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The Evolution of Simulation-Based Learning Across the Disciplines, 1965–2018: A Science Map of the Literature

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Abstract

Background. **Simulation-based learning** (SBL) has been applied and studied in educational settings for at least six decades. While numerous reviews of research have been conducted from different perspectives, none to date have used bibliometric methods to analyze the evolution of simulation-based learning as a 'knowledge base'.

Aim. The review sought to document the **growth and geographic distribution of research** on SBL. In addition, the review aimed to identify **key authors and documents**, and analyze the **intellectual structure** of this knowledge base. Finally, the review highlighted emerging topics in this literature.

Method. The authors identified 2,812 Scopus-indexed SBL documents published between 1965 and 2018. Bibliographic data were exported from Scopus and analyzed using VOSviewer software. Analyses included descriptive statistics, citation and co-citation analysis, and keyword co-occurrence analysis.

Results. The review found a rapidly increasing publication trajectory with 90% of the literature published since 2000. Although SBL studies have been authored in 94 different countries, the literature is concentrated in **Anglo-American-European** societies. The review found that the intellectual structure of this knowledge base is comprised of four **schools of thought** encompassing research on SBL in management education, medical education, technology-enhanced SBL, and learning theories in SBL. Another notable finding was that SBL researchers in medical and management education have progressed on parallel tracks leading to the balkanization on knowledge. Surprisingly, the conceptual core of the field

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is located in the school of thought associated with learning theories in SBL. This implies that SBL is a subfield of education rather than a discipline in and of itself. Emerging topics that have attracted scholars writing on SBL in recent years are identified and implications for future research discussed.

Keywords
Simulation-based learning, game-based learning, computer simulations, experiential learning, bibliometric review

The modern history of published research on simulation-based learning (SBL) reaches back over a period of at least six decades (Faria, 2001; Gosen & Washbush, 2004; Vogel et al., 2006). Proponents have asserted that SBL is a more effective and engaging way of teaching students how to apply theoretical concepts to real-world situations than traditional teaching methods such as lecture and discussion (Faria, 2001; Keys & Wolfe, 1990; Wolfe, 1976, 1994). Faria (2001) noted, for example, that seven out of nine studies on SBL reported that students who participated in SBL activities scored higher on common exams and felt they learned more than students in traditional lecture settings. Reviews of research further support the conclusion that SBL produces positive results on a range of cognitive learning outcomes and offers more engaging and relevant prepararation for the workplace (Anderson & Lawton, 2009; Asiri et al., 2017; Issenberg et al., 2005; McGaghie et al., 2011; Salas et al., 2009; Sitzmann, 2011).

As conceptual and empirical research on SBL has accumulated over time, numerous scholars have undertaken systematic reviews of research focusing on the use of simulation-based learning in a range of different subject domains. For example, reviews of research have been conducted on the use of SBL in K–12 education (D'Angelo et al., 2014; Hew & Cheung, 2010; Merchant et al., 2014), business and management education (Anderson & Lawton, 2009; Faria, 2001; Gosen & Washbush, 2004; Keys, 1976; Keys & Wolfe, 1990; Salas et al., 2009; Vogel et al., 2006; Zantow et al., 2005), engineering education (Deshpande & Huang, 2011; Koh et al., 2010), healthcare education (Cant & Cooper, 2010; Issenberg et al., 1999; McGaghie et al., 2010; Ziv et al., 2003), and general higher education (Lean et al., 2006; Weller, 2004). Research reviews have also been conducted on particular lines of inquiry within SBL. These include reviews on the role of goal-setting (Seijts et al., 2004), debriefing of simulation activities (Cheng et al., 2014; Crookall, 2010; Fanning & Gaba, 2007), use of multimedia applications (Cheng et al., 2014; Hew & Cheung, 2010; Merchant et al., 2014; Sitzmann, 2011; Vogel et al., 2006), and the impact of SBL on various learning outcomes (Anderson & Lawton, 2009; Boyle et al., 2016; de Jong & van Joolingen, 1998; Gosen & Washbush, 2004; Issenberg et al., 2005; McGaghie et al., 2011; Sitzmann, 2011).

Yet, despite the wide range of reviews of research on SBL, to date no scholars have reviewed the knowledge base on SBL from the perspective of 'science mapping' (Zupic & Čater, 2015). 'Science mapping' uses bibliometric analysis to document and analyze features of the literature that shape knowledge production (Hallinger & Kovačević, 2019). This review used science mapping to examine the evolution of the knowledge base on simulation-based learning from 1965 to 2018. Our review was guided by the following research questions (RQs):

RQ1: What are the size, growth trajectory, and geographic distribution of the literature on simulation-based learning?
RQ2: What authors and documents have had the greatest impact in shaping scholarly discourse on simulation-based learning ?
RQ3: What is the intellectual structure of the knowledge base on simulation-based learning?
RQ4: What have been the most frequently studied topics related to simulation-based learning?

In this systematic review, we conducted bibliometric analyses of 2,812 Scopus-indexed documents published between 1965 and 2018. Descriptive statistics, citation analysis, co-citation analysis, visualization of similarities, and keyword co-occurrence analysis were used to document trends in knowledge production as well as to reveal the intellectual structure of the literature on simulation-based learning. The review, which spans all disciplines in which SBL has been used, aims to provide a comprehensive analysis of how simulation-based learning has evolved as a field of study.

Conceptual Background on Simulation-Based Learning

Teachers have used 'simulations' in one form or another for centuries (Faria, 1987; Wolfe, 1994). However, formal research on simulation-based learning emerged during the 1960s out of an older descriptive literature on 'business games' (McKenney & Dill, 1966; Philippatos & Moscato, 1969; Raia, 1966; Schild, 1966). Over time, educators began to transform these games into 'simulations' that incorporated more and more life-like features mirroring the 'work context' in which learners apply their knowledge (Faria, 2001; Keys & Wolfe, 1990). The instructional design and application of interactive games and simulations are predicated on the value of 'learning from experience' (Feinstein et al., 2002; Gosen & Washbush, 2004; Kolb, 1984; Wolfe & Crookall, 1998).

