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ABSTRACT

Bibliometric reviews of research have gained increased popularity since the mid-2010s. Yet, many readers may be uncertain as to the purpose and method of bibliometric reviews. This article provides an introduction to bibliometric reviews, clarifies their purpose, and elaborates on methods of data collection, analysis, and interpretation. The latter half of the article is devoted to an illustrative, state-of-the-science, bibliometric review of research on problem-based learning (PBL). In this illustrative review, the author applied descriptive statistics, citation analysis, and co-citation analysis to a database of 5,764 Scopus-indexed documents on problem-based learning published between 2017 and 2022. The analyses found increasing diversity of the PBL knowledge base with respect to geographical sources, subject area origins, and focus of the research compared with findings reported in past reviews. Author co-citation analysis visualized the intellectual structure of the recent PBL literature revealing four dominant schools of thought: Interdisciplinary PBL Theory and Practice, Active Learning, Social and Experiential Learning, and PBL Process. The findings highlight the continuing growth and spread of PBL, as well as a trend of integration with other methods of experiential and active learning.

Keywords: bibliometric review, problem-based learning (PBL), review method

Over the past 20 years, reviews of research have gained increasing popularity across all disciplines. Two concurrent trends account for the increasingly significant role that reviews of research play in the 21st-century publication environment. First, growth in the volume of conceptual and empirical research since the 1990s has created a need for scholarship that integrates and makes sense of trends in knowledge accumulation. This fact highlights the unique perspective that reviews of research offer on the consolidation of knowledge (Hallinger, 2014, 2021a; Zupic & Cater, 2015). The second trend lies in the growth of evidence-based practice led by scholars in the health sciences (Li et al., 2019). Because reviews of research summarize, evaluate, and integrate evidence extracted from a corpus of research, they have attracted the interest of scholars, as well as policymakers and practitioners (Gough et al., 2017).

These trends have not only resulted in an increase in the volume of published reviews of research, but also the diversity of methods used by scholars to review research. The author's scan of the post-2000 literature using the search term "research review" surfaced a wide range of review methods including meta-analytic (Lipsey & Wilson, 2001), scoping (Pham et al., 2014), systematic (Gough et al., 2017; Munn et al., 2018), rapid (Khangura et al., 2012), integrative (Whittemore & Knafl, 2005), and bibliometric reviews (Chen & Chen, 2003; Zupic & Cater, 2015). Each of these review methods offers a particular approach to the consolidation of formal knowledge.

Similar diversity is evident in the literature on problem-based learning (PBL). The PBL literature has featured meta-analytic (e.g., Dochy et al., 2003; Gijbels et al., 2005; Hallinger, 2021a; Strobel & Van Barneveld, 2009), integrative (Norman & Schmidt, 1992; Schmidt et al., 2011), systematic

(Chen et al., 2021; Hallinger, 2014; Hallinger & Bridges, 2017), and bibliometric reviews (Azer, 2017; Hallinger, 2020, 2021b; Pinho et al., 2015; Xian & Madhavan, 2013). Indeed, PBL research and development have advanced at numerous points over the past six decades through the publication of key reviews of research (e.g., Albanese & Mitchell, 1993; Dochy et al., 2003; Dolmans et al., 2005; Norman & Schmidt, 1992; Strobel & Van Barneveld, 2009).

Although the bibliometric review method is by no means new (e.g., Price, 1976; Small, 1973; McCain, 1986, 1990; White & McCain, 1998), it remains one of the more recent methods of systematic review to gain popularity among scholars. Thus, for example, the first bibliometric review of research on PBL was published in 2013 (Xian & Madhavan, 2013). This recency further implies that readers, reviewers of journal manuscripts, and authors in the field of PBL may lack a basic understanding of bibliometric review methodology. Filling this gap represents the purpose of this article. More specifically, this article intends to reach the following goals:

- to articulate the purpose of the bibliometric review method, including the elaboration of when a bibliometric review is the review method of choice;
- to describe the method and procedures used in a bibliometric review including justification of the methods used in document identification, data analysis, and data interpretation;
- to illustrate how the first two goals are implemented in a state-of-the-science, bibliometric review of PBL literature published between 2017 and 2022;
- and to highlight features contributing to a high-quality, publishable bibliometric review.

The significance of this article lies in three areas. First, the article provides a basic introduction to the bibliometric review method such that PBL scholars will be better equipped to interpret, critique, and undertake bibliometric reviews. Second, the article offers fresh insights into developments in the most recent literature on PBL based on bibliometric analysis. Third, the identification of criteria for assessing bibliometric reviews holds the potential for increasing the quality and rigor of bibliometric reviews of research published in the future.

Bibliometric Review Method

Overview

Scholars tend to be most familiar with review methods that integrate empirical findings (e.g., meta-analytic and systematic reviews) or synthesize some combination of theoretical, methodological, and empirical literature (e.g., integrative, scoping reviews). Bibliometric review is unique among review methods in terms of its purpose, data, and analytical tools. The purpose of a bibliometric review is to document and analyze features of a knowledge base represented by a discipline (e.g., psychology) or a line of inquiry (e.g., PBL). Bibliometric reviews aim to gain insight into the publication landscape, theoretical structure, and topical composition of a knowledge base (Chen & Chen, 2003; Zupic & Cater, 2015).

Given these goals, bibliometric reviews are oriented towards identifying trends in "knowledge production" rather than synthesizing empirical findings or theories reported in particular studies. This purpose is reflected in the process of a bibliometric review which involves the quantitative analysis of bibliographic meta-data associated with a large database of documents using purpose-built software (Van Eck & Waltman, 2010). The document list analyzed in a bibliometric review can range from 200 documents on the low end to tens of thousands of documents. Consequently, bibliometric reviews, "introduce a measure of objectivity into the evaluation of scientific literature and hold the potential to increase rigor and mitigate researcher bias in reviews of scientific literature by aggregating the opinions of multiple scholars working in the field" (Zupic & Cater, 2015, p. 429).

The structure of a bibliometric review is quite similar to other forms of systematic review (Hallinger, 2013). An overview of the process used in a bibliometric review is displayed in Figure 1. Unfortunately, due to space constraints, the author cannot address all of the steps highlighted in Figure 1 in equal depth. Therefore, greater attention is given to those features that distinguish bibliometric reviews from other forms of systematic review.

Preparing for the Review

This phase of developing a bibliometric review is consistent with other forms of systematic research review. The review should be explicitly grounded in a problem of theory, policy, research, or practice. Having defined the problem that motivates the review, it is incumbent upon the reviewer to identify the research gap being addressed in the review. Unfortunately, this essential element is often inadequately addressed, or overlooked entirely, in many bibliometric reviews. Many scholars frequently simply state that the purpose of the article is to conduct a bibliometric review of the topic. Justification for the bibliometric review should reference the types of reviews that have already been conducted on the topic, along with citations.

A bibliometric review would be warranted if other research reviews have not adequately documented and analyzed the landscape and theoretical dimensions that comprise the literature and its evolution. For example, a topic may have only recently emerged and there is a need to understand the theories that are being used to study it. Or there have been paradigmatic changes in the way scholars have approached

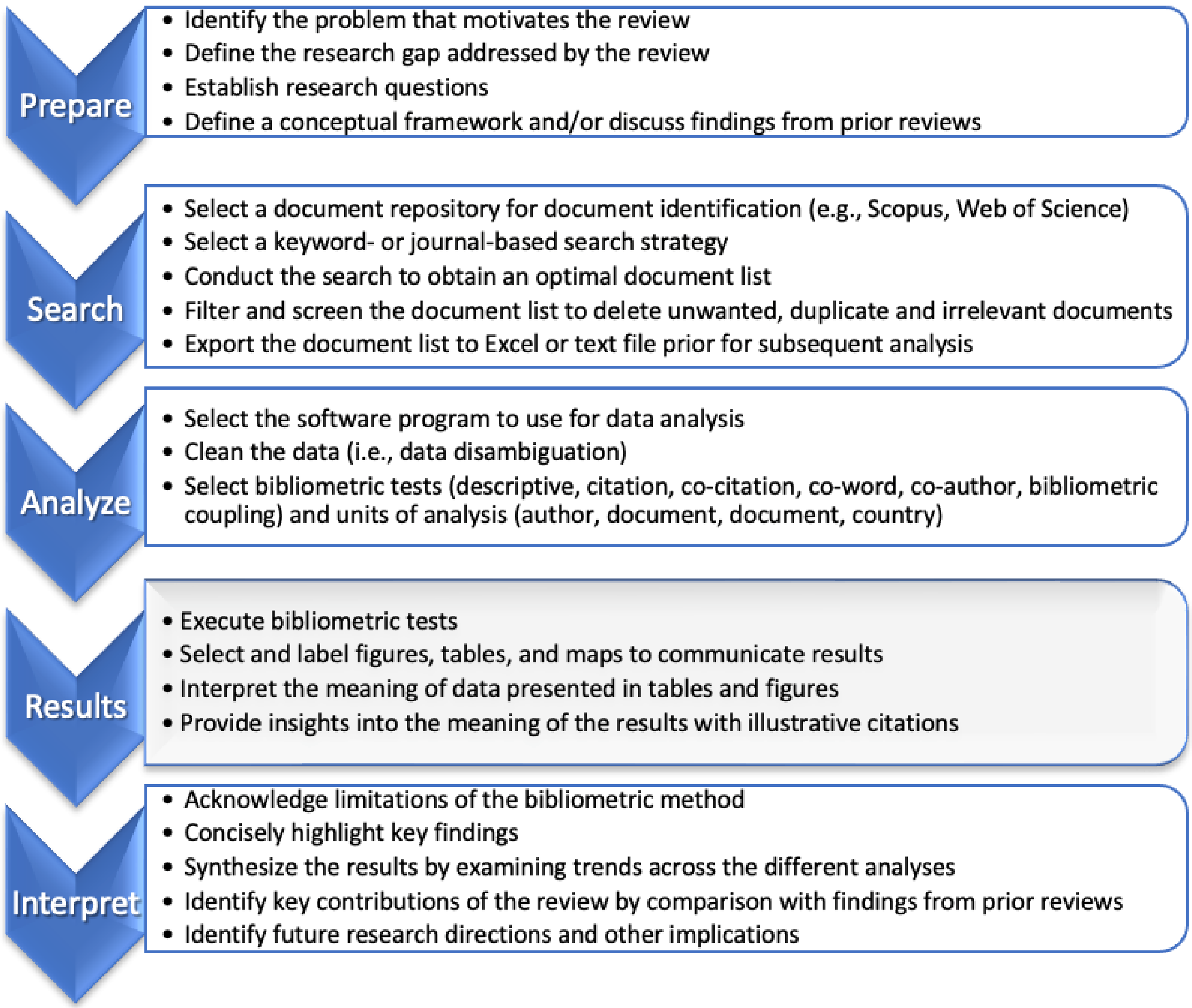

Figure 1. Overview of the bibliometric review process

a topic that deserve explication. An explicit statement of a research gap(s) should be followed by research questions that are clearly linked to the gap(s). The inclusion of explicit research questions that are addressed in the data analyses, and answered at the end of the review are a requirement in publishable bibliometric reviews.

