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Scholarship of Teaching and Learning in Civil and Structural Engineering: A Systematic Literature Review

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Abstract: The Scholarship of Teaching and Learning (SoTL) pertains to scholarly endeavors centered on the pedagogical aspects of teaching and learning, and its principal objective is the enhancement of students' educational experiences. This systematic literature review addresses the following questions: (1) In what capacity do educators within the field of civil and structural engineering (CaSE) engage with SoTL?, and (2) What are the benefits of implementing a SoTL for CaSE educators? The scope of the review encompasses SoTL studies specifically developed by CaSE educators and implemented within CaSE teaching and learning environments. Findings are synthesized and disseminated via a bibliometric analysis and a narrative synthesis. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. It was found that CaSE educators participate in SoTL endeavors through diverse approaches; however, such involvement remains more of an exception than a common practice. The insufficiency of existing benefits and incentives, if any, serves as a barrier hindering broader engagement and participation in SoTL activities. **DOI:** 10.1061/JCEECD.EIENG-2103.

Introduction

An attempt to provide a straightforward and concise definition of the Scholarship of Teaching and Learning (SoTL) involves understanding it as educational research conducted not by educational researchers, but by educators within their specific disciplines during their teaching practice. However, its nature is considerably more complex and dynamic, having undergone significant evolution since its inception over 3 decades ago.

First introduced by Boyer (1990) and within the context of a holistic scholarship perspective, SoTL initially was delineated as one of four interrelated faculty functions: (1) the scholarship of discovery, (2) the scholarship of integration, (3) the scholarship of application, and (4) the scholarship of teaching. According to Boyer, the scholarship of discovery is closely related to research, the scholarship of integration accounts for interdisciplinary approaches, the scholarship of application is related to knowledge application and creation at and from the professional activity at the service of the general society, and the scholarship of teaching involves all kinds of pedagogical procedures (i.e., planning, assessment, teaching, and so forth). Furthermore, Boyer also identified the clear undermining of teaching rewards against other faculty's competing obligations and the paramount importance of scholarship of teaching for the service of students, the creativity of faculty, and the definition of institutional goals.

In 2009, the "systematic reflection" and "study of teaching and learning made public" descriptors were added to the concept (McKinney and Jarvis 2009). Moreover, McKinney and Jarvis (2009) discussed how SoTL can benefit teaching at multiple levels. They highlighted the improvement of class design and redesign at the classroom level; better informed curricular changes at the program level; clear justification of budget requests at the department level; enhanced decision-making at the institutional level in terms of strategic planning, program reviews, and assessment processes; and, as evidence-based creation of teaching and learning, best practice guidance at the discipline level.

Bishop-Clark and Dietz-Uhler (2012) conferred to SoTL the aim of establishing a body of knowledge through the communication of findings obtained by nonspecialized educational scholars through their teaching practices in their respective subjects. Bishop-Clark and Dietz-Uhler delineated the SoTL process within a structured framework consisting of five distinct steps:

1. formulating a research inquiry;
2. crafting the study's framework;
3. gathering the necessary data;
4. analyzing the collected data; and
5. publishing and disseminating the SoTL discoveries.

The imperative for a more comprehensive understanding of student learning was advocated by Felten (2013) as one of the fundamental principles of good practice within SoTL. Furthermore, several key components that are deemed essential for the cultivation of effective SoTL practices included grounding it within a specific contextual framework, conducting it with adherence to rigorous methodological standards in collaboration with students, and ensuring the dissemination of results to the wider public. Swart et al. (2017) presented an expanded eight-axis (or spokes, as per the authors' analogy to the spokes of a wheel) SoTL framework definition. According to their model, the practice of SoTL is underpinned by the following elements: awareness, reflection, discernment, development, application, evaluation, sharing, and crystallization.

Cox et al. (2023) presented an extended 11-step approach to SoTL, positioning it as an integral element within the broader

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construct of educational research. Although all presented definitions primarily centered around the activities undertaken by educators engaged in SoTL and their potential for enhancing teaching practices, the ultimate objective of SoTL remains the provision of superior learning experiences for students.

One challenge confronted by educators in the field of engineering when they initially engage with SoTL is the fundamental disparity between the research demands within their discipline and those inherent to SoTL. Engineering research typically adheres to an objective paradigm, whereas SoTL is characterized by subjectivity. As outlined by Wankat et al. (2002), engineering educators often grapple with skepticism when attempting to assess the influence of input parameters—such as inherited traits, home environments, prior educational experiences, current knowledge and skill levels, learning styles, personality types, and present life circumstances—on the desired output, which is student learning. Most of these effects are not readily observable or quantifiable. Moreover, as posited by Tight (2018), the impact of the SoTL has been limited because it has not significantly contributed to the generation of novel lines or research.

