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Tracking the Evolution of the Knowledge Base on Problem-based Learning: A Bibliometric Review, 1972-2019

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ABSTRACT

The current review employed bibliometric review methods to analyze 14,130 Scopus-indexed documents on problem-based learning published from 1972 through the end of 2019. The goals of the review were to describe the landscape and analyze the evolution of topical foci of interdisciplinary research on PBL over the past five decades. The review identified the accumulation of a substantial interdisciplinary corpus of research on PBL that is significantly larger than the literature on other approaches to active learning. The growth trajectory of the literature on PBL started out "low and flat" during the 1970s and 1980s but steadily gained momentum in subsequent decades, with 58% of the PBL literature published between 2010 and 2019. PBL has achieved an impressive scope of global research over the past 45 years, with a significant number of studies published from emerging regions of the world, especially during the past decade. While a long-term body of research has accumulated on the learning outcomes of PBL, the research front has begun to shift towards the study of self-directed learning, student satisfaction, self-efficacy, critical thinking, and cooperation. Research and practice challenges identified in the review focus on establishing the scope of use and efficacy of PBL across different cultural contexts and more systematically summarizing and synthesizing the use of PBL outside of the health professions.

Keywords: PBL; problem-based learning; bibliometric review; review of research

Introduction

The search for methods of active learning that enhance the transfer of student knowledge and skills emerged over the past half-century as a key driver in educational reform and change throughout the world (Biggs, 2011; Bransford, 1993; Kolb, 1984). Scholars have studied the use of a wide variety of active learning approaches including problem-based learning (Barrows & Tamblyn, 1980), simulations and serious games (Hallinger & Wang, 2019), case-based learning (Kolodner et al., 2003), project-based learning (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991), and flipped classrooms (Bishop & Verleger, 2013). Unique among these methods, problem-based learning has benefited from a sustained, theory-informed program of empirical research that has systematically examined both learning processes and outcomes (Albanese & Mitchell, 1993; Colliver, 2000; Hmelo-Silver & Eberbach, 2012; Koh, Khoo, Wong, & Koh, 2008; Prosser & Sze, 2014).

Initial efforts to conceptualize, design, and implement problem-based learning (PBL) were launched at medical schools in the Netherlands, Canada, and the USA during the 1970s and 1980s (Barrows, 1985, 1986; Norman & Schmidt, 1992; Schmidt, 1983, 1993; Vernon & Blake, 1989). In subsequent decades, the use of PBL spread to other academic and professional fields in higher education, as well as in K-12 schooling (Xian & Madhavan, 2013). The accumulating knowledge base on PBL has been the subject of research reviews focusing on conceptual (Acton, 2019), quantitative (Gijbels, Dochy, Van den Bossche, & Segers, 2005), and qualitative studies (Jin & Bridges, 2016). The current review employed the bibliometric review method (Zupic & Čater, 2015) in order to address the following research questions.

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RQ1: What is the volume, growth trajectory, and geographic distribution of scholarship on problem-based learning?

RQ2: Which authors have played the most influential roles in shaping the knowledge base on problem-based learning?

RQ3: How have topical foci in published scholarship on problem-based learning evolved over time, and what is the current "research front" in this literature?

This review sourced 14,130 Scopus-indexed documents on problem-based learning published between 1972 and the end of 2019. Bibliographic data associated with these documents were analyzed using descriptive statistics and keyword co-occurrence analysis. The foci of this review were selected with the explicit goals of updating and extending findings reported in previous bibliometric reviews of this literature (Azer, 2017; Pinho et al., 2015; Xian & Madhavan, 2013).

Conceptual Background for the Review

The conceptualization of PBL that guided this review was grounded in definitions offered by pioneers in this field (e.g., Barrows, 1986; Barrows & Tamblyn, 1980; Hmelo-Silver, 2004; Savery, 2006; Schmidt, 1983). PBL is a method of learning that prompts students to learn concepts and skills through the solution of complex, real-world problems rather than from the presentation of theories, concepts, and facts by a teacher. Almost all variants of PBL employ self-directed, independent learning with a concurrent emphasis on developing attitudes and skills designed to enhance life-long learning. Learning in teams or groups has also been identified as a common characteristic of PBL (Barrows & Tamblyn, 1980; Bridges & Hallinger, 1995; Neville, 2009; Norman & Schmidt, 1992), even in e-learning contexts where learner collaboration is distributed across time and space (Hallinger, Lu, & Showanasai, 2019; Verstegen et al., 2016).

Bridges and Hallinger (1995) contrasted PBL with the "case teaching" method on several dimensions. They noted that "teaching cases" are often used as a means of applying theoretical knowledge previously learned through lecture and discussion. However, a central tenet of PBL is that "the problem comes first" (Barrows & Tamblyn, 1980). PBL proponents assert that when initial learning takes place in the context of a challenge that students are likely to face in the future, it not only acts as a motivator to learn but also enhances knowledge retention and transfer (Barrows, 1986; Bransford, 1993; Brown, Collins, & Duguid, 1989; Carvalho, 2016; Hmelo-Silver, 2004). In PBL students generally learn in small teams, thereby drawing on the power of cooperative group learning (Preeti, Ashish, & Shriram, 2013; Slavin, 2011; Smith, Sheppard, Johnson, & Johnson, 2005). In most variants of PBL, students demonstrate their learning through presentation of action-oriented solutions to a problem rather than via an analytical paper (Begay et al., 2006; Bridges & Hallinger, 1995; Hallinger & Bridges, 2007). These perspectives on the nature and elements of problem-based learning informed the current review of research.

Prior Bibliometric Reviews of the PBL Literature

The development of the literature on PBL has been facilitated by a decades-long lineage of research reviews. Early reviews sought to define PBL (e.g., Norman & Schmidt, 1992; Walton & Matthews, 1989) and explore issues related to curriculum design and implementation (Albanese & Mitchell, 1993). Subsequent reviews have focused on assessing the effectiveness of PBL (Colliver, 2000; Dochy et al., 2003; Koh et al., 2008; Gijbels et al., 2005), documenting the use of PBL in different subject domains (e.g., Alrahlah, 2016; Hallinger & Bridges, 2017; Jin & Bridges, 2014; Koh et al., 2008; Merritt, Lee, Rillero, & Kinach, 2017), and summarizing progress in the development of this accumulating knowledge base (e.g., Dolmans, De Grave, Wolfhagen, & van der Vleuten, 2005; Neville, 2009; Strobel & Van Barneveld, 2009). These systematic reviews of research used content analysis, quantitative synthesis, and meta-analysis in order to make sense of concepts and findings that emerged over time.

Over the past decade, scholars have complemented these prior efforts through the application of bibliometric methods of research review (Azer, 2017; Pinho et al., 2015; Xian & Madhavan, 2013). Bibliometric reviews seek to synthesize patterns of knowledge production through the analysis of "bibliographic data" associated with a corpus of relevant documents (Van Eck & Waltman, 2014; Zupic & Čater 2015). This variant of systematic review reveals trends that evolve within a literature over time and offers empirical bases for benchmarking progress and charting the way forward.

Three prior bibliometric reviews of the PBL literature were located in a search of the literature (Azer, 2017; Pinho et al., 2015; Xian & Madhavan, 2013). As indicated in Table 1, these reviews examined the PBL literature through the analysis of widely varying research foci and document samples. The author will briefly summarize features and findings from these prior bibliometric reviews in order to establish what has already been learned about the intellectual landscape of this literature, as well as to identify and justify the scope of this review of PBL research.

The prior reviews located the genesis of the knowledge base on PBL in the mid-20th century (Xian & Madhavan, 2013). However, it was not until the mid-1990s that scholarly interest in PBL began to gain a critical mass (Pinho et al., 2015). In subsequent decades there has been a consistent

annual increase in publications with publication volume tripling during the 2000s and then doubling again during the 2010s (see also Figure 2).

