WIP: Beyond Keywords: Demonstrating Reproducible and Transparent Database Search Strategies for Engineering Education Systematic Reviews

Margaret Phillips
Purdue University Libraries
& School of Information Studies
Purdue University
West Lafayette, IN, USA
phill201@purdue.edu

Jason B. Reed
Purdue University Libraries
& School of Information Studies
Purdue University
West Lafayette, IN, USA
reed252@purdue.edu

Dave Zwicky
Purdue University Libraries
& School of Information Studies
Purdue University
West Lafayette, IN, USA
dzwicky@purdue.edu

***Abstract*—This work-in-progress, research-to-practice paper focuses on creating and reporting reproducible and transparent database search strategies for engineering education-focused systematic reviews.**

A systematic review, also known as a systematic literature review, is a type of research method designed to comprehensively collect, analyze, and synthesize the literature related to a specific research question(s) using a structured, linear, and detailed approach. The method has its origins in the medical sciences, but has since been adopted and popularized in many other disciplines. Recent research, conducted by the authors, shows that conducting systematic reviews in engineering education is a popular and growing trend globally, but researchers are generally not following best practices and established guidelines for conducting and reporting their database search strategies, which may result in incomplete data collection, inadequate analyses, and irreproducible reviews. This paper highlights best practices and guidelines (e.g., PRISMA) for developing and reporting transparent, reproducible, and thorough database searches for systematic reviews, since this is a complex aspect of the method that requires careful planning, consideration, and attention to detail. It will also provide a situated learning approach to educating researchers about database search strategies, incorporating a hypothetical research question related to engineering and computing education. The approach will demonstrate the detailed process of selecting appropriate databases to search, how to select keywords and synonyms, how to properly combine terms and phrases into a database search, how to translate a search to a different database, and how to properly report database searching using established guidelines for systematic reviews, all in the context of engineering education. This approach could be used by engineering education instructors, librarians, and other engineering educators in courses or with small groups of students. Future research plans include investigating how extensively and well engineering education researchers (faculty and students) create and report search strategies before and after receiving guided instruction on the process.

***Index Terms*—reviews, reproducibility of results, libraries, search methods, information retrieval**

I. Introduction

Review articles are an important source of information for readers, as the overarching aims are "to provide a valuable, solid, informative, critical summary of a well-defined topic/area" [1]. Previous research by Johnson et al. [2] shows that the volume of scientific literature produced today is enormous, with the existence of 33,100 peer-reviewed English language journals distributing approximately 3 million articles each year in 2018, and rates of growth of 4-5% per year. With these numbers it is not possible for individual researchers to keep up with all of the potentially relevant articles to their areas of interest. Review articles can help as a way for researchers to learn what is collectively known about a topic by reading a synthesized summary of the relevant literature.

However, what constitutes a review article is not universal. Reviews can take many forms, as outlined by Grant & Booth [3], who describe fourteen variations of review articles. The fourteen types range from generic literature reviews that may include only limited searches of the literature or only present author selected results, to systematic reviews, which are designed to comprehensively collect, analyze, and synthesize the literature related to a specific research question(s) using a structured, linear, and detailed approach that is transparent and reproducible. Recently, Saunders-Smits [4] applied Grant and Booth's fourteen-type framework to engineering education and found that it fits well with the discipline and there were no studies they could not classify using the typology.

The systematic review method is the primary focus of this paper. Systematic reviews originated in the medical sciences [5], but have since been adopted and popularized in many other disciplines concerned with evidence-based decision-making, including business [6], psychology [7], and engineering education [8]. The Borrego et al. 2014 article [8] describes the methodological process of conducting systematic reviews specifically within the discipline of engineering education,

which is newer and more interdisciplinary than other fields that have long employed systematic review methods. Additionally, Borrego et al's 2015 article [9] focuses on the state-of-the art of systematic reviews in engineering education, identifying and examining 49 systematic reviews.