Several studies have contributed to the body of literature concerning SoTL, spanning a spectrum of educational contexts. These studies have encompassed general educational contexts (Healey and Healey 2023; How 2020; Tight 2018), the realm of science, technology, engineering, and mathematics (STEM) (Faulconer and Griffith 2023), and inquiries into multi- and interdisciplinary (Kahn et al. 2013) and distinct engineering disciplines (Michelson 2016; Prince 2008). Although some of the overarching findings and discussions articulated in these studies have the potential for extrapolation to the practice of SoTL within civil and structural engineering (CaSE), the discourse surrounding SoTL has experienced subtle variations across diverse disciplines. For example, Garcia et al. (2022) used a SoTL framework to analyze the experiences, views, and needs of two chemical engineering faculty members who had recently moved from industry to academia, and Maisiri and Hattingh (2022) explored the impact of game-based learning on improving a deep understanding of technical knowledge and acquiring nontechnical skills in a third-year industrial engineering module. These distinctions have had consequential implications for the nature, inquiry, and role of SoTL within each discipline (Huber and Morreale 2002). In light of these considerations, a systematic review of SoTL within the specific domain of CaSE appears to be a justifiable endeavor.

This paper presents a systematic literature review focusing on the SoTL within the scope of CaSE. The objective was to comprehensively and rigorously identify all pertinent works pertaining to this subject matter. Specifically, this review investigated the various methodologies and approaches adopted by CaSE educators and explored the underlying motivations driving their engagement in SoTL activities. In particular, the principal aim of this work was to address the following research questions:

- How do CaSE educators (including professors, lecturers, teaching assistants, and so forth) participate in the SoTL?
- What are the benefits, encompassing economic, professional, and personal aspects, associated with the implementation of SoTL practices for CaSE educators?

The remaining sections of this paper are organized as follows. The "Methodology" section outlines the systematic review methodology employed and describes in detail the protocol, search strategy, bibliographic mapping, and narrative synthesis work performed. Subsequently, the outcomes and discussions stemming from the bibliometric and narrative synthesis procedures conducted are presented. Finally, the "Conclusions" section presents the insights and implications drawn from this research.

Methodology

Protocol and Search Strategy

The systematic review presented in this paper adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Page et al. 2021). These guidelines are underpinned by the development of a systematic review protocol, as elucidated by Shamseer et al. (2015), in which the administrative information, introduction, and methods of the systematic review are recorded and reported. The complete protocol of this systematic review was presented by Jiménez Rios et al. (2023b).

Given the paramount significance of transparently reporting the information retrieval process to uphold the quality of this systematic review, we elected to adhere to the PRISMA-S (Rethlefsen et al. 2021) checklist for documenting the executed search strategy. In summary, the electronic databases that were scrutinized encompassed Scopus, Web of Science, Google Scholar, and the OsloMet Library database. Moreover, we consulted OSF Registries to forestall the inclusion of works still in progress and avoid duplication. Relevant initial keywords (i.e., "civil engineering," "structural

Table 1. Search queries and number of records found in each source

Source	Query	No. of records found
Scopus	TITLE-ABS-KEY [("engineer*" OR "civil engineer*" OR "structural engineer*") AND ("scholarship of teaching and learning" OR sotl)]	84
Web of Science	ALL=[("engineer*" OR "civil engineer*" OR "structural engineer*") AND ("scholarship of teaching and learning" OR sotl)]	43
Google Scholar	("engineer*" OR "civil engineer*" OR "structural engineer*") AND ("scholarship of teaching and learning" OR sotl)	34,000
OsloMet Library	Any field contains "engineer*" OR "civil engineer*" OR "structural engineer*" AND Any field contains "scholarship of teaching and learning" OR SoTL	55
Total		34,182

engineering," "scholarship of teaching and learning," and "SoTL") and similar terms of interest were used to form the search queries presented in Table 1, whereas the full title of the systematic review was searched in OSF Registries. Both searches were executed on September 1, 2023. Elaborate details of the search strategy were presented by Jiménez Rios et al. (2023c). To ensure the exclusion of duplicate records, deduplication was executed using an automatic detection tool during the import of RIS files into EndNote version 20. Notably, RIS-formatted records from Scopus, Web of Science, and OsloMet Library exclusively were subjected to this process. Further scrutiny was conducted using manual assessment, involving the organization of all records by title. The first 50 pages of results, amounting to 500 of the most pertinent records from Google Scholar, were inspected manually. After the deduplication of records identified during the manual screening of Scopus, Web of Science, and OsloMet Library records, in conjunction with the manual curation of records from Google Scholar, a total of 156 records were retained for further analysis.