The design and use of PBL-oriented curricula originated at the medical school of Maastricht University in the 1970s (Neville, 2009). Over time, however, reviews have

Author	Azer (2017)	Pinho et al. (2015)	Xian & Madhavan (2013)
Documents	50 articles	2,990 mixed sources	26 mixed papers by Barrows
Source	WoS, GS	WoS	Multiple databases
Timeframe	1983-2015	1981-2014	1974-2009
Focus	PBL-All	PBL-All	Publications by H. Barrows
Software	Excel, SPSS	Vantagepoint	mySql and other
Analytical Foci	geography; document and author citation impact; quality of evidence	growth, geography; author citations; co-authors; journals	impact of Barrows' scholarship; topics, collaborators, disciplines, document citation impact

WoS=Web of Science; GS=Google Scholar

Table 1: Features of bibliometric reviews of research on problem-based learning

documented research on PBL across most parts of the world. Nonetheless, the bulk of research on PBL continues to be produced in the USA, UK, Canada, Australia, and Netherlands (Pinho et al., 2015).

While PBL originated as a method of medical education (Barrows & Tamblyn, 1980), the spread of PBL has subsequently been documented across a wide range of disciplines (Ertmer & Simons, 2006; Xian & Madhavan, 2013). Educators have adapted PBL for use in programs focusing on nursing (Baker, 2000), dental (Azer, 2017), management (Hallinger & Bridges, 2007), pharmaceutical (Cisneros et al., 2002), engineering (De Graaf & Kolmos, 2003), science (Bransford, 1993), and architectural (Maitland, 1997) education. While the cross-disciplinary adoption of PBL is a positive development, critics have asserted that some adaptations of PBL are "poorly designed and not carried out according to the core PBL model" (Xian & Madhavan, 2013, p. 151). This characteristic of the literature can complicate efforts to synthesize findings reported in studies of PBL, both within and across disciplines.

Bibliometric reviews have employed empirical analysis in order to identify key contributors to this literature. For example, Xian and Madhavan (2013) highlighted the pioneering contributions of Howard Barrows which laid a foundation for the subsequent emergence and development of the field. Using "citation analysis" these reviews also identified Henk Schmidt, Cees van der Vleuten, Geoff Norman, Diana Dolmans, Albert Scherpbier, Mark Albanese, Cindy Hmelo-Silver, and Susan Mitchell as other key scholars. With few exceptions (e.g., Hmelo-Silver, Prince, Felder, Kolmos), highly cited scholars in this literature are associated with medical education. This pattern is reprised in analyses of the journals that have been most active in disseminating research on PBL. PBL publications have been concentrated in journals specializing in medicine and medical education (e.g., Academic Medicine, Medical Education, Medical Teaching, JAMA).

Two bibliometric reviews examined topics covered in studies of PBL (Azer, 2017; Xian & Madhavan, 2013). These reported an emphasis on studies of learning effectiveness, clinical competence, and curriculum/program outcomes. Additional topics with an accumulation of studies included the description and rationale of PBL programs, methods used by PBL tutors, PBL curriculum design, and the role of problem solving. However, as indicated in Table 1, these topical analyses were based on very small document samples.

Azer's (2017) review analyzed the 50 most highly cited documents published on PBL through the year 2015. Xian and Madhavan (2103) drew their conclusions on the basis of citation patterns associated with just 26 documents authored by Howard Barrows.

The current review was explicitly formulated in order to update, build upon, and fill gaps in the intellectual space covered by these prior bibliometric reviews of the literature on PBL. For example, in this review the author extracted documents from Scopus rather than the Web of Science and extended the duration of the review to 2019. Consequently, this review analyzes a much larger document database, thereby offering a more comprehensive view of the full PBL literature. In addition, this review adopted a "longitudinal" perspective on data analysis in order to illuminate the evolution of the PBL literature from several perspectives.

Method

Bibliometric reviews are a subset of the broader category of systematic reviews of research (Zupic & Čater 2015). Thus, it is incumbent upon the reviewer to make explicit the procedures used in the review (Hallinger, 2013). This section describes the steps followed in the identification of sources, extraction of bibliographic data, and data analysis.

Identification of Sources

As noted above, bibliometric reviews focus on the analysis of bibliographic data associated with a corpus of documents extracted from one or more data repositories. The most common repositories used in bibliometric reviews are the Web of Science, Scopus, and Google Scholar. While Google Scholar offers the broadest coverage of documents, it lacks a rigorous vetting of peer-reviewed sources and has limited capacity for data extraction. Although the Web of Science has a strong reputation for quality and advanced capabilities for data extraction, its coverage of sources in education and social sciences was considered insufficient for the purposes of this review (Hallinger & Kovačević, 2019; Mongeon & Paul-Hus, 2016). Therefore, this review employed the Scopus index which offered the desired mix of document quality, content coverage, and exportable bibliographic data (Zupic & Čater 2015).

This review sought to obtain a comprehensive perspective on the evolution of the knowledge base on problem-based learning. Therefore, the criteria used to define the boundaries of the review were left quite broad. For example, rather than limiting the search to journal articles, the review also included books, book chapters, and conference papers. Since the review aimed to examine "interdisciplinary research" on PBL, no filters were applied to limit the search to a particular field of study (e.g., medicine, engineering). In terms of the time frame, the search engine was set to seek out the first Scopus-indexed documents and continue to the end of 2019.

The review was guided by the conceptual definition of PBL presented in the prior section of the paper. The operational definition of PBL was encompassed in keywords specified in the Scopus search. In practical terms, the uniqueness of the topic's name—"problem-based learning" or "PBL"—avoided the ambiguity that often complicates bibliometric document searches. In this instance, the reviewer could assume that most papers that included a variant of the "problem-based learning" OR "PBL" in the title, keywords, or abstract would be relevant, thereby limiting the number of "false positives." Similarly, it was extremely unlikely that papers lacking one of these keywords would be relevant to our review. After some experimentation, a comprehensive and efficient search string was developed by adding "school" OR "education" to the basic keyword variants (i.e., PBL, problem-based learning). The final keyword search in Scopus was conducted using the following search string:

> (TITLE-ABS-KEY ("problem-based learning") OR TITLE-ABS-KEY ("problem based learning") OR TITLE-ABS-KEY ("PBL") AND TITLE-ABS-KEY (education) OR TITLE-ABS-KEY (school)) AND NOT ("project-based learning") AND NOT ("project based learning") AND PUBYEAR > 1960 AND PUBYEAR < 2020)

The review followed PRISMA guidelines for reporting systematic reviews of research (Moher, Liberati, Tetzlaff, & Altman, 2009). The above keyword string generated a list of 15,272 documents. As detailed in Figure 1, an iterative process was used to examine the relevance of documents for the review. First, Scopus filters excluded 1,096 ineligible documents by "document type" (e.g., notes, surveys, erratum, editorials). As anticipated, due to the clarity and specificity of the main keyword (i.e., problem-based learning), it was possible to generate a list that contained relatively few irrelevant documents. Additional review of the list led to the exclusion of only 46 duplicate or irrelevant documents. The final list used in the review consisted of 14,130 documents focusing on problem-based learning published between 1972 and the end of 2019. These consisted of 78% journal articles, 19.1% conference papers, 2.5% book chapters, and .3% books.