More recent research by Phillips et al. [10] shows that conducting systematic reviews in engineering education is a popular and growing trend globally, with 276 reviews being identified and analyzed from 45 countries. However, Phillips et al. [10] found the authors are generally not following best practices and established guidelines for conducting and reporting their methods, which may result in incomplete data collection, inadequate analyses, and irreproducible reviews. One particular area that Phillips et al. focused on was the selection of sources (e.g., databases) and the database search strategies used by engineering education researchers. According to Foster and Jewell [11], "searching more than one database for a systematic review is essential." However, Phillips et al. [10] found that nearly 25% of engineering education studies did not report searching any databases or only searching one database and 89% of studies used low quality database search strategies, suggesting the processes of designing and reporting database searches may be challenging for some engineering education researchers.

The goal of this work-in-progress paper is to highlight best practices and guidelines for developing and reporting transparent, reproducible, and thorough database searches for systematic reviews, since this is a time-consuming, complex aspect of the method that requires careful planning, consideration, and attention to detail [12]. It also provides a situated learning approach [13] to educating researchers about database search strategies, incorporating a hypothetical research question related to engineering and computing education. Situated learning theory is heavily used in engineering education and relies upon social activities and interactions, which pairs well with systematic review methods that are typically carried out in research team environments.

The proposed approach discusses the process of selecting appropriate databases to search, how to select keywords and synonyms, how to properly combine terms and phrases into a database search, how to translate a search to a different database, and how to properly report database searching using established guidelines for systematic reviews, all in the context of engineering education. This approach could be used by engineering education instructors, librarians, and other engineering educators in courses or with small groups of students.

II. Resources & Best Practices for Systematic Reviews

Before selecting the best databases to search and the search terms needed, a review team must have a well defined research question. The research question guides the entire process and is helpful to refer back to when making any decision related to the systematic review moving forward. Additionally, a useful exercise in finalizing the research question and helping develop a database search strategy is breaking the research question down into its most important concepts using a research question framework. See Table I for a list of some relevant frameworks for engineering education.

TABLE I
Research Question Frameworks [11]

Framework	Components	Annotation
PICO	**P**opulation; **I**ntervention; **C**omparison; **O**utcome	One of the most common frameworks, recommended by Borrego et al. [8] for engineering education.
PICOT	Adds **T**ime to the PICO framework	Demonstrates adapting standard PICO to better reflect a specific research question.
PEO	**P**opulation; **E**xposure; **O**utcome	Less clinically focused, potentially useful for thinking about use of specific techniques in teaching.
SPI(DER)	**S**etting; **P**henomenon of **I**nterest; **D**esign or **E**valuation or **R**esearch	Recommended in Anderson & Booth's chapter [14] on research question frameworks for education.

With the research question established and the key components broken down using the research framework, a systematic review team is ready to begin selecting the best databases and keywords for their search. To help researchers in this area, there are two types of resources, reporting guidelines and conducting guidelines. Reporting guidelines help researchers identify what should be included in their method write-ups, (e.g., which databases were searched) and conducting guidelines provide more suggestions on how a systematic review team should perform their review (e.g., which databases to search). Table II provides a list of resources including both reporting and conducting guidelines. Researchers should consult both types of resources before starting a review in order to follow best practices and in order to track the methods used.

III. Applying Best Practices for Engineering Education

With the basic outline of a systematic review project in mind, the next step is to educate engineering education researchers on how to select databases and conduct the review using the appropriate conducting and reporting guidelines. Some of this knowledge is specific to the systematic literature review space, such as learning the ins and outs of a particular reporting guideline, but much of it should already be in the core skill set of many engineering educators, engineering librarians, and engineering information specialists. The foundations of formulating research questions (an important first step), selecting databases, developing search strings, etc. are skills that many of these practitioners already teach and apply in their work with students, but a systematic review requires taking these skills to a more advanced level.

As an example, here is a sample scenario: A group of engineering education graduate students approach a faculty