Following deduplication, all retained records underwent a comprehensive evaluation, encompassing scrutiny of both their titles and abstracts. After the first round of screening, only 29 relevant records were preserved for a second round of screening. During the subsequent screening stage, all shortlisted records underwent a rigorous examination, including a thorough assessment of their full content, to determine their ultimate inclusion or exclusion from the systematic review. Only records directly pertinent to the realm of civil and structural engineering education were considered for inclusion. In the culmination of this meticulous screening process, 17 records successfully passed all screening criteria and eligibility filters, rendering them eligible for inclusion in this comprehensive systematic literature review (Fig. 1).

Bibliographic Mapping

The bibliographic data obtained after performing the search strategy has been made available as open source and published in Zenodo (Jiménez Rios et al. 2023a). This database contains all the bibliographic information found after applying the search strategy used for the SoTL in CaSE. It contains information presented in .ris, .bib, and .csv formats from the searched electronic databases which allow downloading such information (namely Scopus, Web of Science, and OsloMet Library).

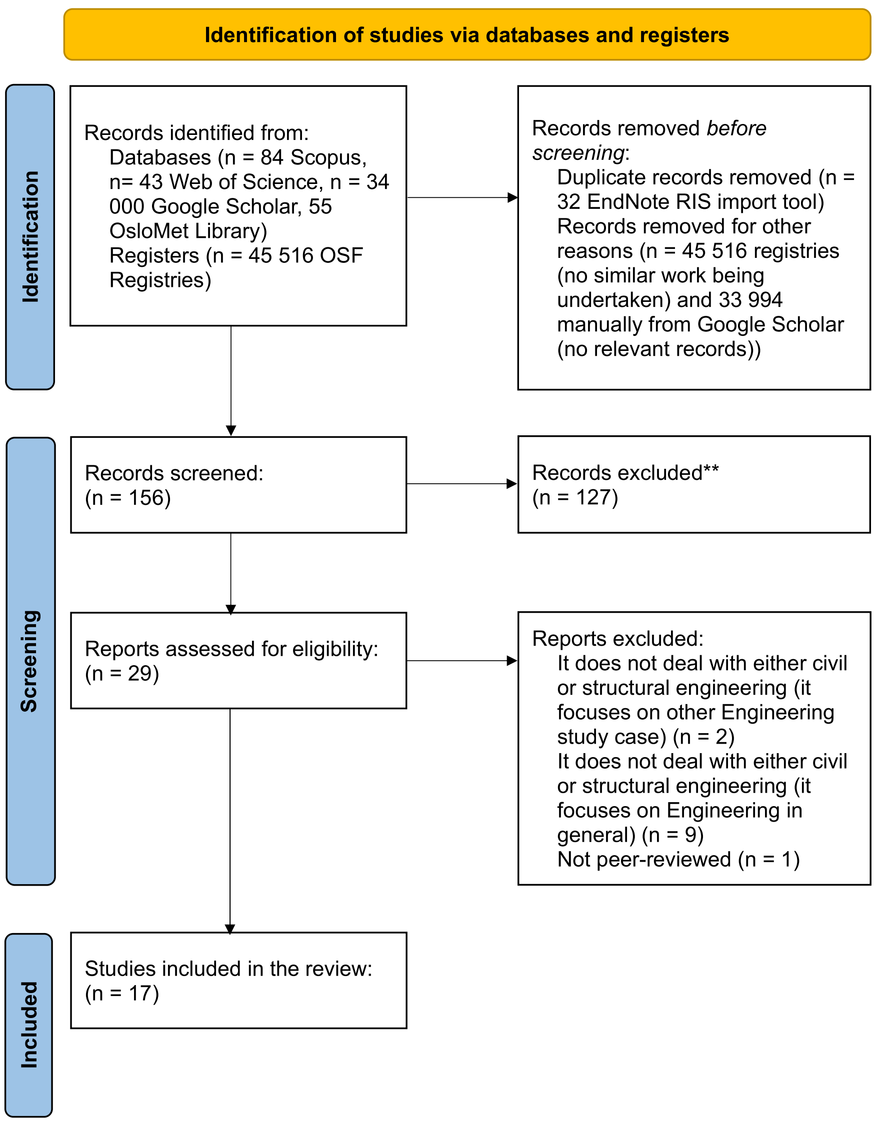


Fig. 1. PRISMA flow diagram with number of identified, screened, and ultimately included records in the systematic literature review.