Data Extraction and Analysis

The bibliometric data associated with the 14,130 documents were exported from Scopus into a MS Excel file. In order to facilitate longitudinal analysis, the data were saved in files corresponding to the decades of publication (e.g., 1972-1979, 1980-1989 etc.). These data files contained

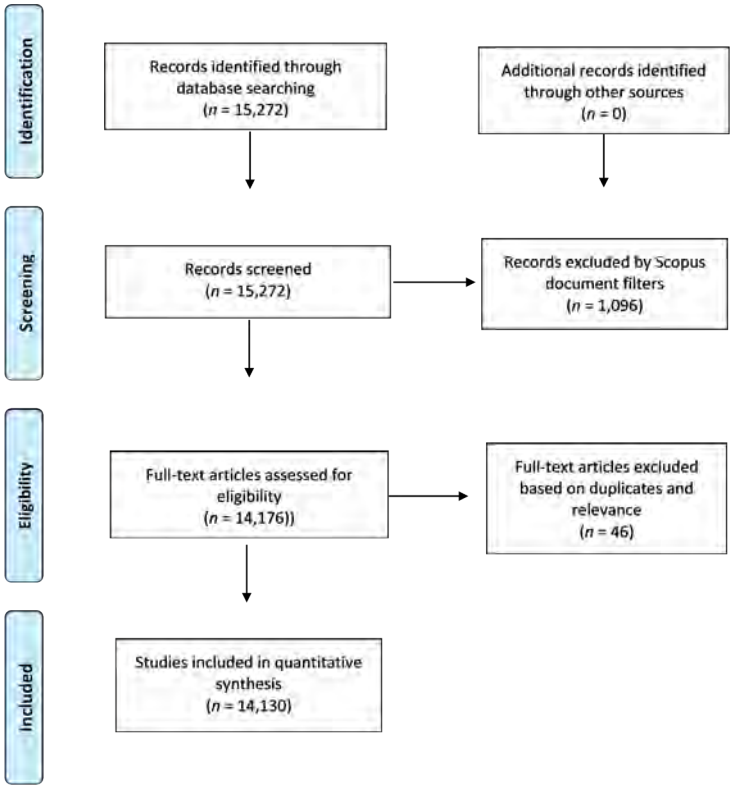

Figure 1: PRISMA flow diagram of search procedures used in the review of research on problem-based learning (Moher et al., 2009)

similarly formatted, descriptive information about the composite documents (e.g., author, title, publication data, citation data, abstract, etc.).

Because bibliometric analysis relies on metadata associated with the composite studies, steps must be taken to ensure the accuracy of these data prior to analysis. It is common, for example, for multiple keywords to share the same meaning (e.g., "student" or "students," "education, medical" or "medical education"). Unless steps are taken to identify and disambiguate these common terms, data analysis will yield inaccurate results (Xian & Madhavan, 2013). VOSviewer software (van Eck & Waltman, 2013) offers the capability to identify these "ambiguous keywords." Then the author created a "thesaurus text file" that included instructions for VOSviewer to replace one form of an ambiguous keyword (e.g., students) with an alternate form (e.g., student) during data analysis. A similar process was used to replace alternate forms of author names (e.g., C.P van der Vleuten, C.P.M. van der Vleuten, C. van der Vleuten) with a common form (e.g., C. van der Vleuten).

Descriptive data analyses used to address the first research question were conducted in Scopus analytical tools, Excel, and Tableau software programs. Analyses that address the second and third research questions were conducted with VOSviewer software (van Eck & Waltman, 2013).

The author employed both "citation" and "co-citation analysis" as means of assessing scholarly impact. Author citation analysis, conducted in VOSviewer, generates the number of times that an author in the review database was cited in other Scopus-indexed documents (i.e., Scopus citations). This is a widely used metric for assessing scholarly impact (Garfield & Merton, 1979; Zupic & Čater, 2015). It should be clarified that Scopus citation counts tend to be larger than those obtained from the Web of Science, but smaller than Google Scholar due to size differences of the respective document indices.

In contrast to citation analysis, co-citation analysis computes the frequency of author citations in the "reference lists" of the review documents. Thus, co-citation analysis identifies scholars who have influenced the authors who have

produced the knowledge corpus under review. Co-citation analysis, therefore, yields a complementary perspective on "scholarly impact" (Zupic & Čater, 2015).

Keyword co-occurrence analysis (co-word analysis), conducted in VOSviewer, was used to analyze the topics studied in this literature. Co-word analysis yields several types of results. First, co-word analysis scans the titles, keywords, and abstracts of documents in the review database in order to identify the most frequently studied keywords or "topics" in the literature (Zupic & Čater, 2015).

Second, co-word analysis also computes the "co-occurrence" of keywords (e.g., PBL and teaching) in the titles, keywords, and abstracts of review documents. Scholars have found that keywords which frequently "co-occur" in documents bear a similarity (e.g., simulation and technology). VOSviewer uses matrices of keyword co-occurrences to create a "science map" that visualizes similarities among keywords in the literature (van Eck & Waltman, 2013). This application of co-word analysis surfaces conceptual themes which emerge in a literature over time (Su & Lee, 2010; Zupic & Čater, 2015).

Finally, VOSviewer offers the option to create a "temporal overlay" on the basic co-word map. Temporal co-word analysis links the occurrence of keywords with the publication years of their associated documents. Then the software analyzes the distribution of dates for each keyword in order to identify the time periods in which they featured most prominently (van Eck & Waltman, 2013). Temporal co-word analysis was used in this review to identify the "research front" in the literature on PBL (Price, 1965; Zupic & Čater, 2015).

Results

The Landscape of PBL Research Publications

The 14,130 Scopus-indexed documents on problem-based learning represent a surprisingly large knowledge base focusing on one specific form of teaching and learning. The earliest papers were published in the 1970s in the fields of compensatory (Dwyer, Elligett, & Brost, 1972) and medical education (Barrows & Neufeld, 1974). Nonetheless, consistent with prior reviews, the author found that growth of the research literature on PBL was slow and relatively flat until the mid-1990s when a critical mass of international researchers began