The Search Process

Selecting a Document Repository. As a form of systematic review, an essential element of a bibliometric review is the use of transparent, reproducible, well-justified methods of document identification. This process begins with identifying a searchable document repository (e.g., Google Scholar, Scopus, Web of Science, Dimensions, Clarivate, Microsoft Academic, Pubmed, Medline). These document repositories are collections of journal articles, books, book chapters, conference papers and other sources. Eligibility criteria for inclusion of a source (e.g., a journal) in a document repository is established by the sponsoring companies. Unknown to many scholars, none of the companies that sponsor data repositories offer fully transparency on the selection criteria used to decide on the eligibility of sources. Thus, the scholarly community's perceptions of which repositories are of higher quality tend to be based on branding and tradition rather than the evaluation of transparent data. Contrary to popular opinion, there is no gold standard when it comes to selecting a document repository for a particular review (AlRyalat et al., 2019; Falagas et al., 2008; Martín-Martín et al., 2021).

In practice, the most commonly sourced document repositories (e.g., Scopus, Web of Science) overlap in their content (Mongeon & Paul-Hus, 2016). The selection of the optimal document repository for a review depends largely on the field of study under review. For example, while the Web of Science offers strong source coverage for the sciences, empirical comparisons have shown that its coverage of the social sciences and humanities is far less comprehensive than that of Scopus (Falagas et al., 2008; Mongeon & Paul-Hus, 2016; Moral-Muñoz et al., 2020; Norris & Oppenheim, 2007). Although Google Scholar offers the most comprehensive document coverage, it would appear to have less rigorous standards for document inclusion (Adriaanse & Rensleigh, 2013), and does not offer the data export capabilities required by most bibliometric software packages. The author refers readers to other sources for detailed descriptions, evaluations, and comparisons of the most frequently used data respositories (see AlRyalat et al., 2019; Archambault et al., 2009; Falagas et al., 2008; Mongeon & Paul-Hus, 2016; Martín-Martín et al., 2021; Moral-Muñoz et al., 2020; Singh et al., 2021; Vieira & Gomes, 2009).

The importance of this selection decision was revealed in one of the first bibliometric reviews undertaken by the author of this article (Hallinger & Kovačević, 2019). A young scholar sent the author a full bibliometric review manuscript for feedback and possible collaboration. Although unfamiliar with the review method, the paper seemed interesting, comprehensive, and well-written. The author's response to the scholar was succinct. "You don't need me as a co-author. The paper employs a novel method of review that appears to have been applied skillfully to the topic. The manuscript is well organized and includes all key elements of a systematic review. I don't see a need for substantial changes or where I could make a significant contribution. Best of luck."

Upon further reflection, however, discrepancies arose between the review's findings and this author's prior knowledge of the field. More specifically, many well-recognized articles were missing from the top-cited papers table featured in the manuscript. Reexamination of the paper's methodology revealed that the scholar had generated the database of review documents from the Web of Science. While many researchers view the Web of Science as the data repository of choice, only three of the top 12 international journals in the field under review were included in the Web of Science (WoS). This explained the omission of important articles from the reviwer.

Therefore, although the scholar's procedures for data collection and analysis were replicable (i.e., reliable), the study lacked validity due to the omission of many relevant data sources from the WoS. This was a critical oversight with massive implications for a bibliometric review that purported to offer an empirically validated analysis of the full landscape of literature on the topic (Zupic & Cater, 2015). Based on this feedback to the scholar, the review was rewritten from scratch after extracting a new dataset from Scopus, and rerunning all the analyses.

This example highlights the importance of selecting the optimal data repository for the topic under review. Space limitations preclude the author from going into a detailed comparison of the most common data repositories. However, several recent articles offer insight into their characteristics and the implications for decision-making for the purposes of a bibliometric review (AlRyalat et al., 2019; Mongeon & Paul-Hus, 2016; Martín-Martín et al., 2021; Moral-Muñoz et al., 2020; Singh et al., 2021).

Search Strategies. Once a document repository has been selected, the author must develop a search strategy that will be used to identify a document list. Although the most commonly used strategy in bibliometric reviews is keyword search, in some cases the reviewer may find it more effective to use a journal-based search strategy. The author will examine the rationale and method associated with both approaches.

Keyword-based Search Strategy. Keyword-based search strategies begin by developing a conceptual definition of the topic under review. For example, for the purposes of the illustrative review reported in this article, problem-based learning was defined as a team-based, active learning and teaching strategy used in K-12 schools, higher education and professional learning settings across all disciplines. The conceptualization of the core construct defines the boundaries of what is and is not to be included in the review. It is essential that the conceptual definition be stated explicitly before beginning the search for documents.

Next, in a keyword-based search, the author will use the document repository's search engine to develop an operational definition of the focal construct. This process involves selecting multiple keywords as search terms in combination with AND/OR/AND NOT operators. The search term string explicitly defines the operational boundaries of the review. The search engine will also offer a variety of search fields such as author-defined keywords, title, and abstracts.

The researcher will typically run a succession of searches using slightly different combinations of search terms, operators, and search fields. Each search will yield a document list that can be examined for congruence with the desired conceptual focus of the review. This iterative process continues until the researcher obtains a document list that includes the maximum number of relevant documents and the fewest irrelevant documents. Most document lists attained at this stage will, however, contain some irrelevant documents. The percentage of irrelevant documents could be as low as

1% and as high as 40%, depending on the clarity of the focal topic, the uniqueness of the search terms, and the skill of the author in executing the search process.

Once a basic document list has been generated in the search engine, the researcher begins a process of filtering and screening. Filtering refers to using native filters in the search engine to exclude categories of documents. For example, if the researcher decides to limit the review to journal articles and reviews, filters would be used to exclude book chapters, conference papers, editorials, and all other types of documents. Or if the researcher decides to limit the review to English language papers, filters would be used to exclude documents published in other languages. These decisions to exclude documents should be justified and carefully described to maintain the replicability of the review.

At this point, the reviewer must execute two steps designed to ensure the validity of the document list. Here, validity has two dimensions that can be explored through two questions. The first question is, Are there any irrelevant documents in the document list (i.e., documents whose content is not relevant to the conceptual focus of the review)? If so, these documents must be screened and deleted from the Scopus list. This process is completed through a time-consuming manual search of titles and abstracts in the document list in the search engine. When irrelevant documents are identified, they can be deleted from the online document list.

After the researcher is confident that all documents in the list are relevant to the topic, the second question to ask is, Are there any relevant documents missing from the list? The inclusion of these so-called missing documents could result from gaps in the search terms or ambiguities in the keywords and titles of the published documents. In order to answer this question, the reviewer may conduct a supplementary search using the names of key authors to check if all of their relevant papers were captured or if alternative search terms were used. If gaps appear, the reviewer can try to assess why and conduct a supplementary search that captures the missing documents.

This entire search and exclusion process should be justified (e.g., why you have decided to limit the review to journal articles) and documented in sufficient detail that it could be repeated by another researcher. A common tool used to communicate this process is a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) chart (Moher et al., 2009). The PRISMA chart conveys each of the search and exclusion steps discussed above. An example of a PRISMA chart is included for the illustrative review carried out in this article (see Figure 3).

Journal-based Search Strategy. Sometimes numerous attempts to develop a successful keyword-based search fails to yield acceptable results. This may be the case when a topic is very broad or comprised of multiple dimensions, such as "bilingual education" or "educational leadership and management". In such cases, the reviewer can assess the viability of a journal-based search strategy. In a journal-based search strategy, the reviewer identifies a set of specialization journals each of which focuses solely and explicitly on the proposed topic. The search engine is then set to identify all articles published in the identified journals.

The author used a journal-based search strategy when conducting a bibliometric review of research on "educational leadership and management" (Hallinger & Kovačević, 2019). Numerous keyword searches either failed to yield a sufficiently inclusive document list, or included far too many irrelevant documents. As an alternative, the author examined the list of Scopus-indexed journals with the objective of identifying journals that specialized exclusively on topics related to educational leadership and management. The authors identified 22 journals whose scope was deemed suitable for inclusion in the review. The names of the 22 journals were entered into the Scopus search engine using the "source" field. The journal-based search yielded a document list comprised of 22,361 documents representing the entire publication output of the 22 Scopus-indexed educational leadership and management journals published through 2018 (Hallinger & Kovačević, 2019).

Using this method meant that the author could be confident that every document in the resulting list was relevant to the review topic. The limitation of this search strategy was that it excluded many potentially relevant articles on educational leadership and management topics published in other journals (e.g., general education, management, social science journals). Not surprisingly, this point was raised by an astute reviewer when the manuscript was submitted for publication. The author's decision was justified based on three factors. First, using citations for support, the author validated the 22 journals as widely recognized sources in the field of educational leadership and management. Second, despite acknowledgment of the missing articles, the author noted (with citations) that the review's database of over 22,000 articles was over 10 times larger than any previously published review of research in the field (Hallinger, 2014). Finally, the use of co-citation analysis in the review mitigated this limitation, to some extent, by highlighting key documents and authors who had published relevant articles in journals that were not indexed by Scopus (see the sub-section on co-citation analysis for further explanation).