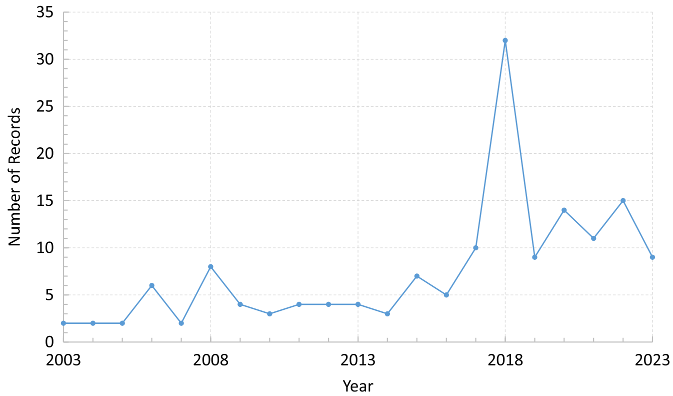


Fig. 2. Number of records found per year.

Subsequent to the deduplication phase, the bibliographic data derived from the retained records underwent comprehensive analysis using a bibliographic mapping approach executed within the software VOSviewer version 1.6.20, as outlined by van Eck and Waltman (2018). The whole deduplicated set of records [the 156 records screened, as presented in the screening stage of the PRISMA flow diagram (Fig. 1)] was used because it could give better insight into the work and attention paid to the topic by the broad educational research community. The co-occurrence of all keywords (both author and index keywords), as well as the co-authorship of authors relationships, were mapped and discussed. This scientific mapping process, commonly referred to as science mapping, enables the visualization of the intricate interconnections among fundamental concepts and ideas within the chosen research topic. Furthermore, our analysis extended to various aspects of the bibliographic data, including the determination of papers with the highest citation counts, the quantification of publications per year, the identification of prevalent keywords, and the evaluation of the distribution of papers among different countries. This comprehensive assessment provides a holistic portrayal of the research topic's performance, effectively capturing the outcomes achieved through our meticulously devised search strategy.

Narrative Synthesis

Because the data collected for this study were qualitative in nature and not amenable to a meta-analysis, the principal findings of this systematic review are presented via a narrative synthesis. This methodological choice enabled us to integrate the diverse types of evidence and qualitative data found, thus addressing the posed research questions. In adherence with the PRISMA guidelines, we registered this systematic review (Jiménez Rios 2023), and we made both the protocol and search strategy publicly accessible. This transparency facilitates peer review and enhances the overall credibility and replicability of our study.

Bibliometric Analysis Results and Discussion

Performance Analysis

Fig. 2 depicts the annual distribution of publications of the total number of records identified (those which were screened as indicated in the PRISMA flow diagram presented in Fig. 1) after conducting the search strategy described in the protocol of this systematic literature review, which used keywords such as "SoTL" and "CaSE." The graphical representation illustrates a discernible trend of incremental growth over the last 2 decades, except for the year 2018, which recorded an exceptionally high number of more than 30 publications on the topic. Specifically, there were 14 publications between 2003 and 2007, a figure that nearly doubled during the subsequent period of 2008–2012, resulting in 23 records. The trend then showed a stabilized growth between 2013 and 2017, culminating in a peak of publications in 2018, yielding a total of 61 publications for this 5-year period. Notably, the period spanning 2018 to 2023 had a substantial surge in publications, averaging more than 11 publications/year. As of the time of our search (September 1, 2023), a limited total of 9 records were identified for the year 2023, which may have increased in the remaining months of the year. This observation underscores the heightened interest exhibited by scholars in the field of CaSE in the domain of SoTL during recent years.