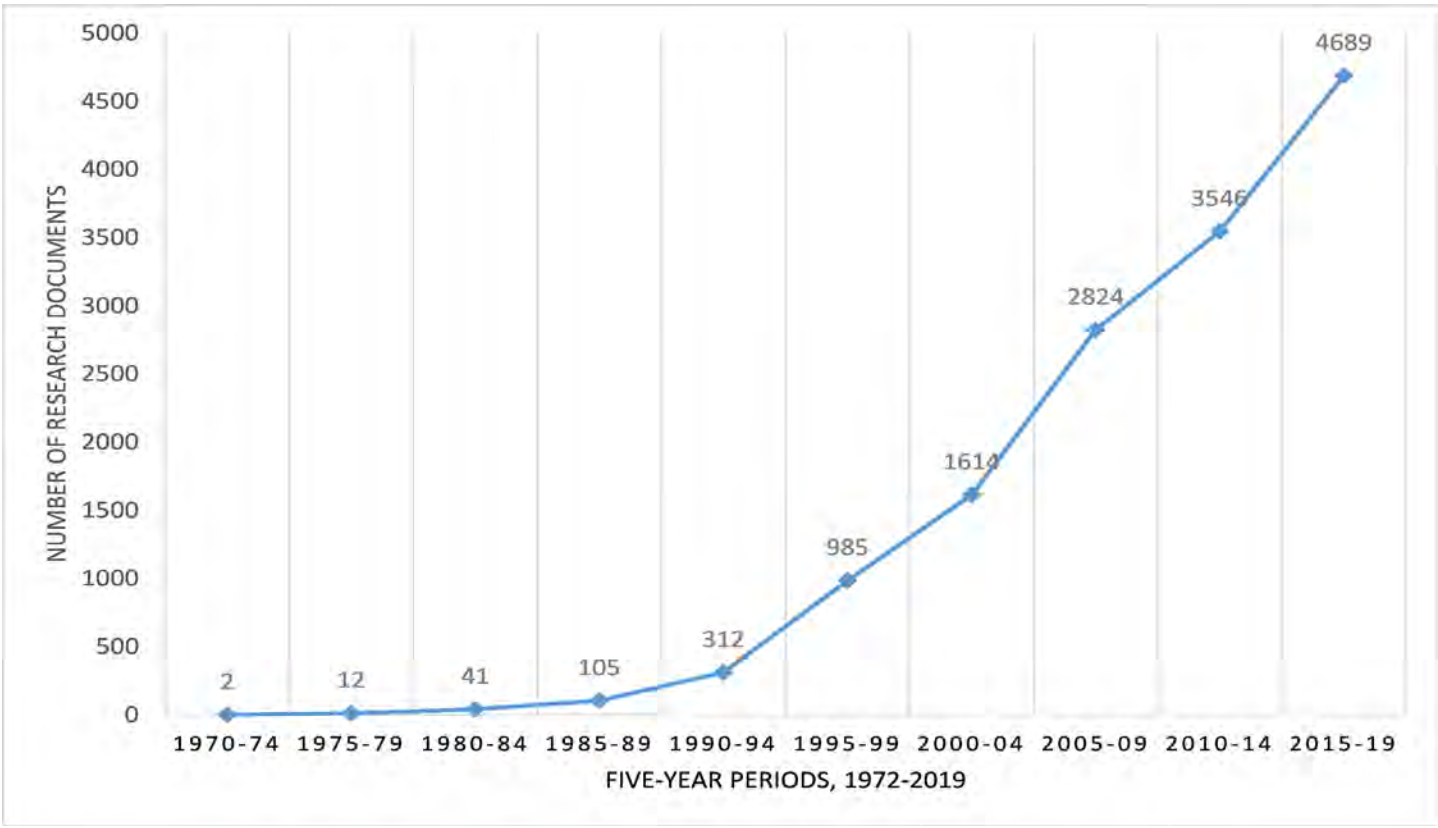

Figure 2: Growth trajectory of Scopus-indexed publications on problem-based learning, 1972-2019 (n=14,130)

to form (see Figure 2). The growth trajectories displayed in Figures 2 and 4 offer visual validation of the continuously accelerating strength of scholarly interest in PBL. This trend reached its zenith during the decade from 2010 to 2019 when 58% of all PBL research documents were published.

In total, this literature has been produced by scholars located in 145 different countries (not tabled). The heat map in Figure 3 shows the document distribution among the 112 countries in which scholars authored at least 10 Scopus-indexed PBL publications. These data verify the emergence of a global knowledge base on PBL. Nonetheless, equally notable was the wide variation in "density" of publications across societies. Indeed, the darker shades on the map highlight the prevalence of research authored by scholars from Anglo-American-European societies. The leading producers of PBL scholarship have come from the USA (5,278 documents), United Kingdom (1,465), Australia (1,019), Canada (937), Netherlands (511), and Germany

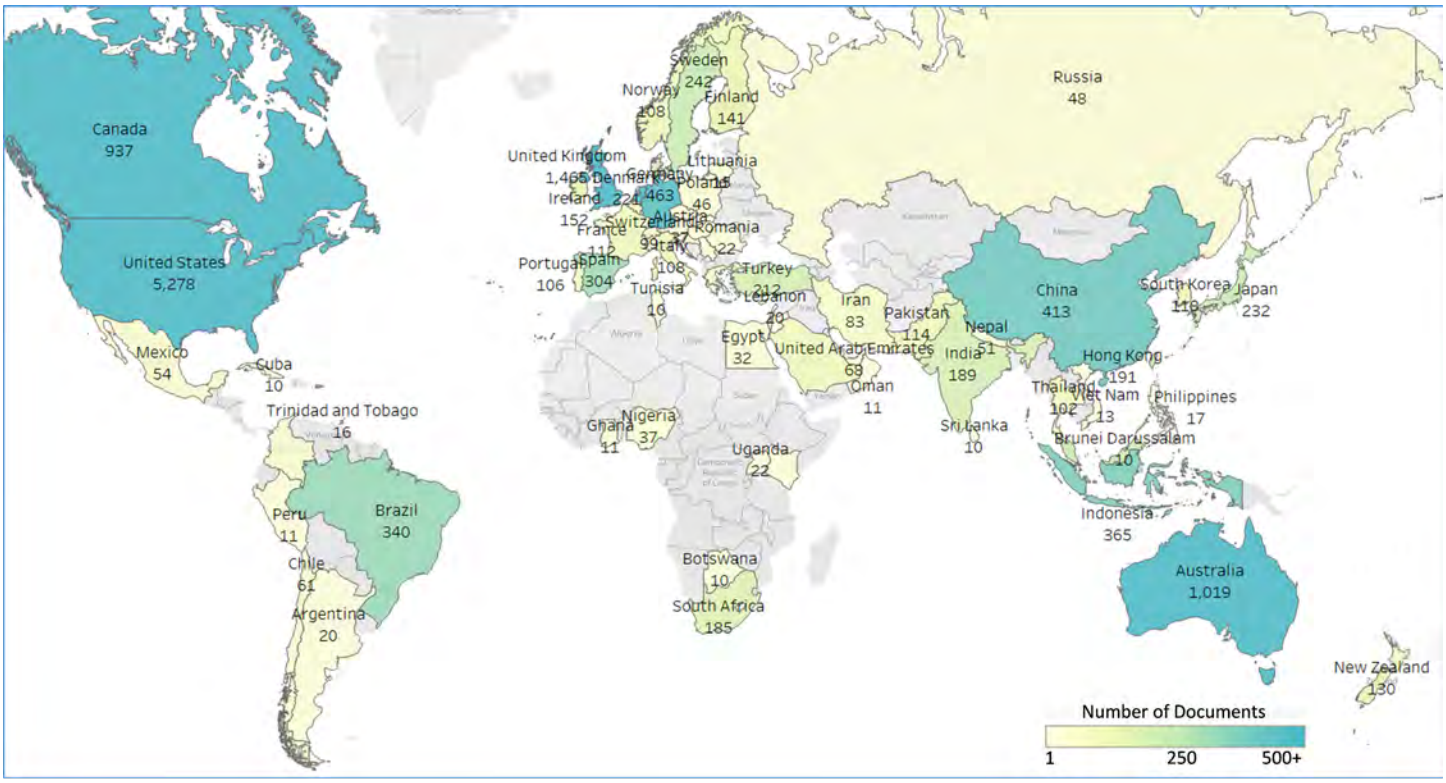

Figure 3: Geographic distribution of research on problem-based learning among nations with at least 10 documents, 1972-2019 (n=14,130)

(463). This finding is broadly consistent with other reviews of educational research published in English-language journals (Hallinger & Kovačević, 2019; Hallinger & Wang, 2019). It was, however, surprising to find a significant corpus of research generated by scholars in the Chinese-speaking societies of mainland China (413), Taiwan (236), Hong Kong (191), and Singapore (124).

The author suggests that these publication statistics offer indirect evidence on geographical patterns of PBL adoption. While the number of research documents authored in a given society is not a fully accurate proxy for the extent of PBL adoption, it seems reasonable to assume that evidence of research publication suggests that PBL has been used—to some extent—in a country's education programs. If so, then we can conclude that there has, at a minimum, been experimentation with the use of PBL across much of the world. This is a significant finding, especially given the extent to which PBL departs from "traditional" modes of teaching and learning.