Notably, a journal-based strategy only works when there is a sufficient number of journals that specialize on the topic. Take, for example, the topic of PBL. A search of

Scopus-indexed journals identified only a single journal, IJPBL, specializing in PBL. Thus, a journal-based search strategy would miss most of the relevant literature.

In sum, the process of document identification is a key step in any bibliometric review. Although sometimes overlooked, the identification and curation of the document list are critical determinants of the quality and rigor of any bibliometric review. It recalls the idiom, "garbage in, garbage out," which is often used with respect to quantitative research.

Data Export. Following identification of the document list, the bibliographic meta-data associated with the documents are downloaded to either an Excel or text file depending upon the bibliographic software that will be used for data analysis. These data consist of a wide range of descriptive information including author names, document titles, abstracts, citation data, author affiliations, funding information, and more.

Data Analysis and Results

Select the Bibliometric Software. The popularity and utility of bibliometrics have given rise to the development of numerous bibliometric software packages over the past decade. These include Bibexcel, Biblioshiny, Bibliomaps, Citespace, CitNetExplorer, CRexplorer, Publish or Perish, SciMat, SciTool, and VOSviewer (see links to these software programs in Appendix A). These packages differ in terms of the data formats they can process, the bibliometric analyses they can perform, and the nature of output they can produce. Although the selection of a software package is a critical decision, the comparative criteria are too extensive to cover in this article. Readers are referred to other sources (see Appendix B) that provide comparisons of bibliometric software packages (see Bales et al., 2020; Cobo et al., 2011; Markscheffel & Schröter, 2021; Moral-Muñoz et al., 2020; Pan et al., 2018).

In this article, the author will illustrate several bibliometric analyses that were executed with VOSviewer software (Van Eck & Waltman, 2020). As described by Moral-Muñoz et al. (2020), "VOSviewer is a software tool designed for constructing and visualizing bibliometric networks, with journals, researchers, or individual publications as actors, and based on co-citation, bibliographic coupling, or co-authorship relations" (p. 11). VOSviewer is a free, easy-to-use software package that includes online support offered by the authors as well as other users (Van Eck & Waltman, 2010). As of early 2023, VOSviewer had been used for data analysis in several thousand Scopus-indexed bibliometric studies. The examples provided in this article using VOSviewer should be taken as illustrative since the capabilities and visual output will differ if another software package is used.

Data Cleaning. Next, the reviewer will export bibliographic data associated with the document list from the online search engine to a computer file. This file, comprised of rows and columns of bibliographic data, acts as an intermediate repository for the data, before it is uploaded into bibliometric software. Bibliometric software packages employ a variety of data formats (e.g., CSV, RIF, plain text, tab-delimited text). The reviewer will make the appropriate selection in the online search engine before exporting the data and saving it to the local computer.

Next, the extracted data will be uploaded into the bibliometric software. Before initiating data analysis, however, the data file must be disambiguated (Strotman & Zhao, 2012; Van Eck & Waltman, 2018). Disambiguation is a form of data cleaning that is critical to the reliability of a bibliometric review.

Take, for example, the current bibliometric review on PBL. When the author ran author co-citation analysis in VOSviewer, the results showed co-citation counts for Schmidt, H. as well as for Schmidt, H.G. Similarly, co-citation counts appeared for Scherpbier, A.J.J.A., as well as for Scherpbier, A.J.J., Scherpbier, A.J., and Scherpbier, A. In these cases, the multiple names referred to the same person. These ambiguities in the data arose from the fact that the software extracted the author names from references expressed in different style formats (e.g., APA, Chicago, Harvard), or that slightly different name variants were used at different periods of a scholar's career (e.g., Schmidt H. or Schmidt, H.G). Similar ambiguity can occur in the case of country names (e.g., USA, America, United States), keywords (e.g., student, students), as well as the titles of documents.

Therefore, steps must be taken to disambiguate these names, keyword terms, and document titles so that accurate counts can be achieved for each analytical unit. VOSviewer relies on a thesaurus file to disambiguate the data before executing the actual data analyses. The thesaurus file is comprised of a set of instructions that tells the software to replace one term (e.g., Schmidt, H.) with another (e.g., Schmidt, H.G.) during a particular data analysis (e.g., author citation analysis).

For example, when preparing a thesaurus for author citation analysis, the reviewer will begin by executing a trial run of author citation analysis in VOSviewer using a relatively low citation threshold. A lower citation threshold (e.g., 10 citations for an author) will yield a long list of authors that can be sorted alphabetically. This allows the user to identify duplicate names (e.g., Schmidt, H. and Schmidt, H.G.), in the document list. The researcher will add these duplicate names to a text file comprised of two columns (i.e., Label and Replace by). So, for example, if the researcher wishes to replace all instances of Schmidt, H. with Schmidt H.G., then Schmidt, H. would be typed into the first column of the thesaurus text file under Label and Schmidt, H.G. into the second column under Replace by.

The combined thesaurus file containing author names, document names, country names, and keyword terms used in the author's review of the full PBL literature consisted of 825 lines (Hallinger, 2020). The large size of this thesaurus file was due to the large size of the review database which consisted of over 12,000 documents. Reliable data analysis requires that considerable time and detailed effort go into preparing the thesaurus file used in any bibliometric review.

Bibliometric Analyses. Bibliometric analyses can be categorized into three broad categories: descriptive analyses, performance analyses, and science mapping. Descriptive analyses are used to describe the research landscape of a topic in terms of size, growth, subject distribution, and/or geographical distribution of the literature. Performance analyses include productivity, citation, and co-citation analysis. These analyses offer insights into key authors, documents, and journals that have made contributions to the topic. Science mapping uses visualization tools to reveal relational features of a body of knowledge based on the analysis of authors, documents, and sources (Moral-Muñoz, et al., 2020; Zupic & Cater, 2015). Science mapping has been used extensively to analyze the thematic structure of topics and fields of study. These methods of analysis are elaborated below in the context of reporting the results of the study.

Results

In the results section of a bibliometric review, the author will respond directly to the research questions. The analyses will be organized around a series of tables and figures generated by the bibliometric and associated software programs. For the purposes of this article, the explication of results will be organized around the three types of data analysis that are typically included in a bibliometric review.

Descriptive Analyses. Descriptive analyses are applied to bibliographic data with the aim of documenting the landscape of research that has been conducted on a topic. Frequently used descriptive analyses include the annual growth trajectory of publications in the database, the geographic distribution of the literature (i.e., by geographic location of the first author), subject area distribution of the documents (e.g., engineering, business, social sciences), and institutional affiliation of authors (e.g., universities, research institutes). These descriptive analyses may be conducted within the online data repository (i.e., Scopus, WoS), and/or in a separate software program such as Excel or Tableau. For example, Scopus offers the capacity to conduct some descriptive analyses online, as well as the capability to export associated data (e.g., country data) into an Excel file for further analysis.

There is no set menu to follow when deciding which descriptive analyses to include in a bibliometric review. Growth trajectory analysis offers insight into the growth and maturation of the field or topic over time. These findings may be helpful in predicting the future growth potential of a topic.

Geographical analysis of the documents clarifies where research on a topic has been conducted. This type of analysis is not only relevant in medical research where vaccine trials may be needed in different countries, but also in educational fields where the application of knowledge is highly contextualized. For example, the author's bibliometric review of research on simulation-based learning found that 83% of the literature accumulated over the past 50 years had been authored in Anglo-American and European nations. This suggested a potentially important gap in a field where learner responses to the pedagogical method may be subject to cultural influences.

Analyzing the subject area distribution of sources is particularly relevant in bibliometric reviews of interdisciplinary subjects. This analysis clarifies the subject areas in which an educational method has been. This analysis can also lend insight into the fields that have adopted a particular educational method, since adoption is a pre-requisite for carrying out a research study. This results of this analysis can also be leveraged by comparing findings from reviews of different active learning methods such as PBL (Hallinger, 2021b), simulations and serious games (Hallinger & Wang, 2020), and service learning (Hallinger & Narong, 2023).

Performance Analysis. Performance analysis can be conducted from the perspective of productivity, citations or co-citations. Each of these can be executed for different units of analysis (e.g., author, document, journal).

Productivity. Productivity analysis is employed to gain insight into the top-producing authors and key journals that have contributed to a topic or field. The findings of productivity analysis can have value in assessing varied patterns that describe the evolution of a field of study or a journal. For example, the author served as a referee on a bibliometric review which found that none of the authors in the field had published more than two papers on the topic. This discovery suggested a lack of programmatic research by scholars studying the topic.

In another case, the author conducted a bibliometric review of the flagship journal in a particular field. Author productivity analysis identified a highly skewed distribution of articles by authors and their affiliated institutions. More specifically, out of the 1,968 authors of articles published in the journal, just 22 authors accounted for 32% of its 1,176 articles. This finding suggested the possibility of a journal that was in need of greater diversification of authors and ideas.

Productivity data can be combined in a data table with other information related to authors and journals such as country of origin, topical focus, h-index, and/or impact factor. Obtaining these data require the reviewer to go beyond the data generated by the software. However, adding these types of data to the output generated by the bibliometric software enables the researcher to go beyond simple analysis. In the best cases, the author is able to synthesize useful trends that would not be apparent from the basic bibliometric output. For example, in a recent bibliometric review, the author found that the 20 journals which had published most frequently on the topic were all ranked in the first quartile of the Scopus index. This result suggested that a significant portion of the accumulated knowledge base on the topic had passed rigorous review. Although this type of indirect proxy for research quality does not substitute for the kind of quality evaluation that might be included in a meta-analysis, bibliometric reviews typically analyze much larger document databases. Thus, even this kind of quality evaluation serves a useful purpose.

Citation Impact. Citation analysis has long been employed by scholars to identify prominent authors, documents, and journals within a domain of knowledge (Gilbert, 1977; Merton, 1973; Small, 1973). Merton asserted that citations can be used to, "prove the historical lineage of knowledge and to guide readers of new work to sources they may want to check or draw upon themselves" (1973, p. VI). Over time, scholars have come to accept that a document (or author) that is heavily cited has made significant contributions to the advancement of knowledge (Garfield, 1979; Hood & Wilson, 2001). This proposition rests on the assumption that authors cite other scholars (or documents) who have influenced their own research (Garfield, 1979). Thus, citation metrics have come to dominate the assessment of the research impact of journals, individual researchers, departments, and universities (e.g., Mingers & Yang, 2017; Zupic & Cater, 2015).