Among the various sources examined in the context of this systematic literature review, only Scopus, Web of Science, and Google Scholar furnish information regarding the number of citations attributed to each record. Within the subset of records that survived the deduplication process previously detailed, Table 2 presents the 10 most frequently cited papers. Notably, the paper with the highest citation count, 57 citations in total, was "Improving teamwork skills and enhancing deep learning via development of board game using cooperative learning method in Reaction Engineering course" (Azizan et al. 2018). This particular work, although noteworthy for its citation count, was not included in the present systematic review because it does not pertain directly to the domain

Table 2. Ten most cited papers found among deduplicated records of this systematic literature review

No.	Title	Reference	No. of citations
1	Improving teamwork skills and enhancing deep learning via development of board game using cooperative learning method in Reaction Engineering course	Azizan et al. (2018)	57
2	Challenges in learning communication skills in chemical engineering	Dannels et al. (2003)	47
3	Constructive controversy and reflexivity training promotes effective conflict profiles and team functioning in student learning teams	O'Neill et al. (2017)	35
4	Modeling and simulation practices in engineering education	Magana and de Jong (2018)	26
5	A (updated) review of empiricism at the SIGCSE technical symposium	Al-Zubidy et al. (2016)	19
6	Teaching and learning styles in engineering education	Kapadia (2008)	19
7	Poly(lactic acid) and its composites as functional materials for 3-D scaffolds in biomedical applications: A mini-review of recent trends	Sikhosana et al. (2021)	17
8	Homework methods in engineering mechanics	Lura et al. (2015)	17
9	Flipped university classrooms: Using technology to enable sound pedagogy	Sankey and Hunt (2014)	16
10	The birth of a notion: The windfalls and pitfalls of tailoring an SoTL-like concept to scientists, mathematicians, and engineers	Connolly et al. (2007)	16

of CaSE. The paper with the highest citation count among those included in this systematic review was "Homework Methods in Engineering Mechanics" (Lura et al. 2015), which had a total of 17 citations. The aim of including highly cited papers obtained during the screening stage, even if they ultimately are not included in the systematic review (the full list of included papers is presented in the Appendix), is to provide a point of comparison. Thus, examples of work done in the SoTL that may not necessarily focus on CaSE also are included in Table 2.

Both Scopus and Web of Science furnish comprehensive bibliographic data about the authors' affiliations for most of the records retrieved from these databases. Fig. 3 illustrates the distribution of authors by country based on the affiliations documented in the deduplicated records within the scope of this systematic literature review. The data set encompasses contributions from authors representing a total of 20 different countries. The US stands out with the highest number of authors, accounting for a total of 125 researchers. Canada follows with 40 authors, and both Malaysia and the United Kingdom have 13 authors each. Additionally, South Africa is represented by 12 authors within the data set. A total of 54 more authors were identified in the remaining countries (Fig. 3).

Bibliography Mapping

Fig. 4 is a coauthorship map containing information pertaining to the top 50 authors engaged in the publication of works identified in the search strategy. In Fig. 4(a) the various clusters emerging from distinct author groups are discernible. Fig. 4(b) presents the average publication year of the corresponding works within each cluster. A qualitative analysis of these clusters revealed a diverse landscape concerning the nature of educators' involvement in the SoTL. For example, Bedewy et al. and Brooks et al. are part of collaborative clusters characterized by robust interconnections. In contrast, certain authors, such as Samah, Adams, and Nesbit, tend to work predominantly in isolation. Additionally, there is a noticeable lack of interconnectivity between these various clusters. This underscores the potential for future improvement through the fostering of collaboration among authors from distinct research groups and/or educational institutions. Such collaborative endeavors could serve to enhance the cohesion and interdisciplinary exchange within the field of SoTL.

Fig. 5 provides a comprehensive bibliometric map illustrating the co-occurrence of the top 50 keywords. This map was constructed based on data derived from the Scopus database. Although Web of Science also offers bibliographic information, including keywords, its database structure differs significantly from that of Scopus. This divergence in structure precludes the amalgamation of both data sets for co-occurrence analysis within a single map. Fig. 5(a) delineates the formation of seven distinct clusters. A central cluster is centered prominently on the keywords "SoTL" and "students." Additionally, two relatively central yet smaller clusters emerge, one each associated with the keywords "intelligent manufacturing" and "practitioner research." The remaining four peripheral clusters encompass concepts such as (1) "iterative methods" and "creativity," (2) "educational environment" and "distance e-learning," (3) "learning strategy," and (4) "cumulative learning" and "communities of practice." Fig. 5(b) captures the evolving trends within these clusters over time. Notably, recent publications demonstrate a pronounced concentration within the latter two peripheral clusters previously delineated. These publications exhibit a heightened focus on educationally oriented concepts. This trend may signify a shift in the interests of educators actively engaged in the SoTL toward a more scholarly oriented approach. This orientation is characterized by a concerted effort to enhance teaching practices, with the potential to yield improved learning experiences for students as an ultimate outcome.