Simulations and games offer learners an opportunity for learners to make decisions aimed at solving highly contextualized, work-related challenges in a safe environment (Faria, 2001; Garris et al., 2002; Salas et al., 2009; Wolfe, 1994). Learners receive feedback on simulated decisions made in response to a changing situation. This enables students to 'experience' and 'see' results of their decisions, and to reflect on the pros and cons of their choices (Kiili, 2007; Lovelace et al., 2016; Penfold, 2009; Wolfe, 1994). Instructor debriefing, a critical dimension of SBL, fosters further reflection on choices and consequences, thereby enhancing transfer of learning to other settings (Cheng et al., 2014; Crookall, 2010; Fanning & Gaba, 2007; Neill & Wotton, 2011; Salas et al., 2009). This experiential learning process increases learner motivation and retention by providing a challenging, life-like, and meaningful context for learning (Garris et al., 2002; Lainema, 2009; Lu et al., 2014; Wolfe, 1994).

Beginning during the 1980s and continuing to the present, the evolution of simulation-based learning has been faciliated by the emergence of new technologies (Faria, 2001; Faria et al., 2009; Issenberg et al., 1999; Mayer, 2010). Computer-based simulations and games enabled educators to exploit the interactive and computational capabilities offered by desktop computers (de Jong & van Joolingen, 1998; Faria, 2001; Hallinger & McCary, 1991; Issenberg et al., 1999; Leutner, 1993). These capabilities enhanced the power of simulations by offering learners opportunities to model different decision sequences and 'see' patterns in the varying consequences (Lu et al., 2014; Mayer, 2010; Vogel et al., 2006).

As the world-wide web developed greater bandwidth during the 2000s, desktop computer simulations evolved into 'online web-based simulations'. Web-based simulations offer wider, 'anytime' access for learners, the ability to link simulations to external content on the worldwide web, and enhanced data collection capabilities for researchers (Kiili, 2005; Lovelace et al., 2016; Penfold, 2009; Showanasai et al., 2013; Squire & Klopfer, 2007; Sterman, 2014). Increased bandwidth and the continued evolution of learning technologies over the past decade have resulted in the design of simulations that leverage vitual reality and immersive learning environments (Dalgarno & Lee, 2010; Hew & Cheung, 2010; Koh et al., 2010; Merchant et al., 2014). These technologies offer enhanced capabilities for modeling the 'real world' in which learners confront and solve simulated problems (Dede, 2009; Dunleavy et al., 2009).

Findings from empirical research suggest that SBL creates an engaging and stimulating learning environment that challenges learners to consider how knowledge can be applied in different domains (e.g., Cant & Cooper, 2010; Dede, 2009; Faria, 2001; Keys & Wolfe, 1990; Lu et al., 2014; Salas et al., 2009). However, several areas of concern have also emerged from critical reviews of the use of simulations in educational settings (Faria et al., 2009; Gosen & Washbush, 2004; McGaghie et al., 2010). For instance, Feinstein and colleagues (2002) noted a frustrating ambiguity with the terminology used in this literature. Specifically, terms such as simulations, games, and role-play are often used inconsistently, interchangeably, and without clear conceptual definitions. According to Crookall and Saunders (1989), simulations provide real-world contexts in which learners develop strategies and make decisions aimed at solving a problem. In contrast, games do not necessarily represent real world systems, though they may also involve some form of strategy. Role-play is a broader category of learning activity that, again, does not necessarily incorporate a complex representation of a real situation. This distinction was used to inform the definition of terms for the current review (Crookall & Saunders, 1989).

Method

Zupic and Čater (2015) noted that the consolidation of past research models, methods, and findings represents an important function for reviews of research. The 'science mapping' method used in this review analyzes 'bibliographic meta-data' associated with a large corpus of documents. This approach to research review offers an empirical means of documenting trends in knowledge production (e.g., size, growth, geographic distribution), analyzing the scholarly impact of authors, documents, and journals, and illuminating the intellectual structure of a knowledge base (van Eck & Waltman, 2014; White & McCain, 1998). As the name implies, science mapping has been applied across numerous fields of study including natural sciences, social science, engineering, management, and education (Hallinger & Kovačević, 2019; Zupic & Čater, 2015).

Identification of Sources

Science mapping reviews typically generate the review database from document repositories such as Scopus or the Web of Science (WOS). In this review, we selected Scopus rather than the Web of Science as the document source due to its superior coverage of social science, management, and education-related publications (Hallinger & Kovačević, 2019; Mongeon & Paul-Hus, 2016). Our search criteria sought to gain a broad, deep, long-term perspective on the use of 'simulation-based learning' in education and training programs. With this in mind, we conducted an 'open-ended search' with respect to the date of publication. Similarly, in order to gain access to as many relevant Scopus-indexed documents as possible, we included conference papers, book chapters, books, and journal articles. In terms of topical criteria, we neither limited research on SBL to a particular discipline (e.g., medicine, management, engineering), nor did we employ a narrow definition. In this review, a 'simulation' could consist of a 'serious game' managed by an instructor (e.g., an extended role play or board game), or a computer simulation. Simulations designed to be used as modeling tools were, however, excluded.

We employed the PRISMA framework (Figure 1) to organize our search (Moher et al., 2009). The initial Scopus search used the terms 'experiential learning' OR 'problem-based learning' OR 'work-based learning' AND "simulation" in order to capture approaches to learning that have been closely associated with simulations. In the end, however, documents associated with these related approaches were only included if they also also focused on simulations (e.g., Steadman et al., 2006). The initial database search yielded 2,746 records (see Figure 1).

Past experience had shown that the Scopus search engine often excludes potentially relevant documents. Therefore, the researchers conducted supplementary searches in Google Scholar. Documents identified in the Google Scholar search were then checked for inclusion in Scopus. These supplementary searches yielded an additional 1,138 Scopus-indexed documents. When added to the existing list, it brought the total to 3,884 documents.

In the next step, the authors reviewed all 3,884 document titles and abstracts for 'topical relevance'. Three criteria were used to assess eligibility at this stage. The simulation or game described in a document had to: 1) incorporate a reasonably high level of complexity, 2) incorporate important features of a real-life context, and 3) offer participants an experience that demanded significant decision-making. Application of these criteria and the deletion of duplicate documents led to the exclusion of 1,072 records (see Figure 1). This left a total of 2,812 documents for bibliometric analysis.