Disaggregation of the geographical evolution of this literature by regions of the world offers further insight (see Figure 4). These data suggest a clear pattern of increasing geographical dispersion of the PBL literature over time, with the number of territories contributing to the PBL literature increasing dramatically over the past five decades (see numbers in parentheses in Figure 4). The graph in Figure 4 highlights the early adoption and growth of research on PBL in

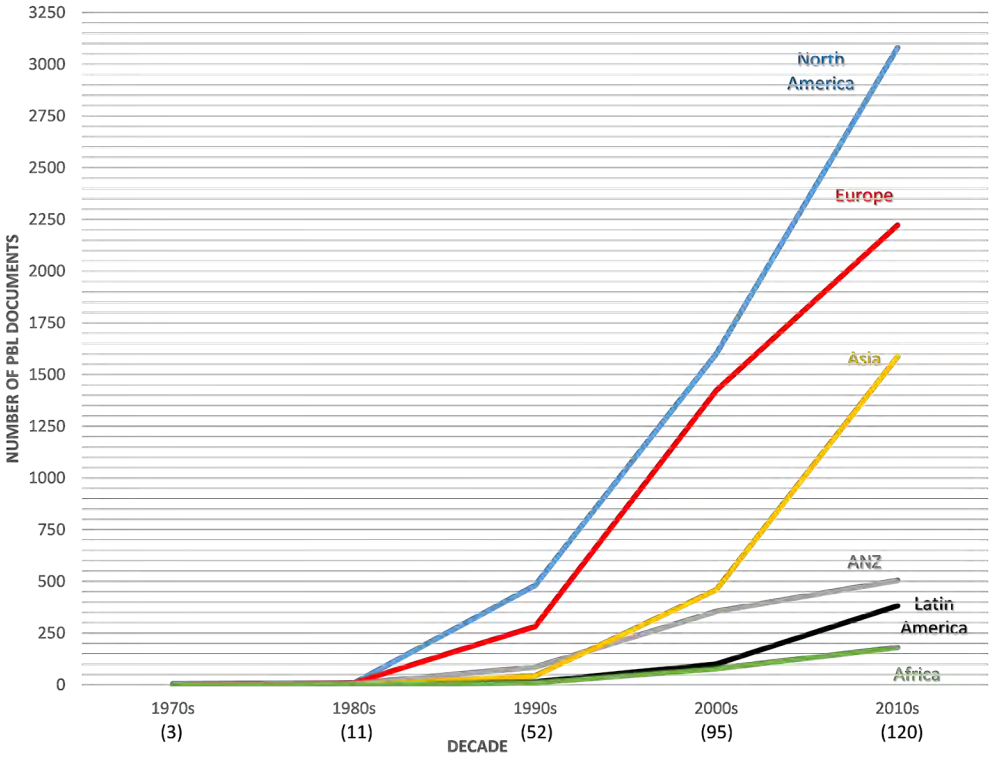

Figure 4: Contributions to the PBL knowledge base over time by regions of the world, 1972-2019
ANZ=Australia and New Zealand; numbers in parentheses indicate the number of discrete territories with authors contributing papers on PBL during each decade.

North America (i.e., USA, Canada) and Northern Europe (Netherlands, UK, Sweden, Germany, Norway) in the 1980s and 1990s.

Two pivot points are indicated by the trend lines, one around 1995 and another in the early 2000s. Prompted by the dissemination of exemplars (Barrows, 1985; Des Marchais, 1991; Leeder, 1991) and landmark reviews of early research (e.g., Vernon & Blake, 1993; Walton & Matthews, 1989), a growing community of North American and European researchers were gradually joined by educators in Asia and Australia-New Zealand (ANZ) in the mid-1990s. A decade hence, PBL also began to gain currency among educators in Latin America and Africa. The trend lines in Figure 4 continue to show varying degrees of growth up until the present.

Key Authors in the PBL Literature

This review used author productivity as well as citation and co-citation analysis in order to gain complementary perspectives on scholarly influence. The most active contributors to research on PBL have been Cees van der Vleuten (88 Scopus documents), Henk Schmidt (68), Albert Scherpbier (61), Diana Dolmans (47), and Geoff Norman (30) (not tabled). These scholars are all associated with medical education and, with the exception of Norman, come from the Netherlands. This suggests that despite being ranked fifth in total PBL-related research output (see Figure 3), the Netherlands has produced the strongest cluster of scholars contributing sustained research and development on PBL. This is extraordinary for a nation of its small size.

Citation analysis reveals the magnitude of citations achieved by the top-cited PBL scholars (see Table 2). Notably, these Scopus citation counts are unusually high for education scholars (see Hallinger & Kovačević, 2019; Hallinger & Wang, 2019). This finding is, no doubt, influenced by the fact that 14 of the 20 authors listed in Table 2 work in the field of medicine where citation impact tends to be higher than in general education or educational psychology (Harzing & Alakangas, 2016). Furthermore, it should be clarified that these authors' citation counts do not reflect their entire publication records, only citations accrued from documents in the PBL review database. Thus, for example, the 5,003 Scopus citations accrued from Henk Schmidt's PBL publications

Rank	Author	Nation	Academic Area	Documents	Scopus Citation	CPD[1]
1	Schmidt, H.	NETH	MedEd	68	5003	74
2	van der Vleuten, C.	NETH	MedEd	88	3606	41
3	Hmelo-Silver, C.	USA	EdPsych	16	3186	199
4	Prince, M.	USA	EngEd	6	2858	476
5	Norman, G.	USA	MedEd	30	2604	87
6	Wenderoth, M.	NETH	MedEd	4	2402	601
7	Scherpbier, A.	NETH	MedEd	61	2389	39
8	Dolmans, D.	NETH	MedEd	47	1943	41
9	Barrows, H.	USA	MedEd	12	1827	152
10	Mitchell, S.	USA	MedEd	5	1713	343
11	Albanese, M.	USA	MedEd	6	1656	276
12	Wolfhagen, I.	NETH	MedEd	25	1198	48
13	Gijbels, D.	NETH	MedEd	3	1169	390
14	Segers, M.	NETH	MedEd	4	1169	292
15	Dochy, F.	NETH	MedEd	4	1131	283
16	van den Bossche, P.	NETH	MedEd	3	1131	377
17	Dornan, T.	UK	MedEd	25	1115	45
18	Harden, R.	UK	MedEd	17	1085	64
19	Boshuizen, H.	NETH	MedEd	19	994	52
20	Vernon, D.	USA	MedEd	3	986	329

[1]CPDs=citations per document; MedEd=Medical Education; EngEd=Engineering Education; EdPsych=Educational Psychology

Table 2: Analysis of PBL scholars ranked by Scopus citations, 1972-2019

listed in Table 2 are only a portion of his more than 17,600 Scopus citations. This reinforces the high citation impact gained by PBL's highly cited scholars.

The top-cited scholars in this literature are Henk Schmidt (5,003 Scopus citations), Cees van der Vleuten (3,606), Cindy Hmelo-Silver (3,186), Michael Prince (2,858), and Geoff Norman (2,604). The scholars listed in Table 2 reflect PBL's "roots" in medical education (Barrows & Tamblyn, 1980; Neufeld & Barrows, 1974; Schmidt, 1983). Michael Prince and Cindy Hmelo-Silver are the exceptions among the top-cited scholars, coming from engineering (Prince, 2004; Prince & Felder, 2006) and educational psychology (Hmelo-Silver, 2004; Hmelo-Silver & Eberbach, 2012).

The scholars in Table 2 have contributed to the development of this knowledge base in several ways. First, they have theorized on the psychological basis of PBL as a method of learning (Hmelo-Silver, 2004; Hmelo-Silver & Eberbach, 2012; Norman & Schmidt, 1992; Schmidt, 1993), and elaborated design principles underlying its application in practice (Barrows, 1985; Dolmans, Snellen-Balendong, & van der Vleuten, 1997). They are also responsible for conducting empirical studies (Verhoeven et al., 1998; Van der Vleuten, Verwijnen, & Wijnen, 1996) and research reviews on various aspects of PBL (Dochy et al., 2003; Dolmans, De Grave, Wolfhagen, & Van Der Vleuten, 2005; Driessen, Van Tartwijk, Van Der Vleuten, & Wass, 2007; Norman & Schmidt, 1992; Vernon & Blake, 1993).