While most readers are familiar with the general concept of citations, it is worthwhile to delve a bit deeper into some features of citation analysis. First, citation analysis can be conducted on different units of analysis. These include such documents, journals, organizations, and even nations. Second, citations take time to accumulate. For this reason, it can be useful to add a "citations per year" metric when conducting document citation analysis.

Second, in operational terms, citation analysis calculates the number of times a unit (e.g., author) has been cited in documents contained in the repository from which the reviewer's database was sourced (e.g., Scopus). For example, in this article, document citation analysis executed in VOSviewer calculated the number of times each document had been cited by other Scopus-indexed documents. Thus, the resulting metric is referred to as Scopus citations.

This point is critical because the citation count of any specific document (or author or journal) will vary depending upon the document repository from which the review database was sourced. This variation is due to differences in the size of the document repositories. Thus, for example, the largest citation counts tend to come from Google Scholar, followed by Microsoft Academic, Scopus, and Web of Science.

In addition, the magnitude of citations varies widely across fields and topics and deserves consideration. For example, compare the citation counts for the "top-cited document" in each of the following education-related fields:

- PBL – 5,003 Scopus citations (Hallinger, 2021b),
- simulation-based learning - 1,653 Scopus citations (Hallinger & Wang, 2020),
- service learning – 691 Scopus citations (Narong & Hallinger, 2023).

Citation analysis can be used to complement the findings of productivity analysis by identifying key authors and journals within a field. While this method is particularly useful for graduate students, it may also be pertinent for scholars who are entering a new field of study. Features of a set of top-cited documents or authors can also be synthesized in order to gain insight into topical interests, types of papers, and geographies. Journal citation analysis will typically reveal not only the journals that have published the most influential work on a topic, but also the journals that have published the most articles on a topic. Again, this approach is of practical interest to scholars as they immerse themselves in the research on a particular topic.

Of perhaps greater importance, citation analysis is also used to gain insights into key trends that emerge in the use of scholarship over time. For example, the analysis of highly-cited authors and documents can be used to identify key trends in the theoretical and empirical lines of inquiry that have gained traction over time. This procedure requires the analyst to take the step of supplementing the citation table with additional information (e.g., topic foci of the highly-cited documents or authors) and then synthesizing patterns from the data.

Co-citations. Though less widely known than citation analysis, co-citation analysis has been used by scholars for more than five decades (Noma, 1984; Small, 1973, 1980, 1981; White & McCain, 1986). When conducted in VOSviewer, co-citation analysis proceeds through several steps. Although this example will focus on author co-citation, the same process applies to document and journal co-citation analysis.

In the first step, VOSviewer examines the reference list associated with each document in the reviewer's database (i.e., uploaded document file). Each time that an author has been cited in a reference list, that author accrues one (co-) citation (Small, 1973). If an author has three publications cited in document X, the author accrues three citations.

Authors who are frequently cited in the reference lists of the review documents are considered influential but in a manner somewhat different from the impact assessed through citation analysis (Zupic & Cater, 2015). As noted, citation analysis identifies the impact of the authors contained in the review database. In contrast, by tracking the reference lists of documents in the review database, co-citation analysis identifies authors who have influences scholars conducting research on the topic being reviewed. This is a subtle but important distinction.

No limit is placed on the authors and documents that have been cited in the review documents. Thus, co-citation analysis accesses much broader literature than citation analysis. This method compensates for the limitation imposed on all document repositories and also reduces the impact of missing documents when using a journal-based search strategy. This feature of co-citation analysis enables the identification of influential literature that may even be outside the scope of the topic being reviewed.

For example, in the author's (2021b) previous review of the PBL literature, author co-citation analysis revealed the influence of scholars such as David Kolb, Richard Felder, David Johnson, Ann Brown, and Albert Bandura. Although these authors had not published on PBL, their work was frequently referenced by PBL scholars. This is quite a common phenomenon. Thus, co-citation analysis is a powerful tool used for revealing external sources of theoretical influence that have shaped the field under review. This capability will be elaborated in the next section on science mapping.

Science Mapping. Science mapping employs software tools to produce visual maps of the literature on a topic. Science mapping is a type of network analysis that can be executed through citation, co-citation, co-author, and keyword analysis (Börner et al., 2003; Chen & Chen, 2003; Zupic & Čater, 2015). In this section, the author will focus on the most common forms of science mapping: co-citation and keyword maps. Readers are referred to other sources that provide an in-depth discussion of the other forms of science mapping (Bankar & Lihitkar, 2019; Gutiérrez-Salcedo et al., 2018; Zupic & Čater, 2015).

Co-citation Analysis. Co-citation analysis has an additional capability that is used to analysis relationships among authors. More specifically, co-citation analysis also tracks the frequency with which pairs of authors are cited together in the reference lists of the review documents. Each time that two authors appear in the same reference list, they accrue one link, a co-citation metric. Thus, for example, if a document authored by H. Schmidt and another authored by H. Barrows appear in the same reference list, each author gains one link (see Figure 2). The bibliometric software tracks the number of each authors links with other authors cited in the reference lists of the review documents (see Figure 2).

In the final step, the bibliometric software uses the matrix of author co-citation frequency and links to create a science map which is a visualization of similarities (i.e., VOS) among co-cited authors in the literature. Author co-citation maps have been used widely as a means of analyzing the intellectual structure of the literature (Small, 1973; White & McCain, 1998). Intellectual structure refers to the dominant schools of thought in the field under review (McCain, 1986, 1990; White & McCain, 1998; Zupic & Cater, 2015). These schools of thought are identified by identifying the invisible colleges of authors synthesized on the author co-citation map (Gmür, 2003; Noma, 1984).

The author co-citation map contains four analytical features. First, size of an author's node on the map reflects the number of times the author was cited in the reference lists of the review documents. Larger nodes indicate more influential authors. Second, density of links between two authors is based on the frequency with which the pair have been cited together by scholars writing on the topic under review. Third, the proximity of nodes on the map also reflects the degree of similarity between the authors based upon their co-citation frequency. Authors located close together tend to have been frequently co-cited, while authors located at a distance from one another have not. Thus, authors located in the same area of the map will tend to bear a closer intellectual affiliation with each other (van Eck & Waltman, 2018; Zupic & Cater, 2015). Finally, the software assigns colors to clusters of authors based on an analysis of their similarities. These colored clusters are interpreted as representing schools of thought or invisible colleges of authors within the literature.

In the author's opinion, maps constructed using VOSviewer are easier to interpret than maps developed in some other software packages. Empirical comparison with alternative techniques used for constructing distance-based maps such as MDS, VxOrd and Kopcsa-Schiebel has identified distinct advantages for the visualization of similarities method (Börner et al., 2003; Cobo et al., 2011; Van Eck et al., 2010). Moreover, the VOS approach has been validated by comparing results obtained through alternative methods (McCain, 1986, 1990; Trujillo & Long, 2018). Consequently, VOSviewer has been used widely in bibliometric research reviews published in information sciences, social sciences, business administration, sciences, nursing, and medicine.

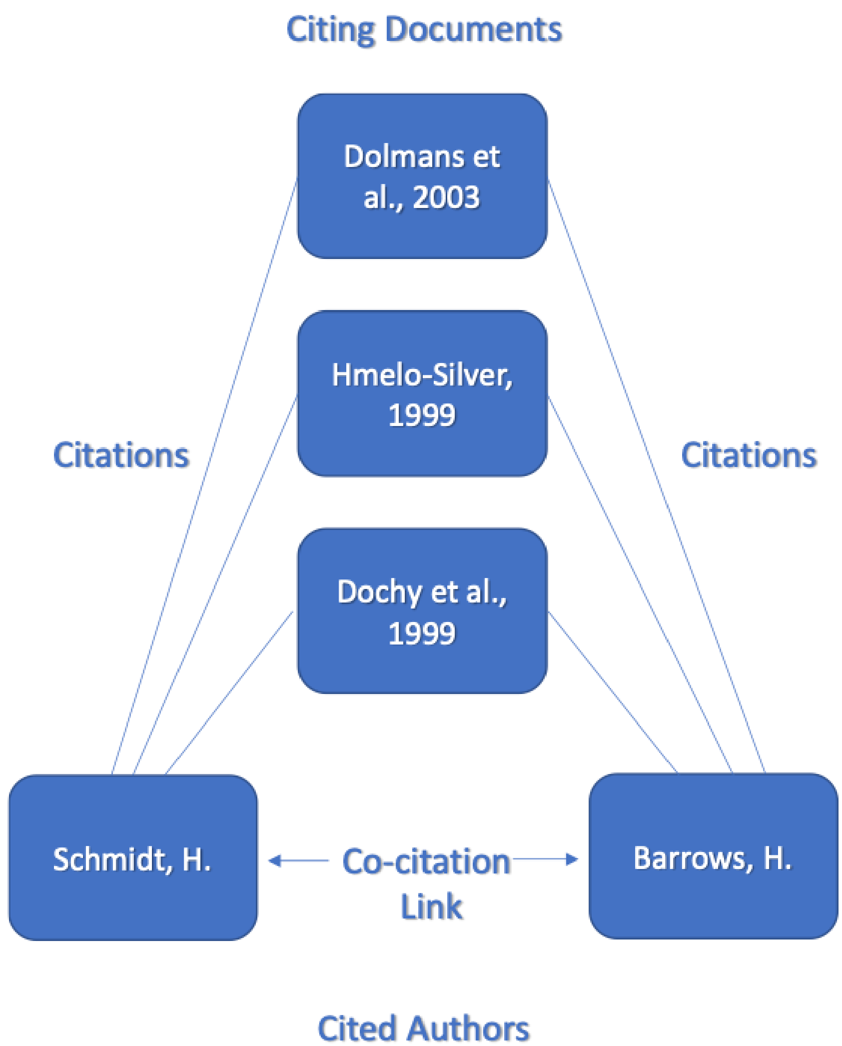

Figure 2. Illustration of author co-citation citations and links

Keyword Analysis. Keyword analysis is another common method of bibliometric analysis (Chen & Chen, 2003; Gutiérrez-Salcedo et al., 2018; Hallinger & Narong, 2023; Radhakrishnan et al., 2017). Keyword analysis extracts and analyzes text from the document titles, keywords, and abstracts in order to identify topical patterns and conceptual themes in the literature (Ding et al., 2001; Gutiérrez-Salcedo et al., 2018; Zupic & Cater, 2015). Keyword analysis is considered a lower inference method of analysis, when compared to co-citation analysis, due to its reliance on actual text in the documents rather than inference from themes based on clusters of authors or documents on a co-citation map.