TABLE II
RESOURCES FOR SYSTEMATIC REVIEWS

Resource	Resource Type	Resource Annotation
PRISMA 2020 Checklist [15]	Reporting Guideline	PRISMA is one of the leading groups in reporting systematic review guidelines. This updated checklist provides recommendations on what should be reported, how it should be reported, and in which section of the manuscript.
PRISMA 2020 Explanation & Elaboration [16]	Reporting Guideline	This article is a deeper explanation of the different components the 2020 checklist recommends reporting for systematic reviews. This can be helpful for newer researchers to develop more understanding of how PRISMA defines each criteria.
PRISMA-Search [17]	Reporting Guideline	An article from the PRISMA group focusing specifically on how to report a reproducible and transparent database search strategy.
Borrego, Foster, & Froyd 2014 [8]	Conducting Guideline	This article provides guidance to engineering education researchers on how to apply the systematic review methodology in their discipline. The article walks through the different components of a systematic review and provides examples and suggestions relevant to engineering education.
EBSE Technical Report 2007 [18]	Conducting Guideline	Report on describing systematic reviews, planning for a review, and conducting a systematic review from start to finish. It was developed from a software engineering perspective, but still relevant to engineering broadly.
Ierardi, Oriheula, & Jurado 2018 [19]	Conducting Guideline	Another engineering focused set of guidelines, this one is focused on systems and automatic engineering. It includes discussion of the most used databases for this discipline and pros and cons of those databases.
Tranfield, Denyer, & Smart 2003 [6]	Conducting Guideline	This article looked at ways to adapt and apply the systematic review methodology as developed for the health sciences into the field of management. It is a good example of how to keep the underlying philosophy of the evidence synthesis method, while adapting the specifics to better reflect the review research question.

member asking for help getting started with conducting a systematic review. They have a rough research question revolving around ethics education as applied in mechanical engineering courses and they have been told to use PRISMA, but they are not sure where to start.

This section will not go through all of the potential answers to each question posed, but an educator or librarian could help the students work through these problems to teach them about systematic review methods. These are also questions that could translate into activities that teach students and faculty about systematic reviews, in a more formal educational setting such as a course or workshop. Since systematic reviews are conducted in teams, due to the need for multiple independent reviewers and the need for a range of expertise [11], educators and librarians could use a situated learning approach to teach about the systematic review searching process, using a scaffolding approach where teams are initially guided through examples. Subsequently, teams could then independently work through developing a research question on a topic of their choosing, select appropriate databases, and develop and translate an appropriate search strategy, mirroring the processes of an actual systematic review.

What is the nature and scope of their review? (PRISMA Item #3) This is an opportunity to clarify that what the students need to produce is actually a systematic review. Researchers unfamiliar with the methodology may conflate systematic reviews with other review types from Grant & Booth's typology [3]. For example, a researcher may erroneously conclude that, because they are a person who approaches any problem systematically, the narrative reviews they conduct are necessarily "systematic reviews."

In the case of our scenario, what are the students actually trying to learn about ethics in mechanical engineering, according to their research question, and how does that translate into methodology? Are they trying to identify an optimal intervention or determine what's been done (and not done) in this area, or, in other words, is this a systematic review or a scoping review? How big and how involved do they intend this project to be? Will it require multiple researchers, how much time will they be able to devote to it, etc.?

What is the specific research question? (PRISMA Item #4) This is an opportunity to lead students through an activity on crafting and refining research questions, such as those proposed by Fincher & Adams [20], Borrego et al. [8], or Kanter & Byrd [21]. Additionally, the aforementioned PICO, PICOT, PEO and SPI(DER) frameworks (see Table I) could be easily broken down into smaller pieces for in-class activities and class discussions. For example, a think-pair-share activity asking different groups within a class to identify each element of PICO for a given problem, and then bringing them all together to show the resultant research question.

Adapting this to our scenario, what might PEO look like? While there are many ways these elements could be framed, in this case "P" (population) could be mechanical engineering undergraduates, "E" (exposure) could be ethics education, "O" (outcome) could be a reduction in academic dishonesty

infractions. This would lead to the research question "What impact does ethics education have on the incidence of academic dishonesty in mechanical engineering undergraduate students?"

What are the basic steps necessary to conduct a systematic review? Given the specific guideline, what pieces of information will the researchers need to collect? For each item in Table 2, there should be a checklist or a description of the necessary steps in the original guideline document. As an example, the PRISMA 2020 checklist [16] includes twenty-seven items that need to be included to satisfy that guideline's requirements. In terms of the search, two of those items would include "... the full search strategies for all databases, registers and websites, including any filters and limits used" and "... all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted."