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Rank	Author	Nation	Area	(Co-) Citations	Scopus Citation Rank
1	Schmidt, H.	NETH	MedEd	3736	1
2	Barrows, H.	USA	MedEd	3296	9
3	van der Vleuten, C.	NETH	MedEd	2031	2
4	Norman, G.	USA	MedEd	2012	5
5	Dolmans, D.	NETH	MedEd	1448	8
6	Hmelo-Silver, C.	USA	EdPsych	1376	3
7	Albanese, M.	USA	MedEd	1043	11
8	Scherpbier, A.	NETH	MedEd	878	7
9	Mitchell, S.	USA	MedEd	824	10
10	Boud, D.	USA	GenEd	799	--
11	Harden, R.	UK	MedEd	793	18
12	Jonassen, D.	USA	EdPsych	761	--
13	Wolfhagen, I.	NETH	MedEd	730	12
14	Biggs, J.	AUS	EdPsych	685	--
15	Kolb, D.	USA	EdPsych	683	--
16	Felder, R.	USA	EngEd	659	--
17	Tamblyn, R.	USA	MedEd	652	315
18	Boshuizen, H.	NETH	MedEd	649	22
19	de Grave	NETH	MedEd	628	24
20	Johnson, D.	USA	GenEd	610	26

*Denotes that this scholar was not among the top 20 authors ranked by Scopus citations
EdPsych=Educational Psychology; EngEd=Engineering Education; GenEd=General Education; MedEd=Medical Education

Table 3: Authors ranked by citations of their scholarship in the review database (co-citation analysis)

the top-cited scholars, coming from engineering (Prince, 2004; Prince & Felder, 2006) and educational psychology (Hmelo-Silver, 2004; Hmelo-Silver & Eberbach, 2012).

The scholars in Table 2 have contributed to the development of this knowledge base in several ways. First, they have theorized on the psychological basis of PBL as a method of learning (Hmelo-Silver, 2004; Hmelo-Silver & Eberbach, 2012; Norman & Schmidt, 1992; Schmidt, 1993), and elaborated design principles underlying its application in practice (Barrows, 1985; Dolmans, Snellen-Balendong, & van der Vleuten, 1997). They are also responsible for conducting empirical studies (Verhoeven et al., 1998; Van der Vleuten, Verwijnen, & Wijnen, 1996) and research reviews on various aspects of PBL (Dochy et al., 2003; Dolmans, De Grave, Wolfhagen, & Van Der Vleuten, 2005; Driessen, Van Tartwijk, Van Der Vleuten, & Wass, 2007; Norman & Schmidt, 1992; Vernon & Blake, 1993).

Co-citation analysis yielded a similar concentration of medical education scholars (see Table 3). In addition, 15 of the 20 "top co-cited" authors were also listed among the "top-cited" authors based on Scopus citations listed in Table 2. These complementary analyses yield the conclusion that these represent key scholars in the PBL literature.

Notably, Table 3 also includes several highly co-cited authors who have seldom, if ever, published research on PBL (e.g., David Jonassen, John Biggs, Richard Felder, David Kolb, David Johnson). Yet these scholars are frequently cited by authors publishing research on PBL. For example, because PBL is a form of experiential learning (e.g., Boud & Felletti, 1997; Hmelo-Silver, 2004; Hmelo-Silver et al., 2007; Savery, 2006), educators engaged in PBL research and practice have frequently drawn on theories of experiential (Kolb, 1984), constructivist (Jonassen, 2002), team-based (Johnson & Johnson, 1999) and active learning (Biggs, 2011; Felder & Brent, 2003; Prince & Felder, 2006). Analysis of these interdisciplinary influences on PBL scholarship are further investigated in a companion paper (see Hallinger, 2020).

Topical Analysis of the Literature on Problem-Based Learning

Co-word analysis was used to identify the most frequently studied topics, reveal conceptual themes, and highlight the research front in this literature. Analysis of keyword frequency yielded several noteworthy findings. First, a large number of keywords attained very high frequency counts. This suggests the strong possibility of knowledge accumulation in the substantive foci of PBL research. Even after discounting keywords used in the document search (i.e., PBL, education), there were still 16 keywords with more than 1,000 occurrences and 212 with more than 100 occurrences. The most frequently occurring keywords were "medical education" (4,404 occurrences), "curriculum" (4,264), "teaching" (4,189), "learning" (2,606), "students" (2,448), "medical students" (2,159), "clinical competence" (1,850), "psychology" (1,610), "educational measurement" (1,576), "problem solving" (1,548), "nursing education" (1,537), "organization and management" (1,354), "attitude" (1,345), "medical schools" (1,280), "engineering education" (1,168), and "standards" (1,108). These keywords suggest the "subject domains" where PBL has gained sustained attention from educators: medical, engineering, nursing, dental, pharmaceutical, science, biology, and undergraduate education. Conversely, these results also shed light on fields where the focus on PBL has been somewhat weaker: business management, teacher training, architecture, social work, counseling, and social sciences.

VOSviewer was next used to generate a "co-word map" that visualizes relationships among frequently occurring keywords (see Figure 5). On the map, the relative frequency of keyword occurrence is indicated by size of the "nodes." Based on the threshold used to generate this map, the smallest nodes indicate keywords that appeared in at least 150 documents. The proximity of keyword nodes reflects the frequency of their "co-occurrence" in titles, abstracts, and keywords of the review documents. Thus, nodes that are close to one another tend to bear a thematic similarity (Zupic & Čater, 2015). Groups of keywords are grouped into colored clusters based on these patterns of co-occurrence. These clusters can be interpreted as "themes" that comprise the conceptual space of the literature (Su & Lee, 2010; Zupic & Čater, 2015).

The co-word map in Figure 5 highlights three keyword clusters. Note also that the keyword "learning" is located near the intersection of all three clusters. The largest cluster represents "PBL in Medical Education." This reprises patterns identified in the author analyses. Further inspection of keywords suggests that research conducted within medical education has focused on the effects of PBL on student learning and satisfaction, clinical issues (e.g., skills, practice, education, clerkship), professional competence, and evidence-based practice.

The second largest cluster is represented by keywords associated with "PBL Curriculum and Programs." This theme includes keywords associated with the design and implementation of PBL curricula and programs (e.g., "quality," "standards," "organization and management," "program development," "educational model," "psychology"). This cluster also highlights the inclusion of several associated domains of healthcare education (e.g., "nursing," "dental," "pharmacy"). The PBL literature related to these fields has emphasized curricular and program issues.

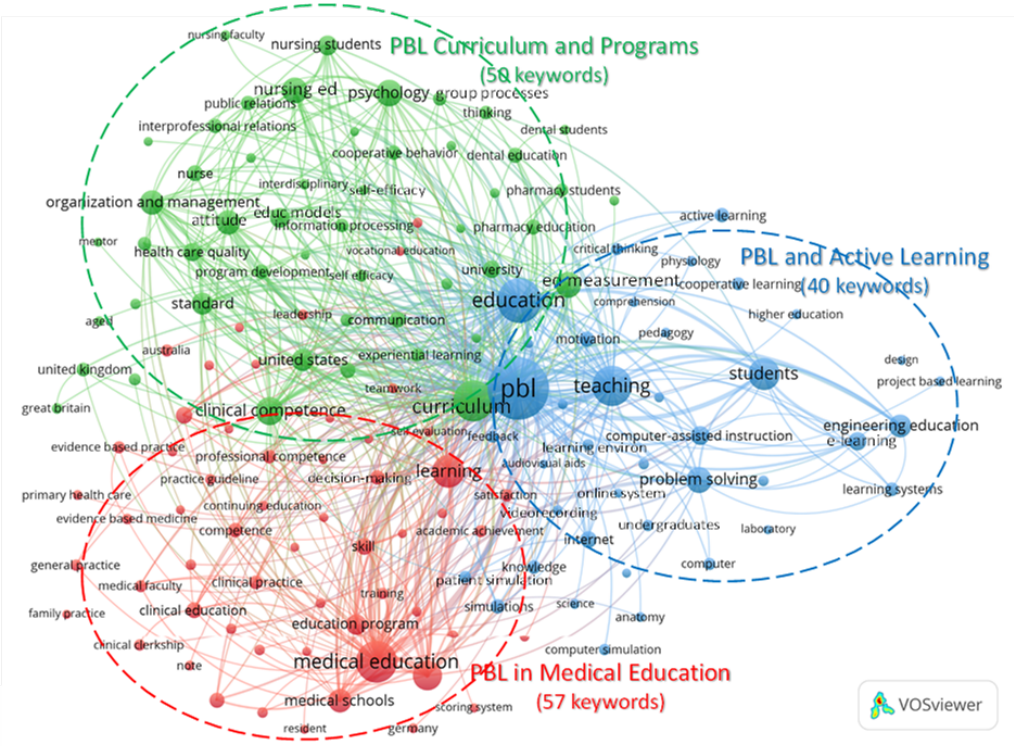

Figure 5: Keyword co-occurrence map of the Scopus-indexed literature on problem-based learning, 1972-2019 (threshold 150 occurrences, display 147 keywords)