Keyword analysis can be conducted in several steps. First, the bibliometric software can be set to generate a list of the most frequently occurring terms found in the keywords, titles, and/or abstracts of documents in the reviewer's database. Frequently occurring keywords may refer to topics (e.g., PBL, students, cognition), countries (e.g., USA, Australia, France), and/or research methods (experiments, surveys, qualitative research). A table of the most frequently occurring keywords extracted from the document database can offer insight into multiple facets of the topic under review. It should be emphasized that careful disambiguation of terms during the data-cleaning step is essential to obtaining useful results in keyword analysis. Indeed, the researcher will generally find it necessary to refine and update the thesaurus file several times during keyword analysis.

At the next stage of keyword analysis, the researcher may execute keyword co-occurrence analysis (co-word analysis) as a means of visualizing the literature under review (Chen & Chen, 2003; Ding et al., 2001; Hallinger, 2021b; Hallinger & Narong, 2023). Co-word analysis is conceptually analogous to co-citation analysis in that it tracks the co-occurrence of keywords in the review documents. VOSviewer then transforms the matrix of co-occurrence patterns into a visual map (i.e., a co-word map). Keywords with a strong similarity (i.e., frequently co-occurring) are located closer to one another on the map, while keywords that seldom appear together are located farther away. Interpretation of the co-word map follows the same guidelines as were used for a co-citation map (Van Eck & Waltman, 2010). Colored clusters of similar (i.e., frequently co-occurring) keywords are interpreted as conceptual themes, analogous to the schools of thought referenced in the section on co-citation analysis (Zupic & Cater, 2015). Thus, co-word analysis offers a complementary means of visualizing the literature that can extend the findings from co-citation analysis.

A co-word map can used to reveal the evolution of topics studied in a field over time. This is accomplished in VOSviewer by applying a temporal overlay onto the basic co-word map (Van Eck & Waltman, 2018). The temporal overlay is based on an analysis of the publication years for the full set of documents in which a keyword appeared (Hallinger & Narong, 2023). The mean of the distribution of publication years is then calculated for each keyword. The mean year of the distribution will reflect the time period when the keyword or topic appeared most frequently or was most popular. The software then assigns a color to each keyword coded to represent the time period during which a topic was most popular (i.e., earlier or more recently).

For example, in the author's prior review of the PBL literature (Hallinger, 2021b), keywords identified with the older literature included "problem-solving," "educational programs," "Canada," "Great Britain," "medical education," and "general practice." Keywords or topics associated with the PBL literature examined in the current review included "active learning," "e-learning," "pharmacy education," "cooperative learning," "simulations," and "student satisfaction". Thus, temporal co-word analysis offers a complementary means of analyzing the changing composition of a literature over time, based on topics, geographies, and research methods.

Other Forms of Science Mapping. Two other forms of science mapping used in bibliometric reviews are co-author analysis and bibliometric coupling. Due to space limitations and their somewhat less frequent usage, only brief explanations will be provided here. For a more extended discussion, please see other sources (Gutiérrez-Salcedo et al., 2018; Liu et al., 2015; Peters & Van Raan, 1991; Zupic & Cater, 2015; Wallin, 2005).

Co-author analysis draws on co-authorship data contained in the database in order to generate maps that also offer insight into the composition of a field. Sampaio et al. (2016) observed that co-authorship analysis allowed assessment of the productivity of research programs, assessment of the relationship between scientific and technological development, mapping of priority thematic areas, evaluation of the regional contribution to knowledge generation, assessment of inter-organizational networks, and assessment of international collaboration. Co-authorship is particularly useful in fields, such as PBL, that feature inter-disciplinarity (Huang & Chang, 2011).

Bibliometric coupling analyzes relationships among documents, authors, or journals based on patterns of shared references in order to gain insights into emerging fields of study. Zupic and Cater (2015) explain that, "Bibliographic coupling uses the number of references shared by two documents as a measure of the similarity between them. The more the bibliographies of two articles overlap, the stronger their connection" (p. 434).

Data interpretation. Data interpretation – not data analysis – holds the key to creating value in a bibliometric review. The capabilities of bibliometric software for producing data tables and visualizing data in charts and maps leads many authors to believe their job is done after simply running the analyses and providing a perfunctory summary of the content. In fact, this is the point at which deeper data interpretation should begin.

In order to gain the most from bibliometric charts (e.g., growth trajectory or subject area distribution), tables (e.g., top-cited documents), and maps (e.g., author co-citation or co-word maps), the reviewer should consider how to add value to the analysis. For example, when the reader inspects the charts, table, and maps in the second section of this article, note that the author has added to the basic output provided by the software program. In some instances additional data were added by hand (see columns 3, 4, 5, and 7 in Table 1 and the red numbers in Figure 4). In other cases, interpretive aids were used to highlight the meaning of the analysis (e.g., see labels and circles around the schools of thought in Figure 6). These additions aid the reader in seeing patterns in the data presentation and take the analysis to beyond the basic level provided by the software. The software turns data into information, but it is the reviewer's job to transform information into intelligence.

Discussion

The discussion section of a bibliometric review typically includes an acknowledgement of the review's limitations, interpretation of the results, and identification of implications that arise from the key findings. Limitations often follow from the choice of the index, conceptual definition of the topic, search method, duration of the review period, and the review method itself (i.e., bibliometric). Interpretation of the findings should briefly summarize key findings, and then focus on synthesizing patterns that emerged across the different analyses.

For example, in a review of sustainable construction, the author co-citation and co-words maps revealed mutually reinforcing perspectives on the intellectual structure of the literature. This subsection should clarify the specific contributions of the review when framed in the light of prior review findings. Finally, it should be noted that because bibliometric reviews do not synthesize the findings of specific studies, they tend to yield more implications for research than for policy and practice. Nonetheless, depending on the topic and depth of analyses provided by the reviewer, a bibliometric can also yield implications for policy and practice (Theeraworawit et al., 2022).

Illustrative Bibliometric Review of Research on PBL, 2017-2022

This section elaborates on the methods presented in this article through an illustrative state-of-the-science, bibliometric review of research on PBL. State-of-the-science reviews seek to identify current trends based on the most recent literature published on a topic. This review was designed to build explicitly on prior bibliometric reviews of the full literature on PBL (Azer, 2017; Hallinger, 2020, 2021b; Pinho et al., 2015; Xian & Madhavan, 2013). Due to space limitations, this bibliometric review neither includes all potentially relevant analyses, nor discusses the findings from each analysis in full depth. The author will, however, generally follow the bibliometric review steps in Figure 1.

Prepare for the Review

Recent bibliometric reviews have examined the evolution of PBL research and practice (Hallinger, 2020, 2021b; Pinho et al., 2015). Three key findings highlighted in these reviews were the increasingly diverse geographical profile of PBL researchers, the expansion of PBL from medicine into other professional fields, and a trend toward integrating PBL and other active learning methods. The impact of these observed shifts has been further accentuated by the exponentially increasing growth trajectory of research publications on PBL. More specifically, 66% of the PBL literature has been published since 2010, and 33% since 2017.

This finding prompted the author to question how the paradigmatic changes suggested in earlier analyses of the full PBL literature have evolved over the past five years. This led the author to undertake a state-of-the-science review that focused a bibliometric lens on PBL research published from 2017-2022. The review will focus on the following research questions that are linked to the trends identified in earlier bibliometric reviews (Hallinger, 2020, 2021b; Pinho et al., 2015).

1. What knowledge production trends are reshaping the direction of research on PBL?
2. What do influential documents published in the recent literature on PBL suggest about current directions in research on PBL?
3. What schools of thought have emerged in the literature on PBL for the period from 2017-2022, and how do they compare with schools identified in prior reviews?

Identification of Documents

This review employed a keyword-based search using the Scopus online document repository. Scopus was chosen due to its superior coverage of relevant inter-disciplinary literature on PBL (Hallinger, 2021b; Mongeon & Paul-Hus, 2016). The keywords used in this review were as shown in the following list:

> TITLE-ABS-KEY "Problem-based learning" OR TITLE-ABS-KEY "Problem based learning" OR TITLE-ABS-KEY "Problembased learning" AND PUBYEAR > 2016 AND PUBYEAR < 2023

This search yielded 6,077 documents comprised of articles, reviews, conference papers, books, book chapters, conference proceedings, editorials, notes, surveys, and letters. Because the review sought to identify trends in the most recent PBL literature, the author decided to include articles, reviews, conference papers, books, and book chapters.

Scopus filters were used to exclude 307 other types of documents (e.g., letters, editorials, notes). Six duplicate papers (conference and published versions) were identified, and the conference paper versions were deleted from the document list. Due to the uniqueness of the search term, "problem-based learning," no irrelevant documents were identified. It should be emphasized that this result is highly unusual; in all previous reviews conducted by the author, the document list included some irrelevant documents. This filtering process left 5,764 PBL-related documents comprised of journal articles and reviews, conference papers, books, and book chapters published between 2017 and the end of 2022. The search and screening process carried out for this review is shown in the PRISMA chart in Figure 3.