Data Extraction and Analysis

Bibliographic data associated with these Scopus documents were exported as a MS Excel file. These meta-data included author affiliation, article title, keywords, abstracts, and citation data. In order to analyze the composition, growth, and geographical distribution of the SBL knowledge base, we used Scopus analytical tools, MS Excel, and Tableau (Tableau, 2003-2019) software. Citation, co-citation, co-word, and network visualization analyses were conducted with VOSviewer (2009–2018) software (van Eck & Waltman, 2014).

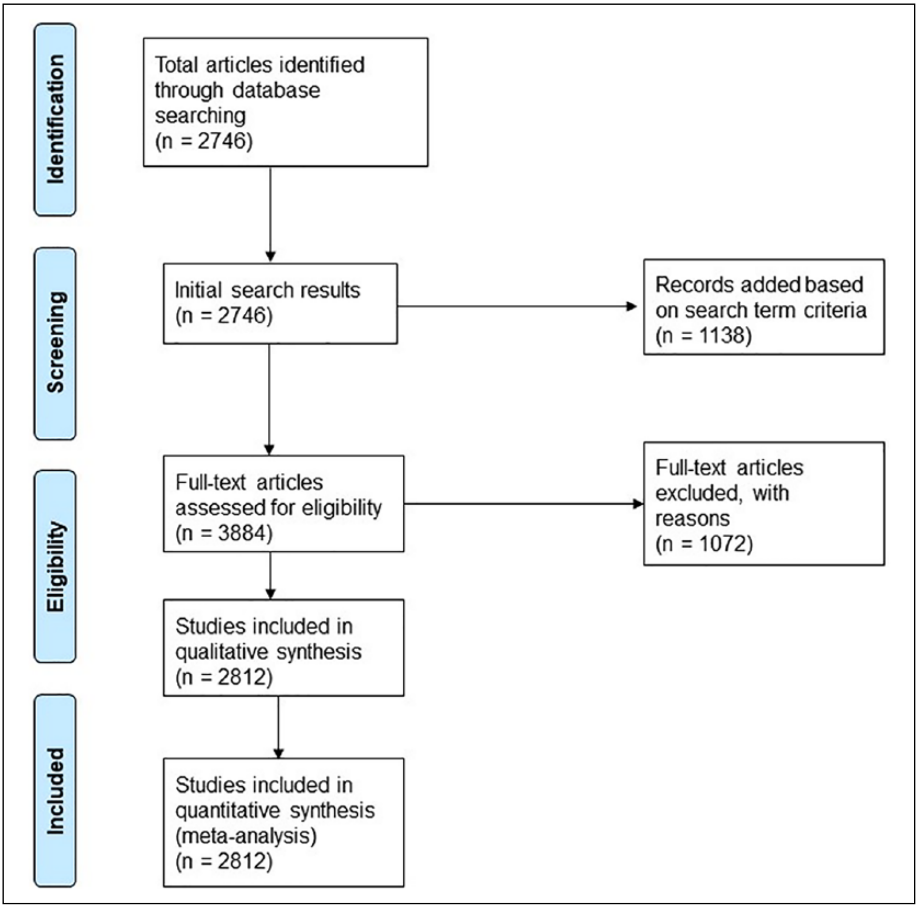

Figure 1. PRISMA diagram of source identification procedures used in this review of simulation-based learning (Moher et al., 2009).

This review employed citation analysis to identify influential authors and documents in the SBL literature (Zupic & Čater, 2015). When conducting citation analysis, VOSviewer identifies the number of times that documents (or authors) in the review database (e.g., our 2,812 documents) had been cited by other Scopus documents. The study also conducted 'co-citation analysis' of key documents and authors. Two publications are co-cited if there is a third publication that cites both publications in its reference list (Small, 1973). Van Eck and Waltman (2014) stated that, "The larger the number of publications by which two publications are co-cited, the stronger the co-citation relation between the two publications" (p. 286). Co-citation analysis has been used as the basis for social network analysis that visualizes simiarities among authors in a field of study (Small, 1973; White & McCain, 1998). In this review, VOSviewer software was used to create visual representations or 'network maps' based on author co-citation analysis. Author co-citation maps have been used to uncover the intellectual structure or research traditions that comprise a knowledge base (Hallinger & Kovačević, 2019; White & McCain, 1998; Zupic & Čater, 2015).

For the final research question, we employed keyword co-occurrence analysis or 'co-word analysis' to analyze the topical composition of the SBL knowledge base. Co-word analysis "calculates the number of publications in which two keywords occur together (i.e., co-occur) in the titles, abstracts, and author keyword lists of documents included in the review database" (van Eck & Waltman, 2014, p. 287). Temporal co-word analysis extended the basic co-word analysis by identifying the topics of most recent interest in the SBL literature (van Eck & Waltman, 2014; Zupic & Čater, 2015).

Results

The key findings are presented in the order of the research questions outlined at the beginning of the paper.

Size, Growth Trajectory and Geographic Distribution of the SBL Literature

The 2,812 Scopus-indexed SBL documents represent a considerably larger database than had been identified in prior reviews of SBL research (e.g., Anderson & Lawton, 2009; Boyle et al., 2016; Connolly et al., 2012). The Scopus-indexed SBL literature consisted of 1,652 journal articles, 1,010 conference papers, 134 book chapters, and 16 books. The journals publishing SBL scholarship spanned education, management, engineering, medicine, nursing, social science, law, computer science, tourism, sciences, and geography (not tabled). The subject breakdown shown in Figure 2 affirms the multi-disciplinary nature of this knowledge base. The Scopus-indexed documents in our database included papers from both academic (e.g., chemistry, geography) and professional fields (e.g., nursing, management, medicine, engineering).