The third theme concerns "PBL and Active Learning." Keywords located in this cluster suggest that research and practice on PBL is both linked to and incorporates findings from research on a broader array of active experiential teaching and learning methods (Biggs, 2011; Jonassen, 2002; Smith et al., 2005). These include "cooperative learning" (Johnson & Johnson, 1999; Slavin, 2011), "flipped classroom" (Bishop & Verleger, 2013), e-learning (Jin & Bridges, 2014), simulations and serious games (Hallinger & Wang, 2019; Kang et al., 2015), and project-based learning (Prince & Felder, 2006). Keywords located topics within this theme highlight teaching-learning processes associated with PBL (e.g., "learning environment," "feedback," "technology," "audio-visual aids," "online systems," and "video-recording").

The inclusion of engineering education in this cluster is notable. Indeed, its "physical distance" on the map from fields of professional education located in the other clusters suggests that engineering education has proceeded on a somewhat different path. More specifically, in engineering education PBL has been adopted in concert with other methods of active learning such as project-based learning rather than in the "traditional form" used in medical education (Mills & Treagust, 2003; Prince, 2004; Prince & Felder, 2006).

Next the author used VOSviewer to generate a "temporal overlay" on the co-word map (see Figure 6) that highlights the "research front" in the PBL literature (Price, 1965) This co-word map used a somewhat lower frequency threshold (i.e., 100 occurrences) in order to display a larger number of topics. On a temporal overlay, keywords that featured earlier in the period of the review are shown in darker shades/colors. Keywords (topics) featured in more recent years appear in lighter shades/colors. The legend shows 2012 as the beginning of the most recent period due to the fact that the time period associated with a keyword is based on a "distribution of dates." Thus, on this map the "median date" for keywords with 100 or more occurrences did not extend beyond 2012. Other interpretive guidelines for this map remain the same as above (i.e., node size and proximity).

After examining the color, size, and proximity of nodes on the temporal co-word map, the author synthesized three themes that comprise the PBL research front. First, the

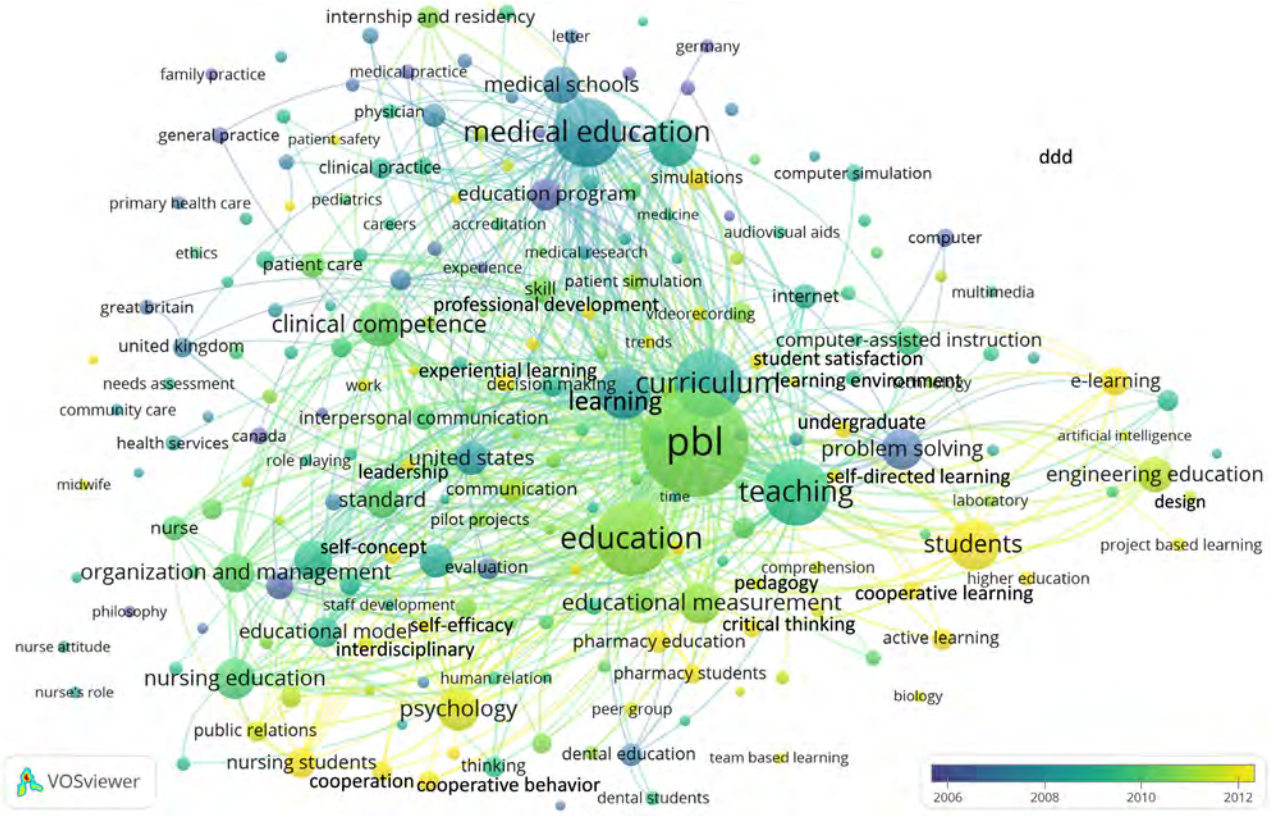

Figure 6: Temporal co-word map of the literature on problem-based learning, 1972-2019 (threshold 100 occurrences, display 228 keywords)

map highlights the currency of research conducted on PBL in engineering (Guerra, 2017), nursing (Gandhi & Dass, 2019), pharmaceutical (Zhou et al., 2016), dental (Alrahlah, 2016), and undergraduate education (Johnston, Schooling, & Leung, 2009). The yellow/light shaded keywords in Figure 6 indicate that research on the use of PBL in these subjects is gaining a critical mass.

Second, the map suggests that the substantive focus of PBL research has, over the past decade, expanded beyond the field's long-term interest in test performance and clinical competence. Recent research is exploring how PBL impacts a broader range of cognitive competencies and student attitudes. In order to get a sense of this research, the author identified research reviews in the database published during the past five years. The rationale for this approach follows from Garfield's (1994) assertion that reviews of research "serve as surrogates for earlier literature" (p. 4).

Examination of these recently published reviews of PBL-related research confirmed an emerging focus on examining the effects of PBL on students' "critical thinking" and "higher order thinking" (e.g., Alrahlah, 2016; Carvalho et al., 2017; Dolmans, Loyens, Marcq, & Gijbels, 2016; Ismail, Maasum, & Bakar, 2017; Oliveira, Díaz, Carbogim, Rodrigues, & Püschel, 2016; Tyo & McCurry, 2019). Studies have also sought to understand how "interpersonal skills" such as "group interaction" (Azer & Azer, 2015) and "communication" (Kaplonyi et al., 2017; Li, Wang, Zhu, Zhu, & Sun, 2019) both mediate learning and develop in the context of a problem-based curriculum. Recent research has also examined how PBL enhances the development of student attitudes such as "satisfaction" (Kang et al., 2015; Kilgour, Grundy, & Monrouxe, 2016), "self-efficacy," and "self-concept" (Durkin & Feinn, 2017; Geitz, Joosten-ten Brinke, & Kirschner, 2016). Notably, as suggested above, many of these reviews were conducted outside of medical education.