Data Analysis

The data analyses selected to address the research questions began with descriptive analyses aimed at documenting the subject area distribution and geographical distribution of the recent PBL literature. Subject matter distribution was

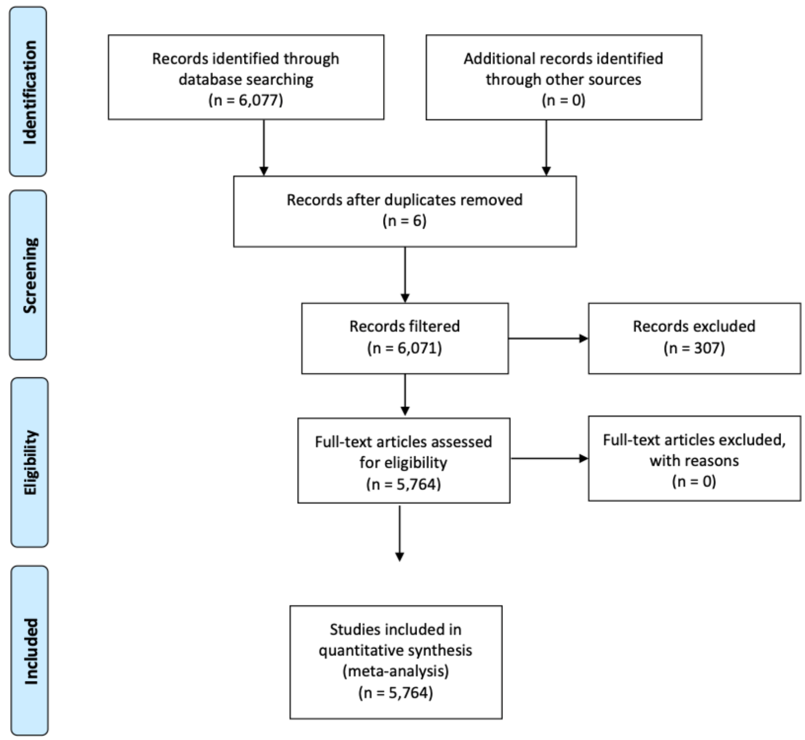

Figure 3. PRISMA chart showing the search and filtering process (Moher et al., 2009)

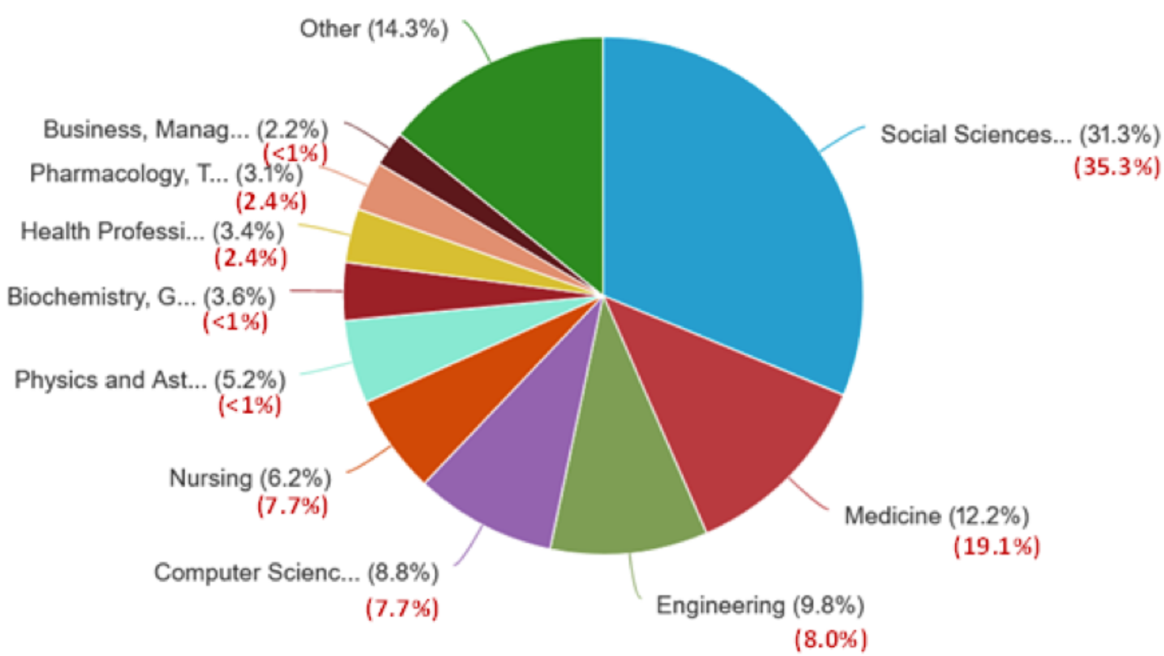

Figure 4. Subject area distribution of the literature on PBL, for the periods1974-2016 (n=11,711) and 2017-2022 (n=5,764 documents)

Note: Numbers in black refer to the period 2017-2022 and numbers in red indicate refer to the period from 1974 through 2016.

analyzed using Scopus analytical tools. Data on the geographical distribution of authors was exported from Scopus and subsequently analyzed in Tableau software. The remaining data analyses were conducted in VOSviewer version 1.6.8 (Van Eck & Waltman, 2020). In order to identify recently published documents with high potential for scholarly impact, the author employed citation analysis. Author co-citation analysis was used to analyze the intellectual structure of the literature. Due to space limitations, please refer to the prior rationale and descriptions offered for these analyses.

Results

Knowledge Production Trends

First, the size of the database of recent PBL documents identified in Scopus (i.e., 5,764) is quite extraordinary. A Scopus search using the same terms and filtering criteria for the period 1970-2016 yielded a database of 11,711 documents. This means that during the past five years scholars generated one-third of the entire published knowledge base on PBL. This represents exponential growth in the knowledge base on PBL and validates its growing relevance.

Subject matter distribution is of interest primarily as a means of gaining insight into the extent of interdisciplinary research and practice in PBL. Research interest is not a direct proxy for the usage of PBL in educational programs across different subject areas. Nonetheless, there is undoubtedly a relationship since scholars are unlikely to conduct research on PBL unless the method is in use.

The black numbers in Figure 4 show that the subject area distribution of research on PBL is quite diverse. Data in Figure 4 affirm that research and practice in PBL remains of interest not only in medical education but also across the health professions. More broadly, Figure 4 also shows that educators have increasingly adopted PBL as a method of learning and teaching in a wide variety of other fields as well.

In order to assess whether there have been any changes in the past five years, the author ran a Scopus search using the same search string for the years from 1970 to 2016. Then, a similar analysis was executed in Scopus analytical tools. The most striking changes are represented by the decreasing proportion of the literature contributed by scholars in medicine, social sciences, and, nursing, with concomitant increases noted for physics and astronomy, biochemistry, engineering, computer science, business management, health professions, and pharmacology.

Two points related to this analysis deserve emphasis. First, these figures refer to proportions of the whole. Thus, for example, a decreasing proportion of research documents from medicine does not necessarily imply that medical researchers are publishing less than in the past. It could simply be doing to larger increases in research published by scholars in other fields. Second, given the large document total, even small percentages can be quite significant.

The next analysis examined the geographical distribution of the knowledge base (see Figure 5). While the top 15 nations contributing to the recent PBL literature still feature strong representation from North America and Northern Europe (e.g., ranked [1] USA, [3] UK, [4] Canada, [8] Germany, [9] Spain, [10] Denmark, [11] Netherlands), there is a distinct trend of increasing contributions from Asia (e.g., ranked [2] Indonesia, [7] China, [12] Malaysia, [13] Japan, [14] Taiwan, [15] India) and Latin America (e.g., [6] Brazil).

Moreover, the data indicate dramatically increasing interest in PBL from numerous societies outside of the traditional sources of PBL scholarship. For example, consider the following comparative data showing the total number of PBL-related documents published for the entire pre-2017 period and the five-year period from 2017 through 2022 for the following countries: Indonesia, 43 documents pre-2017 / 693 documents post-2017; Columbia, 36/65; China, 242/229; Malaysia, 197/155; Saudi Arabia, 109/74. This trend of increasingly diversified PBL adoption and research bodes well for developing a strengthened globally representative knowledge base.

Shifts in the Focus of Research on PBL

Identifying highly cited documents in a body of knowledge is useful for directing readers towards concepts and research findings that have attracted the attention from other scholars. However, document citation in a state-of-the-science review takes on a slightly different perspective since relatively little time has passed in which documents can gain citations. In the current review, this limitation of citation analysis especially disadvantaged documents published in the past two years of the review.

With this limitation in mind, several useful insights can still be gleaned from the Scopus citation data presented in Table 1. First, note the dispersed geographical origins of the top-cited documents. While half of them were authored in traditional sources of PBL scholarship (i.e., USA, Canada, Denmark, Australia), the others came from non-Western societies (e.g., Hong Kong, China, Malaysia, Turkey, Ethiopia, Iran). Second, six of the documents were reviews of research and empirical papers. The presence of these reviews reflects a continuing maturation of the PBL literature, which has accumulated a significant number of empirical studies. Finally, the topics studied in these papers reflect the increasing integration of PBL with other forms of active learning, including flipped classrooms, simulations and games, and team-based learning.