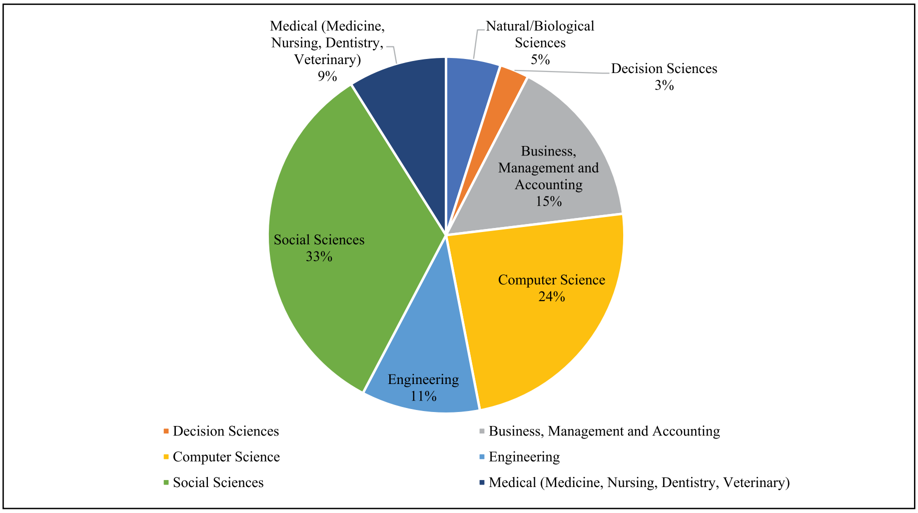

Figure 2. Subject area breakdown of the simulation-based learning literature, 1965–2018 (n = 2,812).

Figure 3 offers insight into the growth trajectory of the SBL literature since 1965 when the first relevant, Scopus-indexed document was published. While the publication history of 'educational games' has been traced back over a full century (Faria, 1987, 2001; Faria et al., 2009), analysis of our database suggests that scholarly interest in SBL grew slowly from the mid-1960s (McKenney & Dill, 1966; Philippatos & Moscato, 1969; Schild, 1966) until the 1990s when the annual rate of publication began to rise (Crookall & Saunders, 1989; de Jong & van Joolingen, 1998; Faria, 1987; Keys, 1976; Keys & Wolfe, 1990; Wolfe, 1976, 1994). The publication of research papers on SBL grew still more rapidly from 2000 to 2018, with 84.5% of the literature published since 2000 and 63.5% since 2010.

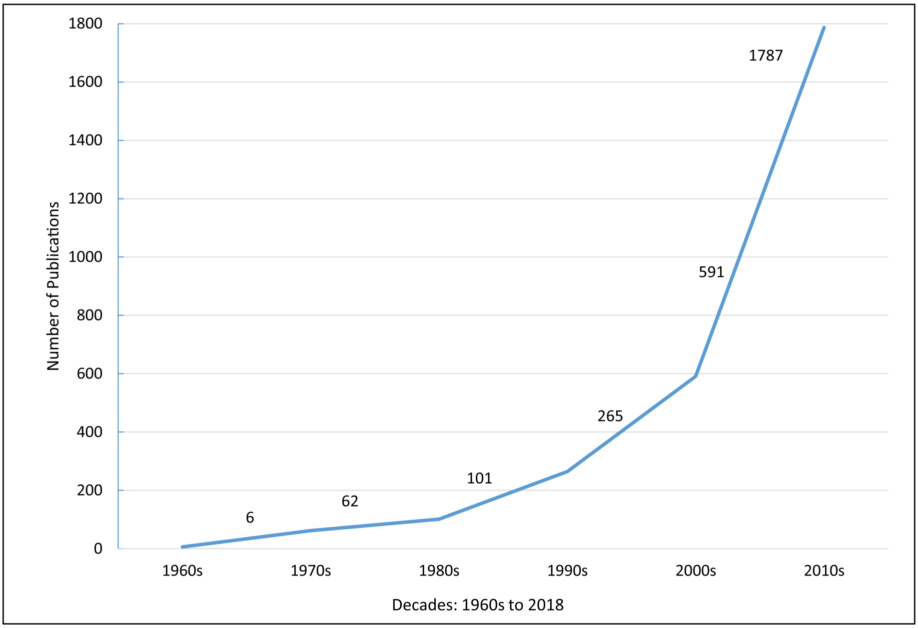

Figure 3. Growth trajectory of the literature in simulation-based learning, 1965–2018 (n = 2,812).

Although interest in simulation-based learning is global in scope (see Figure 4), publications are dominated by authors located in Anglo-American-European societies. Authors publishing on SBL are located predominately in the United States (918 documents), United Kingdom (252), Netherlands (191), Germany (161), Canada (141), and Australia (132). Published research on SBL authored in Africa, Latin America, and Asia accounts for only 17% of the full corpus (not tabled). Nnetheless, we do note that scholars from Taiwan (70 papers), Japan (61), Israel (46), South Korea (39), Brazil (38), and Singapore (36) have contributed actively to the SBL knowledge base.

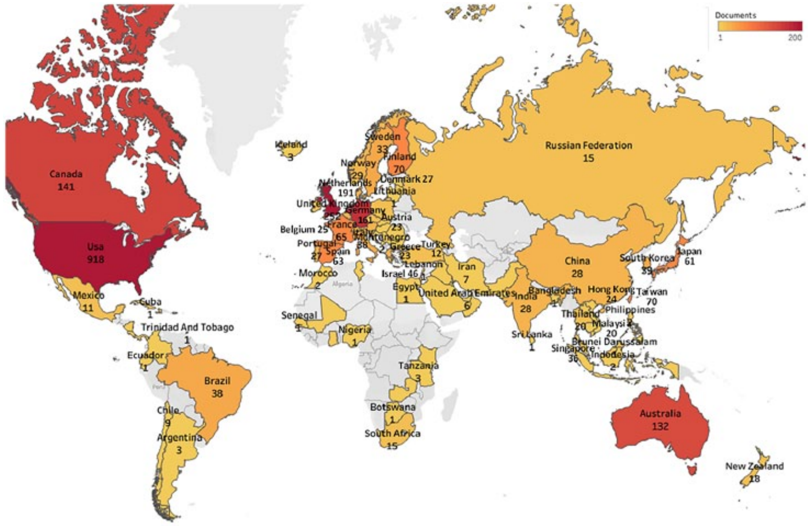

Figure 4. Geographic distribution of Scopus-indexed publications on simulation-based learning, 1965–2018, with map of Europe (n = 2,812).