Narrative Synthesis Results and Discussion

The 17 studies incorporated into this review are systematically presented and discussed using narrative synthesis. They are categorized into two primary groups, as delineated by the two core inquiries central to this systematic literature review: (1) how do CaSE educators conduct and/or are involved in the SoTL?, and (2) what are the benefits, incentives, and outcomes stemming from the implementation of SoTL for CaSE educators? It is important to note that studies addressing both facets are appropriately referenced

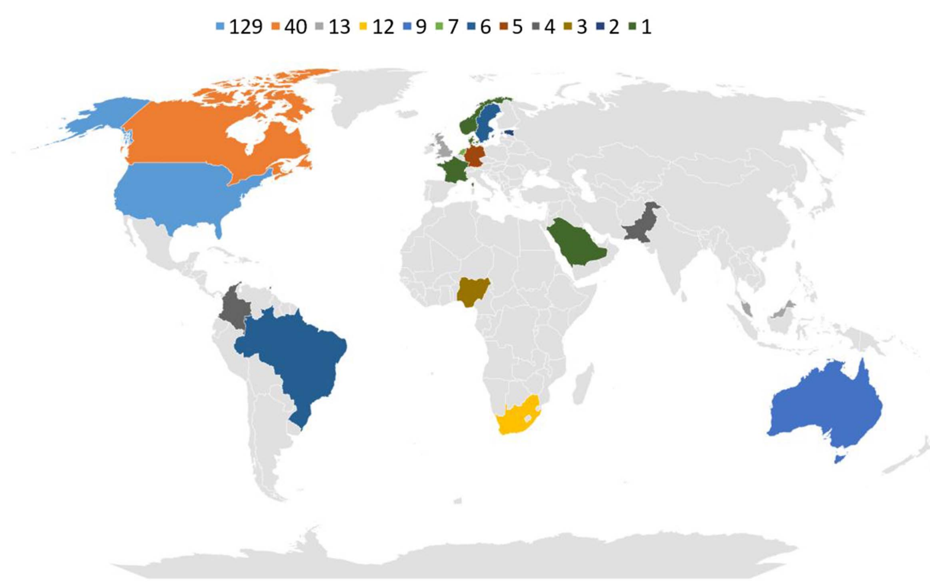


Fig. 3. Number of records per country based on the affiliations found among the deduplicated records of this systematic literature review.