What databases should they choose? (PRISMA Item #6) This will, of course, depend on what resources are available, but the educator or librarian could encourage the student to prioritize databases with the best coverage in the relevant subject areas as well as databases that support advanced search techniques (e.g., Boolean logic, truncation, targeting specific data fields) and that allow for reproducibility of search results. In this case, they could use their existing area knowledge to suggest engineering-specific databases (e.g., Compendex, Inspec), education-specific databases (e.g., ERIC, EBSCO Education Source), engineering education-specific databases (e.g., ASEE PEER), or expansive interdisciplinary databases that might capture interdisciplinary and multidisciplinary content (e.g., Scopus, Web of Science). Google Scholar may also be an appropriate choice, albeit with recognition that its searches are not reproducible. If necessary resources are unavailable, the research team could consider potential partners from other institutions and organizations. For the example research question, depending on institutional access, we would recommend searching Compendex, Inspec, ASEE PEER, ERIC, EBSCO Professional Development Collection, and either Web of Science or Scopus.

What other search options could be considered? (PRISMA item #6) Depending on the specific research question, the scope of available resources, and the allowances of the chosen conducting and reporting guidelines, the researchers may want to consider other modes of searching such as searching cited and citing references (i.e., "snowballing") and searching the tables of contents of specific journals (i.e., "hand searching"). Additionally, the researchers could be guided towards other forms of literature outside of traditional scholarly publications as appropriate, such as grey literature (e.g., preprints, government documents).

What should the search string look like, and how can that be translated into each of the selected databases? (PRISMA item #7) This is an opportunity to teach researchers about developing database search strategies from the research question. This process is complex, involving breaking down the research question into an initial search strategy, identifying and applying appropriate natural language and controlled vocabulary terms and synonyms, using Boolean operators (and / or / not) appropriately, incorporating database phrase, truncation, wildcard, proximity operator, limit, and filter functionality, and adapting the initial strategy to other databases [22].

For example, an engineering ethics education-related search may start with a simple keywords strategy, such as *(ethics AND education AND mechanical engineering AND undergraduate AND academic dishonesty)*, and be transformed into a lengthy search that takes up many lines of text. It is crucial with a systematic review to report enough detail so that reviewers and future researchers can replicate the search.

IV. Conclusion

This paper discusses an approach to teaching engineering education researchers about conducting and reporting database searching for systematic reviews, provides an overview of resources that support these efforts, and gives a related, discipline-specific example. This approach could be used by engineering educators, engineering librarians, and other information specialists in a situated learning context, in order to increase adherence to appropriate conducting and reporting guidelines among engineering education systematic reviews.

We plan to iterate on this work-in-progress approach by gathering feedback from engineering educators and librarians and investigating how well engineering education researchers (faculty and students) select databases and create and report search strategies for systematic reviews before and after receiving guided instruction on the process. This will inform the creation of more fully developed, discipline specific search examples that could be used as resources by engineering education researchers conducting systematic reviews.

V. Acknowledgment

Funding for this work was provided by the Purdue University Office of Research and the Purdue University Libraries & School of Information Studies.

VI. References

[1] R. Balon, "What is a review article and what are its purpose, attributes, and goal(s)," *Psychotherapy and Psychosomatics*, vol. 91, no. 3, pp. 152–155, Mar. 2022. DOI: 10.1159/000522385.

[2] R. Johnson, A. Watkinson, and M. Mabe, *The STM report: An overview of scientific and scholarly publishing*, 5th Edition. STM, Oct. 2018. [Online]. Available: https://www.stm-assoc.org/2018_10_04_STM_Report_2018.pdf (visited on 05/13/2024).

[3] M. J. Grant and A. Booth, "A typology of reviews: An analysis of 14 review types and associated methodologies," *Health Information & Libraries Journal*, vol. 26, no. 2, pp. 91–108, 2009. DOI: 10.1111/j.1471-1842.2009.00848.x.

[4] G. N. Saunders-Smits, *Towards a typology in literature reviews in engineering education research - using the right review for the job*, May 2024. DOI: 10.13140/RG.2.2.15048.74241.

[5] J. Lind, *A treatise on the scurvy. In three parts. Containing an inquiry into the nature, causes and cure of that disease. Together with a critical and chronological view of what has been published on the subject.* London: A. Millar in the Strand, 1757.