Key Authors and Documents in the SBL Literature

The SBL literature features 31 scholars with 10 or more Scopus-indexed publications. The most productive authors publishing on SBL are Issenberg (51 publications), McGaghie (38), Wolf (37), de Jong (31), Crookall (29), Lainema (24), Mayer (21), and Verbraek (20). As indicated in Table 1, the most active SBL scholars are affiliated with medical and management education.

The most influential SBL scholars come from a group of American medical education researchers who collaborated on a series of high impact reviews of research (e.g., Issenberg et al., 1999, 2005; McGaghie et al., 2010, 2011). Other key scholars conducting research in other domains of SBL include van Joolingen, Wolfe, Faria, Salas, de Freitas, Crookall, Lainema, and Keys. It should be noted that due to differences in index size, Scopus tends to yield lower citation counts than Google Scholar, but larger than the Web of Science. Since the citations counted in Table 1 only refer to these authors' Scopus-indexed publications on SBL, we conclude that the citation totals are extremely high for the education literature (see Hallinger & Kovačević, 2019).

Document citation analysis complemented these trends surfaced by author citation analysis. Again, the citation impact of these SBL documents is very impressive for a niche field of educational research (see Table 2). Documents from medical education (e.g., Gaba, 2004; Issenberg et al., 1999, 2005; McGaghie et al., 2010) again accumulated the most Scopus citations. Technology-enhanced SBL displaced management education for second place in this table (e.g., Dalgarno & Lee, 2010; de Jong & van Joolingen, 1998; Dunleavy et al., 2009; Sitzmann, 2011). The distribution of papers by type (i.e., 10 conceptual, seven reviews, three empirical papers) suggests that this is a reasonably mature field of inquiry. Theory-informed empirical studies have led to the accumulation of knowledge which has been consolidated in periodic reviews of research (e.g., Cant & Cooper, 2010; de Jong & van Joolingen, 1998; Gaba et al., 2001; Issenberg et al., 1999, 2005; McGaghie et al., 2010; Sitzmann, 2011).

Table 1. Most Highly-Cited Authors With at Least Five Scopus-Indexed Publications on Simulation-Based Learning, 1965–2018 (n = 2,812).

Rank	Author	SBL[1] Focus	Documents	Scopus Citations	CPD[2]
1	McGaghie, W.	Medical Education	38	5382	142
2	Issenberg, S.	Medical Education	51	5132	101
3	Petrusa, E.	Medical Education	12	3308	276
4	Scalese, R.	Medical Education	12	3004	250
5	Gordon, D.	Medical Education	10	2507	251
6	de Jong, T	Medical Education	31	2112	68
7	Gaba, D.	Medical Education	13	2053	158
8	Wayne, D.	Medical Education	18	1880	104
9	Barsuk, J.	Medical Education	13	1468	113
10	van Joolingen W.	Science Education	16	1334	83
11	Wolfe, J.	Management Education	37	1013	28
12	Feinglass, J.	Medical Education	7	882	126
13	Cohen, E.	Medical Education	11	794	72
14	Faria, A.	Management Education	19	714	38
15	Salas, E.	Multi-domain	11	656	60
16	de Freitas, S.	Simulations and Games	6	509	85
17	Crookall, D.	Management Education	29	489	17
18	Lainema, T.	Management Education	24	390	16
19	Dieckmann, P.	Medical Education	10	388	39
20	Keys, B.	Management Education	9	353	39

[1]SBL=simulation-based learning [2]CPD = Citations Per Document.

Issenberg and colleagues' (2005) review of research on how simulations contribute to student learning is the top-cited paper in the SBL knowledge base (see Table 2). Garris et al.'s (2002) conceptual paper on student motivation and learning through the use of games was the next most influential document in our SBL database. More broadly, the substantive foci of these highly cited papers cover an interesting range of topics. Nine of the papers focused explicitly on assessing the 'effectiveness' of SBL (e.g., Cant & Cooper, 2010; de Freitas & Oliver, 2006; Gaba et al., 2001; Issenberg et al., 2005; Kozlowski et al., 2001; McGaghie et al., 2011; Sitzmann, 2011; Steadman et al., 2006; Wayne et al., 2008). Several examined core elements of the simulation-based learning process such as goal-setting (Kozlowski et al., 2001), debriefing (Fanning & Gaba, 2007), motivational strategies (Garris et al., 2002), and context enhancements through technology (Dalgarno & Lee, 2010; Dunleavy et al., 2009).

Table 2. Most Highly Cited Documents in the Literature on Simulation-Based Learning By Scopus Citations, 1965–2018 (n = 2,812).

Rank	Document	Type[1]	Focus	Scopus Citations
1	Issenberg et al. (2005). Features and uses of high-fidelity medical simulations that lead to effective learning.	Rev	SBL-Medical Education	1,653
2	Garris et al. (2002). Games, motivation, and learning: A research and practice model.	Con	SBL Theory	1,407
3	de Jong & van Joolingen (1998). Scientific discovery learning with computer simulations of conceptual domains.	Rev	Technology-enhanced SBL	751
4	Gaba (2004). The future vision of simulation in health care.	Con	SBL-Medical Education	723
5	McGaghie et al. (2010). A critical review of simulation-based medical education research: 2003–2009.	Rev	SBL-Medical Education	695
6	Issenberg et al. (1999). Simulation technology for health care professional skills training and assessment.	Con	SBL-Medical Education	611
7	Fanning & Gaba (2007). The role of debriefing in simulation-based learning.	Con	SBL-Medical Education	611
8	McGaghie et al. (2011). Does simulation-based medical education with deliberate practice yield better results than traditional clinical education?	Rev	SBL-Medical Education	573
9	Dalgarno & Lee (2010). What are the learning affordances of 3-D virtual environments?	Con	Technology-enhanced SBL	536
10	Ziv et al. (2003). Simulation-based medical education: An ethical imperative.	Con	SBL-Medical Education	526
11	Wayne et al. (2008). Simulation-based education improves quality of care during cardiac arrest team responses at an academic teaching hospital.	Emp	SBL-Medical Education	402
12	Dede (2009). Immersive interfaces for engagement and learning.	Con	SBL Theory	413
13	de Freitas & Oliver (2006). How can learning with games and simulations be evaluated?	Con	SBL Theory	397
14	Gaba et al. (2001). Simulation-based training in anesthesia crisis resource management (ACRM).	Rev	SBL-Medical Education	393
15	Cant & Cooper (2010). Simulation-based learning in nurse education: Systematic review.	Rev	SBL-Medical Education	378
16	Dunleavy et al. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning.	Con	Technology-enhanced SBL	375
17	Kanawattanachai & Yoo (2007). The impact of knowledge coordination on virtual team performance over time.	Emp	SBL-Management Education	333
18	Sitzmann (2011). A meta-analytic examination of the effectiveness of computer simulation games.	Rev	Technology-enhanced SBL	290
19	Steadman et al. (2006). Simulation-based training is superior to PBL for the acquisition of skills.	Con	SBL-Medical Education	278
20	Kozlowski et al. (2001). Effects of training goals and goal orientation traits on multidimensional training outcomes and performance adaptability.	Emp	SBL Theory	271