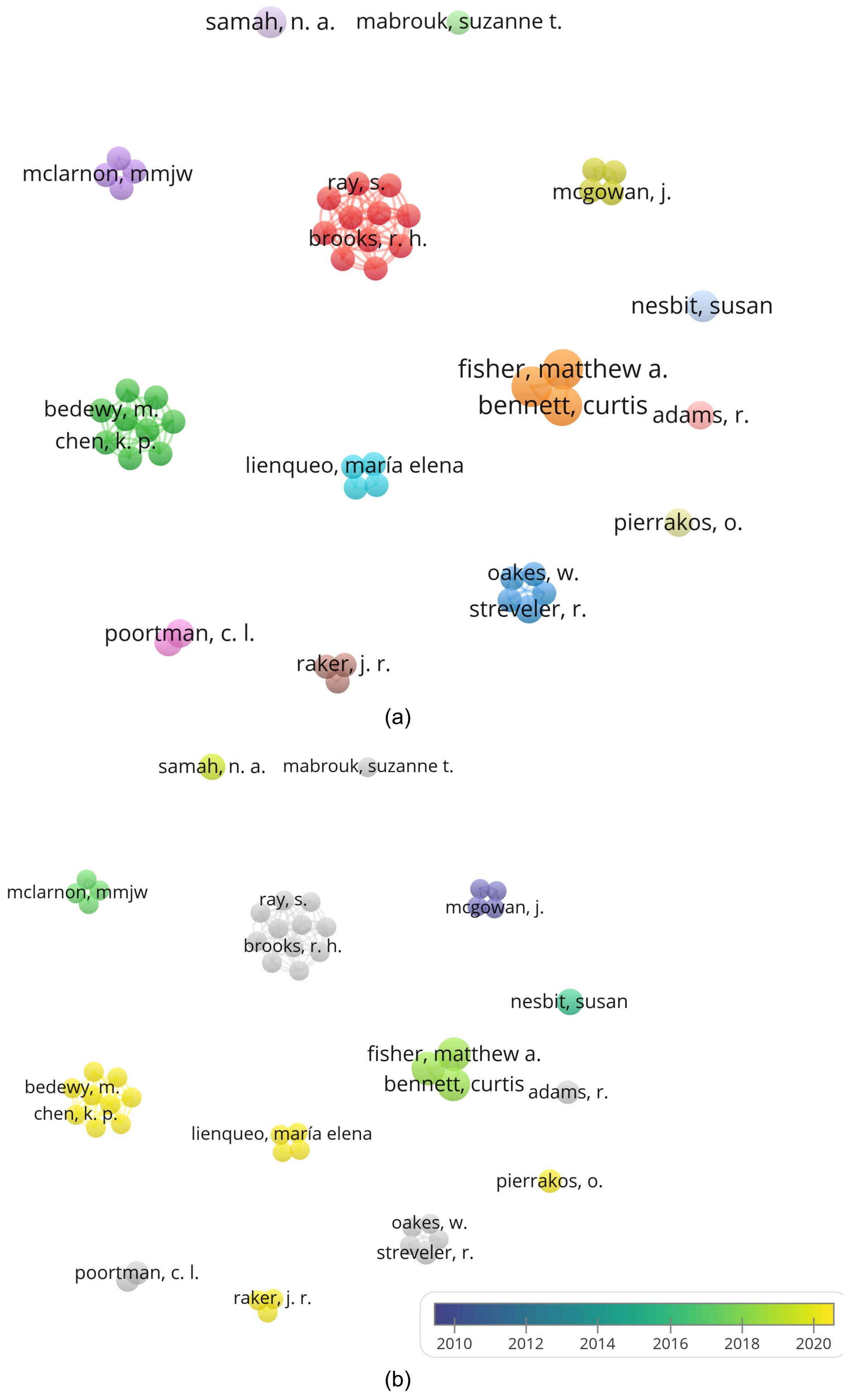
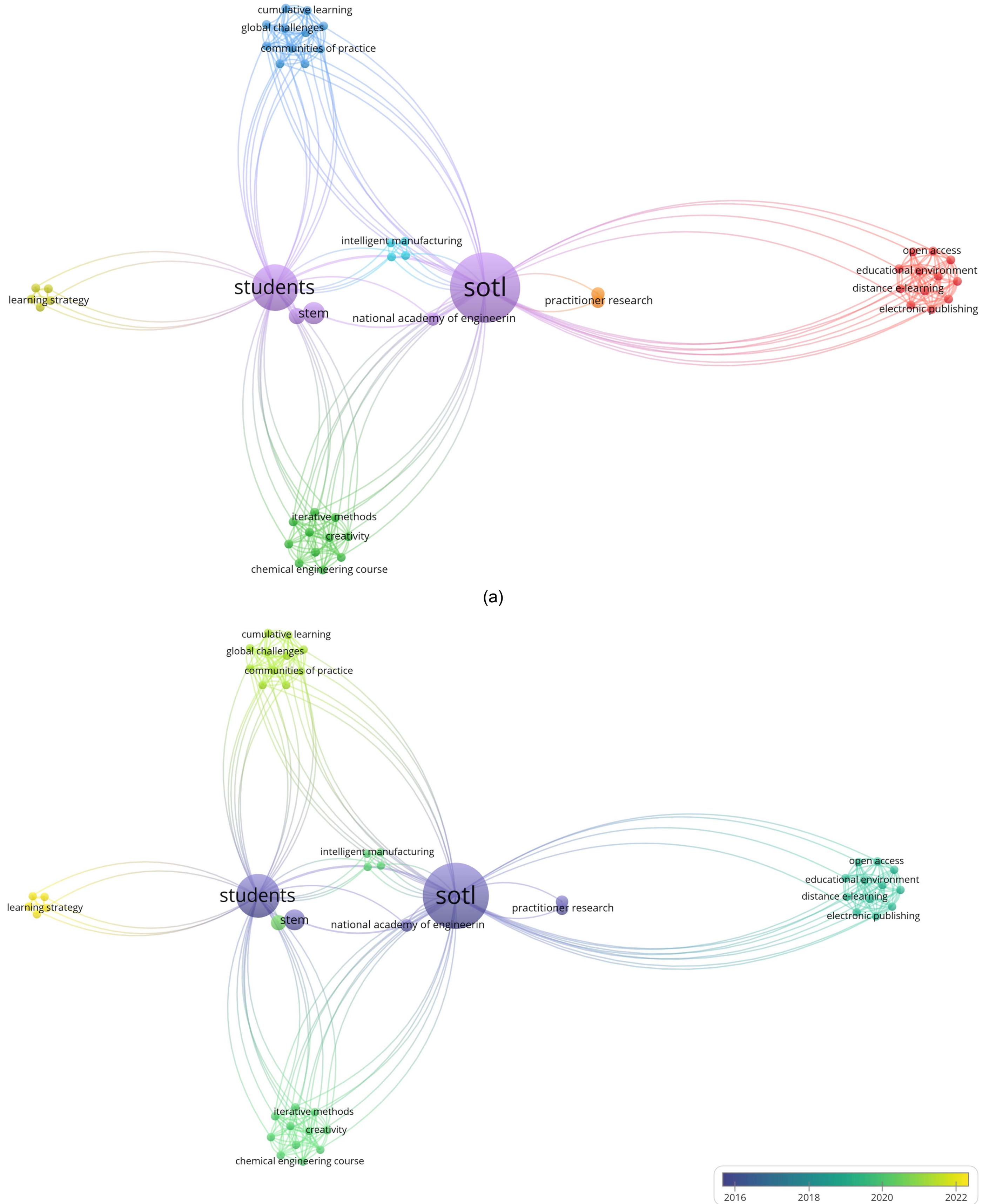


