessment of technical skills transfer from the bench training model to the human model. *Am J Surg* 1999 Feb 28;177(2):167-70.	297
31	Reznick RK. Teaching and testing technical skills. *Am J Surg* 1993 Mar 1;165(3):358-61.	296
32	Vassiliou MC, Feldman LS, Andrew CG, Bergman S, Leffondré K, Stanbridge D, Fried GM. A global assessment tool for evaluation of intraoperative laparoscopic skills. *Am J Surg* 2005 Jul 31;190(1):107-13.	281
33	Wayne DB, Didwania A, Feinglass J, Fudala MJ, Barsuk JH, McGaghie WC. Simulation-based education improves quality of care during cardiac arrest team responses at an academic teaching hospital: a case-control study. *Chest* Journal. 2008 Jan 1;133(1):56-61.	278
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36	Taffinder NJ, McManus IC, Gul Y, Russell RC, Darzi A. Effect of sleep deprivation on surgeons' dexterity on laparoscopy simulator. *Lancet* 1998 Oct 10;352(9135):1191.	262
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41	Bradley P. The history of simulation in medical education and possible future directions. *Med Educ* 2006 Mar 1;40(3):254-62.	243

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Supplentary Digital Content 5.
Pearson's correlation between years since publication and number of citations of the 100 top-cited articles in simulation in healthcare education and research as listed in Scopus. These 100 articles and their citation counts were retrieved via searches conducted in Scopus on 03/07/17.