[1]Con=conceptual; Emp=empirical; Rev=review of research
SBL=simulation-based learning

Intellectual Structure of the SBL Literature

Our third research question centered on identifying the ‘intellectual structure’ or key research traditions underlying the SBL knowledge base (White & McCain, 1998; Zupic & Čater, 2015). Author co-citation analysis conducted in VOSviewer identified 71,555 discrete authors in the reference lists of our review documents. Using a threshold of 60 author co-citations, VOSviewer yielded an author co-citation map that displays the 138 most highly ‘co-cited authors’ in the SBL literature (Figure 5).

On a co-citation map, the node size reflects the relative frequency of author co-citations. ‘Links’ identify ‘co-cited scholars’. The proximity of authors on the map suggests their frequency of co-citation by other scholars and, therefore, their degree of intellectual affinity. Colored clusters highlight ‘schools of thought’ comprised of scholars who share common theoretical perspectives or lines of inquiry. The author co-citation map derived from our SBL database revealed four coherent, inter-connected clusters of scholars (see Figure 5).

The large red cluster comprised of 69 scholars reflects a school of thought representing *Learning Theories in SBL* (see Figure 5). Notably, this is the only school of thought that includes authors who have not published papers on simulation-based learning (e.g., Bandura, Bransford, Brown, Collins, Csikszentmihalyi, Lave, Senge, Simon, Vygotsky, Wenger). Their inclusion on the map is due to their frequent ‘co-citation with scholars writing on SBL’ in the reference lists of our review documents.

These scholars, predominantly psychologists, are responsible for developing the theories of human and organizational learning and decision-making that have provided the conceptual underpinnings for simulation-based learning (Bandura, 1971; Brown et al., 1989; Lave & Wenger, 1991; Simon, 1983). Indeed, the most highly ‘co-cited scholar in the SBL literature is David Kolb whose theory of experiential learning has influenced many of the scholars doing research on simulation-based learning. Also contained in this school are ‘co-cited scholars’ who have explicitly applied these learning theories to the examination and evaluation of of simulation-based learning (de Freitas & Oliver, 2006; Merchant et al., 2014; Prensky, 2001; Shin et al., 2003; Vogel et al., 2006).

We classified the yellow cluster as the school of *Technology-Enhanced SBL*. The 15 authors in this cluster have published research on games and simulations that exploit the capabilities of learning technology (e.g., Cannon-Bowers & Bowers, 2009; de Jong & van Joolingen, 1998; Mayer, 2002, 2010; Salas et al., 1998; Vogel et al., 2006). While scholars associated with the application of learning technologies to SBL are not limited to this school, these authors are among the pioneers in this domain. Although this is the smallest of the four schools of thought, it includes several highly co-cited authors (Salas, 442 co-citations, de Jong, 389; Mayer, 174; van Joolingen, 171; Cannon-Bowers, 157; Sweller, 157; Kozlowski, 94) with numerous links to the other schools. This suggests its enduring influence on this field.

This school also includes Eduardo Salas who features as the key ‘boundary spanning author’ in the SBL literature. Boundary spanning authors connect and integrate

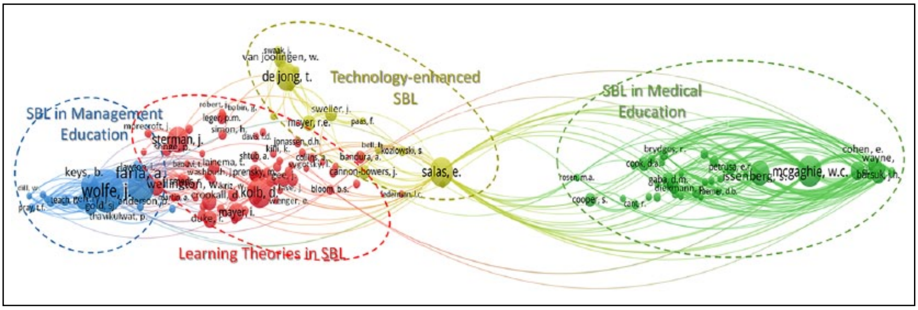

Figure 5. Author co-citation map of the SBL knowledge base with 71,555 authors in the citation network, threshold 60 author co-citations, 131 authors (map generated in VOSviewer software with permission from van Eck & Waltman, 2009–2018).

ideas across different schools of thought (White & McCain, 1998). Salas' role is indicated by his central position on the map, high frequency of co-citation, and numerous links to scholars in all four schools of thought. Notably, Salas has authored key documents on the use of SBL (including technology-enhanced simulations) in management (Salas et al., 2009), aviation (Salas et al., 1998), medical (Rosen et al., 2008; Salas & Burke, 2002) and general education (Wilson et al., 2009).