Finally, Figure 6 reveals that linkages with research on other forms of "active learning" are a relatively recent trend in the PBL literature. Indeed, the temporal map highlights PBL's place within a broader constellation of "active learning" methods. These span a wide range of constructivist, experiential learning methods (Acton, 2019; Bransford, Brown, & Cocking, 2000; Biggs, 2011; Brown et al., 1989; Dewey, 1986; Jonassen, 2002; Smith et al., 2005). The recent literature increasingly examines how educators are designing

and implementing PBL in combination with other forms of active learning including "simulations" (Hallinger & Lu, 2011; Kang et al., 2015), "project-based learning" (Gandhi, Yang, & Aiash, 2017), "e-learning" (Jin & Bridges, 2014), and "cooperative"/"team-based" learning (Ismail et al., 2017).

Discussion

This bibliometric review of research sought to document and analyze the full Scopus-indexed, interdisciplinary literature on problem-based learning. The review is distinguished by its longitudinal analysis of a very large set of PBL-related documents. This section of the paper highlights limitations of the review, interprets the findings, and identifies several implications of the findings.

Limitations

The main limitation of this review arises from the review methodology. More specifically, because bibliometric reviews do not examine the findings of studies, the reviewer can neither draw conclusions about the quality of research and nor assess progress along specific lines of inquiry. Thus, this review focused on documenting trends in knowledge production based on the analysis bibliographic data.

It should also be noted that this review only examined the English-language literature. Thus, the research output of countries where other languages are the primary mode of scholarly communication (e.g., Chinese, Portuguese, Spanish, French) is under-reported in this review.

Interpretation and Implications of the Findings

The database of 14,130 Scopus-indexed documents identified in this review is over four times the size of the next largest database analyzed in a review of PBL research (i.e., Pinho et al., 2015). The size of this knowledge base is placed in perspective when compared with literatures on other methods of active learning such as "cooperative learning," "project-based learning," "flipped classroom," "simulations and serious games." Simulated Scopus searches on these topics yielded document lists that ranged from 2,000 to 4,000 documents. This suggests that problem-based learning has accumulated the most extensive research literature among related methods of active learning. Moreover, this review identified an accelerating growth trajectory with 58% of the PBL literature published between 2010 and 2019. Given this publication trajectory, the literature on PBL will likely double in size over the next decade.

This review extended previous findings concerning the geographic distribution of the PBL literature (see Pinho et al., 2015). The Scopus-indexed PBL literature has been authored in 145 different countries. This highlights the global scope of research that has accumulated on problem-based learning over the past five decades. Moreover, the PBL literature is gaining in cultural diversity with an increasing proportion of the knowledge base being authored in "emerging regions." This contrasts, for example, with the literature on simulation-based learning where the global distribution of scholarship is far more attenuated (Hallinger & Wang, 2019).

Nonetheless, geographical imbalance in the production of knowledge on PBL calls into question the cultural validity of this knowledge base. Scholars have demonstrated that the "context of learning" shapes both teacher and learner attitudes and behaviors (Brown et al., 1989; Watkins, 2000). This conclusion applies to experiential learning approaches such as PBL which challenge traditional teacher-centered norms (Biggs, 2011; Hallinger & Bridges, 2007). For example, using Hofstede's (1980) cultural dimensions framework, Jippes and Majoor (2008) found that in European societies which evidence high "power distance," instructors tend to encounter more significant barriers in the implementation of PBL. This is due to the traditionally wide gap experienced between teachers and learners. Similar findings have been reported in Asia (Al-Eraky, 2013; Choon-Eng Gwee, 2008; Hallinger & Bridges, 2007; Hallinger & Lu, 2011; Walker et al., 1996).

This highlights the need to pay increased attention to the "cross-cultural validity" of PBL materials and instructional methods (Al-Eraky, 2013; Hallinger & Bridges, 2007; Walker et al., 1996). Scholars therefore emphasize the need to design PBL curricula around "authentic" problems that reflect the local context (Hallinger & Lu, 2011; Jippes & Majoor, 2008; Walker et al., 1996). Educators working in "high power distance cultures" have also proposed the need for stronger scaffolding as students proceed through a problem-based curriculum (Al-Eraky, 2013; Frambach et al., 2012; Frambach, Driessen, Beh, & van der Vleuten, 2014; Hallinger & Bridges, 2007). Thus, the author recommends that scholars in emerging regions undertake research that more systematically examines the design principles and impact of different refinements in PBL curriculum and instruction.

Author productivity and citation analyses conducted for this review identified a group "canonical scholars" (White & McCain, 1998) whose contributions to this literature are distinguished by high citation impact sustained over a period of decades. Predominately from the Netherlands and the USA and associated with medical education, these authors include Howard Barrows, Henk Schmidt, Geof Norman, Cindy Hmelo-Silver, Cees van der Vleuten, Diana Dolmans, and Albert Scherpbier. Bibliometric scholars have demonstrated that the identification of canonical scholars offers insights into the emergence of paradigms and key lines of inquiry in a literature (Price, 1965; White & McCain, 1998; Zupic & Čater, 2015). Thus, for example, this review surfaced the

influence of these and other high impact scholars (see Tables 2 and 3) in shaping key lines of inquiry into the psychological basis for PBL (Hmelo-Silver & Eberbach, 2012; Norman & Schmidt, 1992), design principles (Barrows, 1985), implementation issues (Albanese & Mitchell, 1993), and impact on learning outcomes (Dochy et al., 2003; Norman & Schmidt, 1992). These scholars have also influenced the evolution of inquiry into PBL through a series of high impact reviews of research (e.g., Albanese & Mitchell, 1989; Dochy et al., 2003; Gijbels et al., 2005; Norman & Schmidt, 1992; Vernon & Blake, 1993).

The topical analyses conducted in this review revealed a literature that has cohered around a long-term, focused program of research. This program of research is notable for its aim to understand if and how PBL impacts learning effectiveness. The research front in this literature appears to lie in expanding the range of individual learner and program outcomes to include self-directed learning, student satisfaction, self-efficacy, critical thinking, and cooperation among students.

Second, although medical education dwarfs all other educational domains in terms of research output, this review found that PBL research and practice has gained a critical mass of interest in engineering, nursing, dental, and pharmaceutical education. This finding, supported by multiple analyses, leads the author to ask, "Why has research on PBL failed to evidence a similar scope of interest in other disciplines?" While there is evidence of PBL use in other subjects (e.g., management, teacher education, education management, architecture, construction, K-12 education), research in these domains has remained sporadic and fragmented (Hallinger & Bridges, 2017). Does this reflect unsustained "adoption," or simply sparser publication of research? If PBL has not gained sustained adoption in other fields of professional education, why not? (Ertmer & Simons, 2006; Hallinger & Bridges, 2017; Hung, 2011)

Third, both author co-citation and temporal co-word analyses highlighted a trend of increasing cross-fertilization between PBL and other forms of "active learning" (Acton, 2019; Biggs, 2011). Temporal co-word analysis found that this was a relatively recent trend. Co-citation analysis highlighted the influence of experiential learning theorists on PBL research and practice (e.g., David Kolb, David Jonassen, John Biggs, David Johnson, John Dewey, Donald Schön). Scholars are exploring ways of increasing the impact of PBL through the more intentional integration of active learning approaches such as simulation-based learning, project-based learning, cooperative learning, flipped classrooms, and e-learning. Xian and Madhavan (2013) worried that this could lead to confusion over what constitutes PBL when reporting research results. However, the author still views this as a generally positive trend that will lead to the wider use of PBL over time. Indeed, there is also evidence of "reciprocal influence" with proponents of other forms of active learning choosing to incorporate principles of PBL into their instructional design.

This bibliometric review of research has documented the evolution of the knowledge base on PBL from multiple perspectives. The findings presented in this review describe the "state of the PBL knowledge base" in 2020. It is hoped that these findings can serve as benchmarks for future assessments of the evolution of this literature.

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