[6] D. Tranfield, D. Denyer, and P. Smart, "Towards a methodology for developing evidence-informed management knowledge by means of systematic review," *British Journal of Management*, vol. 14, no. 3, pp. 207–222, 2003.

[7] M. Petticrew and H. Roberts, *Systematic reviews in the social sciences: A practical guide*. Wiley, 2006.

[8] M. Borrego, M. J. Foster, and J. E. Froyd, "Systematic literature reviews in engineering education and other developing interdisciplinary fields," *Journal of Engineering Education*, vol. 103, no. 1, pp. 45–76, Jan. 2014. DOI: 10.1002/jee.20038.

[9] M. Borrego, M. J. Foster, and J. E. Froyd, "What is the state of the art of systematic review in engineering education?" *Journal of Engineering Education*, vol. 104, no. 2, pp. 212–242, 2015. DOI: 10.1002/jee.20069.

[10] M. Phillips, J. B. Reed, D. Zwicky, and A. S. Van Epps, "A scoping review of engineering education systematic reviews," *Journal of Engineering Education*, Jul. 2023. DOI: 10.1002/jee.20549.

[11] M. J. Foster and S. T. Jewell, Eds., *Piecing together systematic reviews and other evidence syntheses* (Medical Library Association Books). Rowman & Littlefield, 2022.

[12] W. M. Bramer, G. B. de Jonge, M. L. Rethlefsen, F. Mast, and J. Kleijnen, "A systematic approach to searching: An efficient and complete method to develop literature searches," *Journal of the Medical Library Association: JMLA*, vol. 106, no. 4, pp. 531–541, Oct. 2018. DOI: 10.5195/jmla.2018.283.

[13] A. Johri and B. M. Olds, "Situated engineering learning: Bridging engineering education research and the learning sciences," *Journal of Engineering Education*, vol. 100, no. 1, pp. 151–185, Jan. 2011. DOI: 10.1002/j.2168-9830.2011.tb00007.x.

[14] P. F. Anderson and A. Booth, "Question frameworks," in *Piecing together systematic reviews and other evidence syntheses*, ser. Medical Library Association Books, M. J. Foster and S. T. Jewell, Eds., Rowman & Littlefield, 2022, pp. 45–56.

[15] M. J. Page, D. Moher, P. M. Bossuyt, *et al.*, "PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews," *BMJ*, vol. 372, n160, Mar. 2021. DOI: 10.1136/bmj.n160.

[16] "PRISMA 2020 checklist," PRISMA statement. (2021), [Online]. Available: https://www.prisma-statement.org/prisma-2020-checklist (visited on 05/13/2024).

[17] M. L. Rethlefsen, S. Kirtley, S. Waffenschmidt, *et al.*, "PRISMA-S: An extension to the PRISMA statement for reporting literature searches in systematic reviews," *Systematic Reviews*, vol. 10, no. 1, p. 39, Jan. 2021. DOI: 10.1186/s13643-020-01542-z.

[18] B. A. Kitchenham and S. Charters, "Guidelines for performing systematic literature reviews in software engineering," Technical EBSE-2007-01, 2007.

[19] C. Ierardi, L. Orihuela, and I. Jurado, "Guidelines for a systematic review in systems and automatic engineering. case study: Distributed estimation techniques for cyber-physical systems," presented at the 2018 European Control Conference, Limassol, Cyprus, Jun. 2018, pp. 2230–2235. DOI: 10.23919/ECC.2018.8550218.

[20] S. Fincher and R. Adams, "Interactive session-developing engineering education research questions: What do they look like? how do i get one?," presented at the 2004 Frontiers in Education Conference, Savannah, Georgia, United States, Oct. 2004. DOI: 10.1109/FIE.2004.1408616.

[21] N. R. Kanter and V. L. Byrd, "A method for transforming a broad topic to a focused topic for developing research questions," presented at the 2020 Frontiers in Education Conference, Uppsala, Sweden, Oct. 2020. DOI: 10.1109/FIE44824.2020.9273817.

[22] J. Lawless and M. J. Foster, "Searching systematically and comprehensively," in *A step-by-step guide to conducting an integrative review*, C. E. Toronto and R. Remington, Eds., Springer International Publishing, 2020, pp. 21–44. DOI: 10.1007/978-3-030-37504-1_3.