The blue cluster is comprised of 17 scholars noted for their research on *SBL in Management Education.* This school encompasses management education and training in the business, education, and government sectors. Key scholars include Wolfe (715 co-citations), Faria (511), Keys (280), Anderson (185), Gold (173), Thavikulwat (171), Lawton (145), and Gentry (104). These scholars have examined the challenges of designing and evaluating SBL (Feinstein et al., 2002; Gentry & McGinnis, 2007), paying particular attention to documenting the effects of SBL on management learners (Adobor & Daneshfar, 2006; Gosen & Washbush, 2004; Lu et al., 2014; Wolfe, 2014). It should be noted that scholars in this school have also focused on technology-enhanced SBL (e.g., Anderson & Lawton, 2009; Gold, 2014; Keys et al., 1996; Lean et al., 2006; Showanasai et al., 2013; Wolfe, 2014). Nonetheless, co-citation identified their scholarly 'home' in the management school.

The green cluster, comprised of 37 scholars, is associated with *SBL in Medical Education*. Here we use the term 'medical education' to include all domains of healthcare education. Key scholars in this school include McGaghie (472 co-citations), Issenberg (342), Gaba (264), Cooper (224), Wayne (233), Barsuk (214), Cohen (203), Cook (158), Petrusa (155), Diekmann (122), and Brydges (116). This school is highly empirical with more extensive use of experimental and quasi-experimental research designs than, for example, the management school (Cant & Cooper, 2009; Fanning & Gaba, 2007; Kneebone, 2005; Steadman et al., 2006; Ziv et al., 2003). Authors located in this school have also been responsible for highly cited meta-analytic reviews aimed at documenting the effects of SBL on learners (Issenberg et al., 2005; McGaghie et al., 2011).

Examination of the author co-citation analysis map from a broader perspective reveals additional insights. The size and centrality of the Learning Theories in SBL school, as well as its numerous 'links' to the other three schools identify it as the 'conceptual anchor' for the SBL knowledge base. The location of the management (blue cluster) and medical (green cluster) education schools on opposite sides of map as well as the paucity of links between their respective scholars suggest a balkanization of knowledge accumulation in this literature.

Topical Foci in the Simulation-Based Learning Literature

Our last research question inquired into the topics that have attracted the interest of scholars studying SBL. We began by analyzing the frequency of keywords appearing in the titles, abstracts and keywords of the 2,812 review documents. After discounting "simulation-based learning", our main search term, the most frequently studied topics in the literature were teaching and learning (529), simulations and games (490), serious games (381), students (335), computer simulation (331), business simulations (199), decision-making (186), curricula (166), experiential learning (160), e-learning (154), software design (151), clinical competence (142), engineering education (141), learning systems (141), medical education (138), nursing education (126), and computer-assisted instruction (123). The results of this co-word analysis reinforce foci identified in the author co-citation analysis, with the additional benefit of being grounded in actual 'content' of the papers.

Next, we generated a 'temporal co-word map' (see Figure 6) which distinguishes keywords based on their time distribution of occurrence (van Eck & Waltman, 2014; Zupic & Čater, 2015). The 'hot topics' in this literature (i.e., yellow and bright green nodes) are concentrated in the region of the map associated with medical education. Two emerging themes in the medical education literature are *SBL skills training* (e.g., clinical competence, skills, surgical training, patient safety and care, standards, simulation training) and *SBL research* (e.g., controlled study, experiment, questionnaire, procedures, clinical study, randomized controlled trial).

A second set of emerging topics are located on the left side of the map where the topics tend to be associated with management education. One theme highlights the use of *multi-media and game-based learning in SBL* (e.g., game-based learning, computer games, educational computing). A second emerging theme centers on *SBL and sustainability* (e.g., sustainability, water management, risk management, climate change). This suggests that educators view simulation-based learning as a high impact approach for learning how to learn about the complex, systemic challenges associated with social and environmental sustainability (Gatti et al., 2019; Klopfer & Squire, 2008; Sterman, 2014).

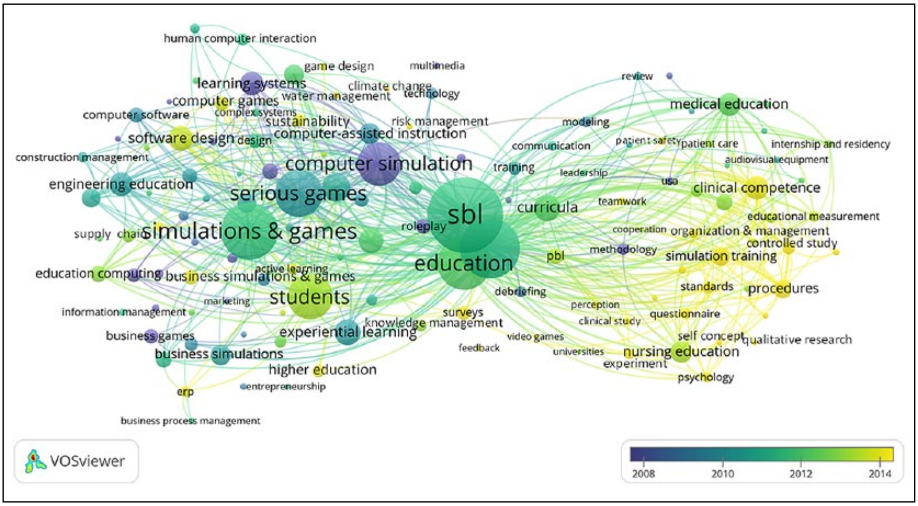

Figure 6. Temporal keyword co-occurrence map of the simulation-based learning literature, 1965–2018 (map generated in VOSviewer software, van Eck & Waltman, 2009–2018).

Discussion

This review of research documented and synthesized patterns of knowledge production in the multi-disciplinary literature on simulation-based learning from 1965 to 2018. The review leveraged the capacity of science mapping to highlight trends through quantitative synthesis of a large database of studies. In this section, we highlight limitations of the review methodology, and discuss our intepretation and implications of key findings.

Limitations of Study

The main limitation of this review arises from the use of Scopus as the index from which to extract documents. While Scopus offers comprehensive coverage of peer-reviewed literature in education (Mongeon & Paul-Hus, 2016), it does not include every potentially relevant document in this literature. Fortunately, the use of co-citation analysis mitigated this limitation by capturing relevant research from the literature beyond Scopus.