Intellectual Structure of the Emerging Literature in PBL

Author co-citation analysis was used to visualize the intellectual structure of the recent literature on PBL. The map was generated using a threshold of at least 100 co-citations. This means that authors represented by the smallest nodes on the

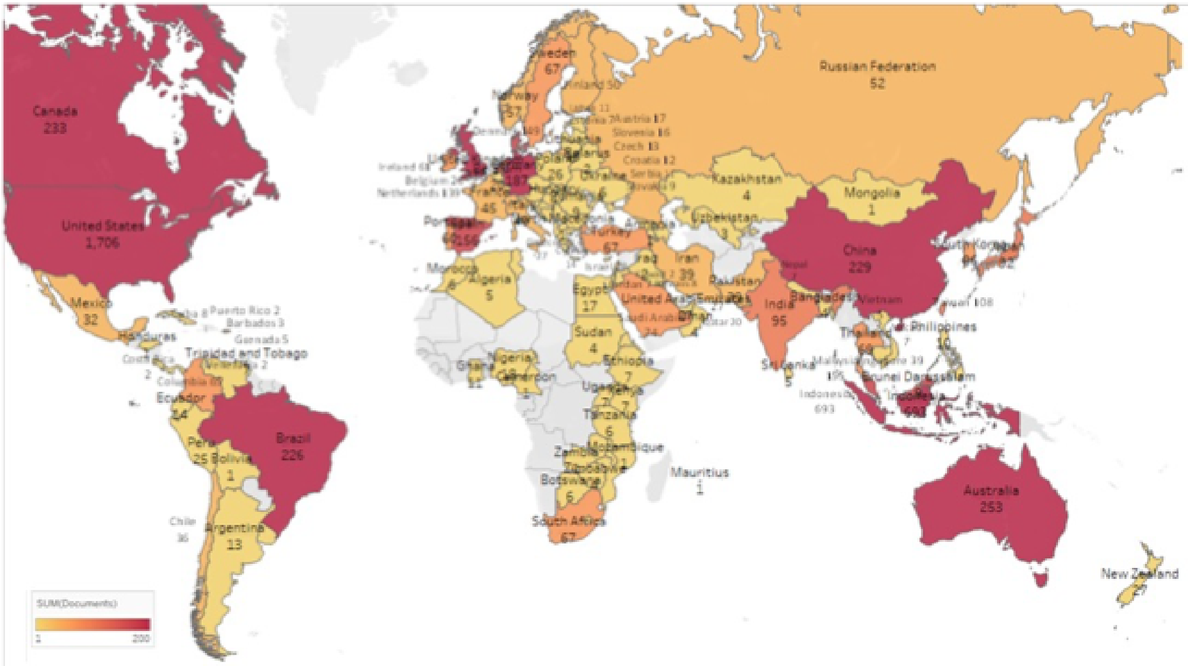

Figure 5. Geographical heatmap of the documents produced on problem-based learning by country, 2017-20221 (n=5,764)

map had each been cited about 100 times in the reference lists of the PBL documents (e.g., A. Brown, S. Mamede, D. Treagust). Likewise, the largest nodes refer to authors who had been cited most frequently in the reference lists (e.g., H. Schmidt, 1,000 citations; Barrows, 932; Hmelo-Silver, 836). As explained earlier, the colored clusters of authors are interpreted as schools of thought or invisible colleges that cohere to represent the intellectual structure of the literature. These invisible colleges, are "research networks [of scholars] that refer to each other in their documents without being linked by formal organizational ties" (Gmür, 2003, p. 27). Co-citation analysis offers an empirically based method of visualizing the self-organized relationships that evolve among scholars working within a field of study.

The co-citation map in Figure 6 visualizes four schools of thought in the recent PBL literature. In order of size, they are Interdisciplinary PBL Theory and Practice, Social-experiential Learning, Active Learning Methods, and PBL Process. The size of author nodes (i.e., citation frequency) and density of links between authors (i.e., frequency of co-citation) on the left side of the map affirm the intuitive observation that Interdisciplinary PBL Theory and Practice and PBL Process represent the core of this literature. Social-experiential learning and active learning represent theoretical streams or lines of inquiry that PBL scholars frequently draw upon (i.e., cite) in conceptualizing and studying PBL. Note also that the emergence of the Active Learning Methods school reinforces the earlier finding from document citation analysis through a different bibliometric analysis.

Labeling these schools of thought requires tacit knowledge of the PBL literature. Because the author of this article has been using and researching PBL since the 1980s, most of the authors appearing on the map were immediately familiar. Thus, the author could discern similarities among authors located in the same color cluster and synthesize this information to create a name for the school of thought. Scholars who lack this tacit knowledge would need to search on the names of key authors in a cluster (e.g., in Google Scholar or Scopus).

For when my first-year PhD students generate an author co-citation map, the names mean nothing to them due to their lack of tacit knowledge. They build that knowledge by searching for documents authored by the co-cited scholars, and then scanning the titles, abstracts, and portions of the articles. After going through that process for multiple authors in a cluster, the similarity or theoretical affiliation that connects them will begin to emerge. Indeed, the author uses this approach to familiarize first-term Ph.D. students with the literature on their proposed topics.

Rank	Document	Nation	Topic	Type	Scopus Cita-tions	CPY
1	Hew, K. & Lo, C. K. (2018). Flipped classroom improves student learning in health professions education: a meta-analysis.	HK	Flipped class	Rev	289	73
2	Chen, F. et al. (2017). A systematic review of the effectiveness of flipped classrooms in medical education.	USA	Flipped class	Rev	270	54
3	Deslauriers, L. et al. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom.	USA	Active learn	Emp	264	88
4	Theobald, E. et al. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math.	USA	Active learn	Emp	242	121
5	Ramnanan, C. J., & Pound, L. D. (2017). Advances in medical education and practice: student perceptions of the flipped classroom.	CAN	Flipped class	Emp	133	27
6	Ballen, C. J. et al. (2017). Enhancing diversity in undergraduate science: Self-efficacy drives performance gains with active learning.	USA	Active learn	Emp	105	21
7	Topalli, D., & Cagiltay, N. E. (2018). Improving programming skills in engineering education through problem-based game projects with Scratch.	TUR	PBL games	Emp	83	21
8	Reimschisel, T. et al. (2017). A systematic review of the published literature on team-based learning in health professions education.	USA	Team-based learn	Rev	83	17
9	Morton, D. A., & Colbert-Getz, J. M. (2017). Measuring the impact of the flipped anatomy classroom: The importance of categorizing an assessment by Bloom's taxonomy.	USA	Flipped class	Emp	83	17
1O	Adams, V. et al. (2018). Can you escape? Creating an escape room to facilitate active learning.	USA	PBL games	Emp	82	21
11	Jabarullah, N. H., & Hussain, H. I. (2019). The effectiveness of problem-based learning in technical and vocational education in Malaysia.	MAL	PBL effects	Emp	80	27
12	Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education.	TUR	PBL effects tech	Emp	77	26
13	Guerra, A. (2017). Integration of sustainability in engineering education: Why is PBL an answer?	DEN	PBL sust	Emp	74	15

Table 1. Top-cited documents in the PBL literature, 2017-2022 (n=5,764)

14	Argaw et al. (2017). The effect of problem-based learning (pbl) instruction on students' motivation and problem-solving skills of physics.	ETH	PBL effects	Emp	71	14
15	Njie-Carr, V. et al. (2017). An integrative review of flipped classroom teaching models in nursing education.	USA	Flipped class	Rev	65	13
16	Burgess, A. et al. (2017). Team-based learning (TBL) in the medical curriculum: better than PBL?	AUS	Team-based learn	Emp	63	13
17	Tang, F. et al. (2017). Comparison between flipped classroom and lecture-based classroom in ophthalmology clerkship.	CHI	Flipped class	Emp	61	12
18	Dehghanzadeh, S., & Jafaraghaee, F. (2018). Comparing the effects of traditional lecture and flipped classroom on nursing students' critical thinking disposition: A quasi-experimental study.	IRA	Flipped class	Emp	54	14
19	Kim, N. J. et al. (2018). Effectiveness of computer-based scaffolding in the context of problem-based learning for STEM education: Bayesian meta-analysis.	USA	PBL tech	Rev	51	4
20	Berkhout, J. J. et al. (2018). Context matters when striving to promote active and lifelong learning in medical education.	NET	Active learn	Con	51	

AUS=Australia; CAN=Canada; CHI=China; DEN=Denmark; HK=Hong Kong; ETH=Ethiopia; MAL=MalaysiaIRA=Iran; NET=Netherlands; TUR=Turkey; USA=United States

con=conceptual; emp-empirical; rev=review of research CPY=citations per year

Table 1(continued). Top-cited documents in the PBL literature, 2017-2022 (n=5,764)

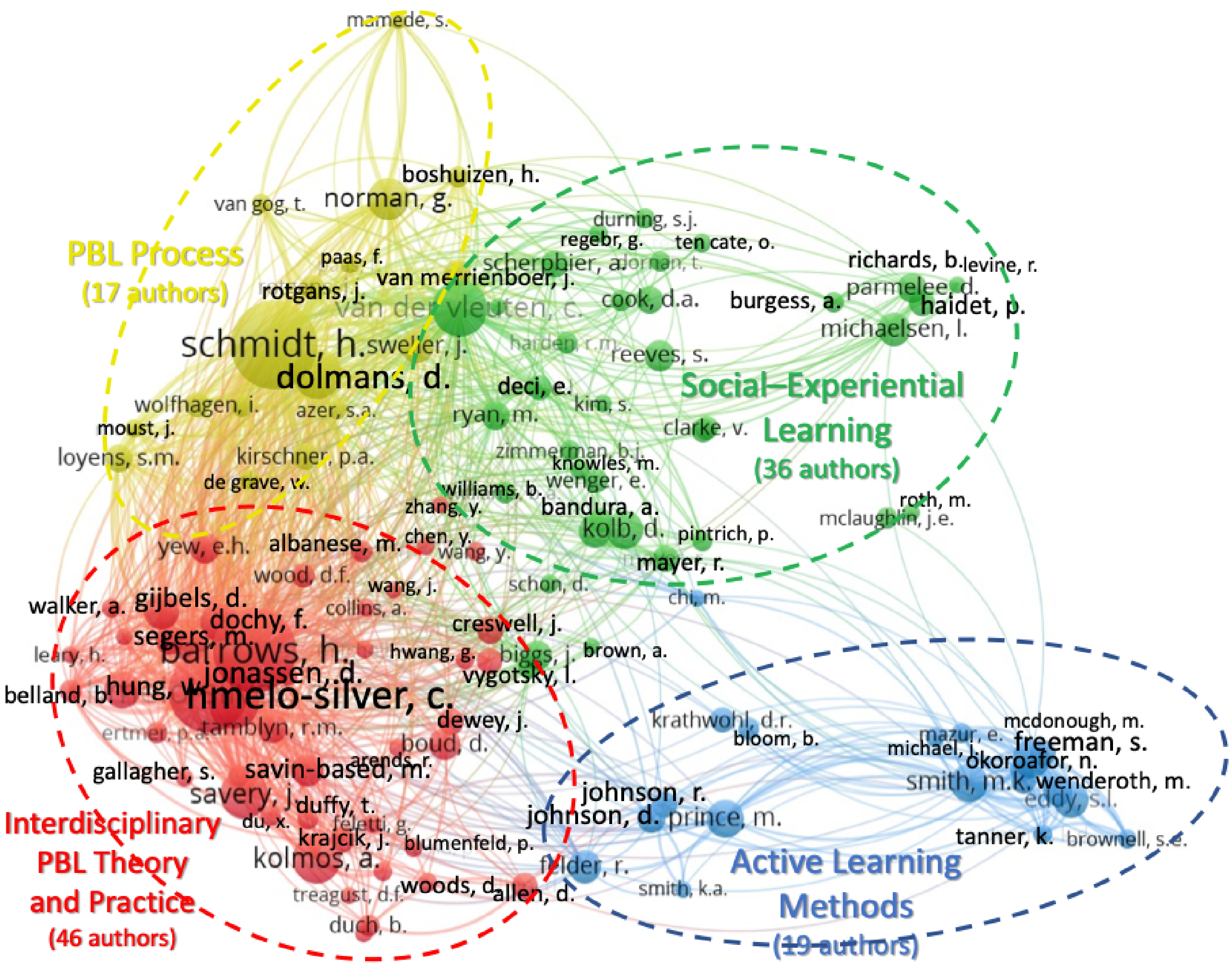

Figure 6. Author co-citation map of the literature on problem-based learning, 2017-22
(threshold 100, display 118, .90 resolution)