A second limitation follows from the inconsistent use of terminology associated with simulations and games by scholars (Crookall, 2010; Faria, 2001; Gosen & Washbush, 2004; Keys & Wolfe, 1998). The practical impact of this issue on the current review lies in the potential omission of relevant papers that may have used terms other than simulation and game-based learning. Thus, despite the comprehensive coverage of this review, the authors do not claim to have reviewed the entire field.

Interpretation of the Findings

The 2,812 documents identified in this review represent a very substantial literature for a 'niche subject' in educational research (see Hallinger & Kovačević, 2019). Indeed, the substantial size of this database offers empirical evidence that SBL research and practice has attracted a critical mass of scholars. This conclusion is further reinforced by the high author and document citation impact and global audience of multidisciplinary scholars and educators documented in this review. Moreover, the growth trajectory of SBL publications suggests that this literature will continue to accumulate rapidly, and could double in size by 2030.

Nontheless, analysis of the geographical distribution of this SBL literature found that publications are concentrated in a relatively small number of Anglo-American-European societies (see Figure 4). We could not determine if this trend results from less frequent use of SBL or simply less frequent publication of research outside of economically developed, 'Western' societies. In either case, this finding suggests a significant gap in this literature since educational research has found that the 'context of learning' shapes both teacher and learner responses to different teaching and learning methods (Brown et al., 1989; Hu, 2002; King et al., 2015; Lu et al., 2014).

While there is cause for optimism concerning the generalizability of 'Western' findings on SBL beyond Anglo-American-European societies (e.g., Auyeung, 2004; Koh et al., 2010; Lu et al., 2014; Tao et al., 2009), this review raises three challenges for strengthening the global knowledge base in simulation-based learning. First, additional cross-cultural validation of findings on SBL processes and outcomes are required (Salas et al., 2009). Second, research is needed that explores the design considerations which guide the adaptation of simulations crafted in one 'context' for use in other 'contexts' (Hallinger et al., 2017; Lu et al., 2014). Finally, the field needs research that identifies the range of instructional adaptations (e.g., goal-setting, debriefing, structuring) that are most effective with students in different contexts. Here, 'contexts' refers not only to cultural contexts, but also different institutional contexts for learning (e.g., K–12, undergraduate, graduate, corporate training).

A series of citation analyses highlighted authors and documents that have shaped the evolution of simulation-based learning research and practice over the past six decades. The most influential scholars identified through Scopus citation analysis came from medical education (e.g., Barsuk, Cant, Cooper, Duke, Gaba, Gordon, Issenberg, McGaghie, Petrusa, Scalese, Wayne). This was not surprising since the field of medicine tends to generate higher rates of citation than other fields covered in this review (Harzing, 2010). Co-citation analysis revealed additional influential scholars associated with other fields that have adopted SBL (e.g., Anderson, Crookall, de Jong, Faria, Keys, Salas, Sterman, Wellington, Wolfe). Author co-citation analysis singled out Salas as the key 'boundary-spanning' scholar in the literature on simulation-based learning. Another group of noteworthy scholars identified through co-citation analysis consists of psychologists whose theories of social, cognitive, experiential, and constructivist learning have provided the conceptual underpinnings for simulation-based learning. These include Bandura, Brown, Dewey, Jonassen, Kolb, Lave, Simon, Senge, Vygotsky, and Wenger. Their inclusion on the co-citation map in Figure 5 reveals the ‘connective tissue’ that links SBL to the broader literature on human learning. For example, Kolb’s (1984) conceptualization of experiential learning has had enduring impact on scholars who have designed simulations as well as the instructional processes used with them.

Both author co-citation and keyword analyses highlighted the extent to which research and practice in SBL has become intertwined with the evolution of learning technologies. Early research in this domain focused on the use of simulations that leveraged basic computational capabilities of computers (see de Jong & van Joolingen, 1998; Gee, 2003; Kiili, 2005; Mayer, 2002, 2010; Prensky, 2001; Sitzmann, 2011; Vogel et al., 2006). More recently, experimentation with simulations that incorporate virtual reality and ‘immersive learning interfaces’ has led to an exciting new line of research and practice in SBL (e.g., Dalgarno & Lee, 2010; Dede, 2009; Hew & Cheung, 2010; Klopfer & Squire, 2008; Koh et al., 2010; Merchant et al., 2014). Given the importance of embedding human decision-making into ‘real contexts’ in SBL, the use of emerging technologies will certainly continue to attract the attention of SBL designers, practitioners, and scholars. Notably, this trend also opens the door to the use of a much broader range of research methods since the technologies that underlie these simulations also have the capability to collect rich data on learning processes and outcomes (Mayer et al., 2010; Showanasai et al., 2013; Stasser, 1988).

Author co-citation and keyword analyses (see Figures 5 and 6) revealed a significant degree of ‘balkanization of knowledge’ in this literature. More specifically, SBL researchers from medical and management education seem to be progressing on parallel tracks, failing to learn from each other and leverage their respective strengths. Increased cross-fertilization could, for example, strengthen the theoretical orientation of research on SBL in medical education and diversify the research designs and methods used in research on SBL in management education.

Findings from this review also hold relevance for discourse on the scope and nature of the ‘knowledge base’ on simulation-based learning (e.g., Crookall, 2010; Faria, 2001; Ruben, 1999). The large size, high citation impact, and accelerating growth trajectory of peer-reviewed publications leave no doubt that SBL has evolved into a significant corpus of knowledge. At the same time, author co-citation analysis revealed Learning Theories in SBL as the conceptual core of the knowledge base. This empirically derived conclusion implies that SBL is not a discipline in and of itself, but rather a subfield of education (see Crookall, 2010). This represents a significant conclusion given ongoing debate among SBL scholars on this issue.

In conclusion, this effort to map the knowledge base on simulation-based learning leads us to conclude that the future for simulation-based learning is bright. Among available active learning approaches (e.g., problem-based learning, project-based learning, case-based learning), SBL is uniquely suited to employ continuing technological innovations towards the development of more effective learning tools that not only engage students, but also enable them to go beyond surface understanding of disciplinary content. This will place SBL at the forefront of education that aims to develop the capacity of students to apply knowledge and skills to the solution of complex social and organizational challenges.

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