In a full paper, the author would now proceed to interpret each school of thought by defining the meaning of the school, highlighting the nature of the contributions made by key authors and documents, and providing relevant citations (see Hallinger, 2020; Hallinger & Kovačević, 2019; Hallinger & Wang, 202). Who are the key authors in the school of thought? What has been the focus of their research? How are authors connected to one another? Why are some schools of thought larger than others? What does the location of a school on the map imply about its influence in the literature? It is this level of data interpretation that creates value in a bibliometric review.

Discussion

This state-of-the-science bibliometric review of research on PBL was undertaken for the purpose of examining the extent to which trends identified in past bibliometric reviews (e.g., Azer, 2017; Hallinger, 2020, 2021b; Pinho et al., 2015; Xian & Madhavan, 2013) have continued in the most recent literature. First, the descriptive analyses further reinforced the prior finding (Hallinger, 2021b) of a rapidly accelerating publication trajectory of research on PBL. Second, while the social sciences and medicine continue to produce the most research publications on PBL, scholars in engineering, sciences, computer science, and business management have increased their contributions to this literature. This finding reaffirms the broad and growing interdisciplinary interest in PBL research and practice.

The geographical analysis yielded further insight into the nature of the growth trajectory by validating the increasingly diverse geographical distribution of the global knowledge base on PBL. In particular, scholars from non-Western societies accounted for 40% of the knowledge base on PBL published during the past five years. This number compares with less than 5% of the literature in 2000 (not tabled). This result bodes well for the development of a global knowledge base. This geographical trend was reprised in analyzing highly cited PBL documents published since 2017. Highly-cited documents were authored not only in traditional sources of PBL scholarship (e.g., USA, Canada, Australia, Denmark, Netherlands), but also in developing and non-Western societies (e.g., Hong Kong, Turkey, Iran. China, Ethiopia, Malaysia).

The results of the document citation and author co-citation analysis results were mutually reinforcing. They elaborated on a trend of increasing integration of PBL with other forms of active learning identified in bibliometric reviews conducted by Xian and Madhavan (2013) and Hallinger (2020). A comparison of the author co-citation map in Figure 6 with maps of previous decades (Hallinger, 2020) affirms a clear acceleration of this trend during the past five years.

When compared, for example, with a map for the period from 2010-2018 (Hallinger, 2020, p. 1435), the current map yields greater differentiation in active and experiential learning methods studied in conjunction with PBL. The range of these active learning methods is elaborated in the document citation analysis, which found a concentration of empirical studies and research reviews on flipped classrooms, team learning, serious games, active learning, and learning technologies among the most highly cited documents in the recent literature. PBL is being used increasingly as a pedagogical framework designed to leverage distinctive features of other active learning approaches such as simulation-based learning (see Hallinger & Wang, 2020) and service learning (Hallinger & Narong, 2023).

These findings have several implications for further research in PBL. First, the subject area analysis suggests the potential for bibliometric, integrative, and systematic reviews of PBL research that focus on several emerging disciplinary domains. The timeliness of this recommendation is reinforced by the fact that five such reviews featured in the table of top-cited PBL documents published since 2017 (e.g., Hew & Lo, 2018; Kim et al., 2018; Njie-Carr et al. 2017; Reimschisel et al., 2017). Second, the trend toward integrating PBL with other forms of active learning deserves further unpacking. For example, which design features are being used when integrating PBL with other methods of active learning and what are the effects? Third, evidence of increasing geographical dispersion suggests the relevance of conducting country-specific bibliometric reviews on PBL in societies such as China, Indonesia, Brazil, Taiwan, and Malaysia. These reviews should take note of how the cultural context influences the implementation of PBL (Frambach et al., 2014; Hallinger & Bridges, 2007; Hallinger & Lu, 2011; Walker et al., 1996).

Conclusions

This closing section will highlight a key limitation of this article, reflect on the utility of the bibliometric review method, and identify common pitfalls observed in bibliometric reviews. The purposes of this article were, first, to introduce the bibliometric review method, and second, to illustrate this method through a review of recent research on PBL. To compensate for limitations in the discussion of the bibliometric review method, the author has additional information on software tools (see Appendix A) and document repositories (see Appendix B). The reference list includes numerous citation of articles that provide additional detail on bibliometric analyses (Börner et al., 2003; Chen & Chen, 2003; Ding et al., 2001; Liu et al., 2015; Peters & Van Raan, 1991; Van Eck & Waltman, 2010; Wallin, 2005; Zupic & Cater, 2015).

The value of a bibliometric review derives from the unique ability of this method to (1) document trends in the evolution of a knowledge base, (2) analyze the theoretical and topical composition of the literature, and (3) provide directions for future research. Bibliometric reviews are not designed to analyze topics in depth like an integrative review, nor are they equipped to synthesize findings from empirical studies as is done in systematic and meta-analytic reviews.

Bibliometric reviews can, however, be justified as the review method of choice in a variety of circumstances. Once an emerging field or topic has generated sufficient research, a bibliometric review can highlight theoretical connections to other fields of study and identify avenues for moving the literature forward productively (Hallinger, 2021a). Bibliometric reviews also have a unique ability to visualize the evolution of a field over time (Hallinger, 2020, 2021b; Hallinger & Kovačević, 2019). Furthermore, as illustrated in the current review, they can be conducted as a state-of-the-science review that highlights emerging trends represented in the most recent literature.

Unfortunately, the seeming ease of conducting bibliometric analyses with modern software has turned the bibliometric review method into a hammer to which everything else begins to look like a nail. Too many bibliometric reviews fail to identify a research gap that is suitably addressed by using bibliometric methods. Many authors simply introduce a topic and then state, "The purpose of this article is to conduct a bibliometric review of _______," as if the need/gap is self-explanatory.

The lack of an explicit gap to justify the method often leads to a second common flaw: the absence of research questions. Without research questions, the researcher cannot justify the selection of bibliometric tests. This scenario is frequently observed in bibliometric reviews in which the author executes a series of bibliometric tests simply because they are easily generated by the software.

During the data-collection phase, the author should justify the selection of the document repository and explain why it is suitable for the field being reviewed. Then, all search, filtering, and screening steps taken to develop the document list should be clearly recorded. Procedures used to clean the exported database should be briefly acknowledged. The goal at this stage of the review is to report the research procedures in sufficient depth so that they can be replicated.

It should also be emphasized that bibliometric tests yield distorted results when the document database is too small – for example, a co-word or co-citation map generated from a document sample of just 75 or 100 documents. The author or keyword nodes on the map will look larger or smaller in relation to one another, as on a map generated from a large document sample; however, the thresholds used to generate the map will be so small (e.g., 3 or 4 occurrences or co-citations) that the results will not be meaningful. How useful is it to know that three documents in the literature focused on a particular topic? Can an author co-cited in just three, four, or five reference lists be considered "influential"?

Even the descriptive statistics in a review based on a small document sample may lack meaning and utility. For example, the author recently refereed a bibliometric review in which the author had analyzed a database consisting of 45 documents. Each of the descriptive analyses yielded long-tail distributions around a very low mean (e.g., most productive authors by number of papers: 3, 2, 2, 1, 1,1, 1, 1. . . ; geographical distribution of documents: 2, 2, 2, 1, 1, 1, 1, 1, 1, 1. . .). With a sample of just 45 documents, the author should have used a scoping review. The author suggests a guideline of at least 200 documents to gain the best value from a bibliometric review. The number of documents has no upper limit.

Analyses conducted in bibliometric software yield potentially useful charts, tables, and maps. However, as elaborated earlier, the usefulness of the output depends upon the author's ability to highlight the meaning of the analysis. Simply displaying a series of tables and charts without offering useful interpretation fails to achieve the purpose of a research review.

Finally, extracting meaning from the data analysis should continue in the discussion section of the paper. This review phase should do more than summarize the findings. It should synthesize findings across the different analyses and highlight key contributions of the review by comparing the findings to those of prior reviews.

In closing, the bibliometric review method offers a unique and complementary perspective within the repertoire of research review methods. Indeed, because the findings of a bibliometric review concern features of the knowledge base and knowledge production, they often yield recommendations for conducting additional research reviews on specific topics using alternate review methods. Thus, as knowledge accumulation continues to accelerate, the relevance of bibliometric reviews will continue to grow.

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Appendix A. Bibliometric Resources

Links to Bibliometric Software

Bibexcel: https://homepage.univie.ac.at/juan.gorraiz/bibexcel/

Biblioshiny: https://www.bibliometrix.org/home/

Bibliomaps: http://www.sebastian-grauwin.com/bibliomaps/

Citespace: https://citespace.podia.com/

CitNetExplorer: https://www.citnetexplorer.nl/

CRexplorer: https://andreas-thor.github.io/CRExplorer/

Litmaps: https://www.litmaps.com/

Publish or Perish: https://harzing.com/resources/publish-or-perish

SciMat: https://sci2s.ugr.es/scimat/

SciTools: https://www.scitools.com/features

VOSviewer: https://www.vosviewer.com/

Appendix B. Bibliometric Software Reviews and Comparisons

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