Fig. 4. Top 50 authors (by number of publications) mapped in a bibliographic network presented: (a) by cluster; and (b) by overlay with respect to average publication year.

and discussed within the respective subsections dedicated to these questions.

Limitations

The relatively low number of records included in this systematic literature review (a full list and details of the included records are presented in the Appendix) is not due to a lack of educational research activity by CaSE academics, but might be an indication that authors are not aware of SoTL and therefore do not present it as such. This observation is based mainly on the personal experience of the authors and their knowledge about the existence of literature which could be considered as SoTL, but that has not been identified as such by their authors. Therefore, such records



(b)

Fig. 5. Top 50 keywords (by number of counts) mapped in a bibliographic network presented: (a) by cluster; and (b) by overlay with respect to average publication year.

did not comply with the inclusion criteria of this systematic review. Some examples of this issue are Binnekamp et al. (2020), Campos et al. (2020), and de la Torre et al. (2021). This fact demonstrates the paramount need to provide training on SoTL to CaSE academics, or at least the need to increase their awareness about the topic by other means, so that future educational research can be identified correctly.

Involvement of CaSE Educators in the SoTL and Methodologies Applied

Based on a bibliometric and statistical analysis of data related to the US, Bielefeldt (2015) and Bielefeldt et al. (2015) studied the demographic and faculty characteristics of CaSE academics involved in the SoTL and the closely related Learning through Service (LTS) mentoring experiences; Bielefeldt (2015) and Bielefeldt et al. (2015) were included here because they compared the involvement of civil engineering faculty in SoTL and that of faculty in other engineering areas such as environmental or electrical and computer engineering. LTS encompass traditional classroom learning with hands-on service experiences in the community. LTS programs aim to provide students with practical opportunities to apply their academic knowledge and skills to real-world problems and challenges. This approach often is associated with service-learning and community engagement (Delaine et al. 2023). According to Bielefeldt (2015), about 5.6% of civil engineering faculty are involved with these practices (in comparison, the percentages of electrical and computer engineering and environmental engineering faculty involved in SoTL are 4.6% and 8.9%, respectively, and they differ considerably from the rest of civil engineering faculty. Bielefeldt's results showed that engineering educators implementing SoTL practices tend to be (1) a higher percentage of assistant professors, (2) a lower percentage of full professors, (3) a higher percentage of women, (4) higher percentage employed at Baccalaureate or Master's institutions, and (5) a smaller percentage from institutions with very high research activity.

One of the initial instances of implementing a SoTL approach in a CaSE context was documented by Brannan et al. (2004) (this work was considered to be eligible because the primary interest of one of the coauthors is teaching structural engineering within a SoTL framework, and therefore this study is relevant to the research questions of this systematic literature review). Their research was undertaken within the Citadel Academy for the Scholarship of Teaching, Learning, and Evaluation (CASTLE) program, which actively encouraged faculty members to conceive novel teaching practices aimed at measuring learning outcomes. Brannan et al. examined student performance with respect to immediate and delayed quizzes. Their findings revealed a notable improvement in students' on-task behavior, coupled with significantly higher scores on immediate quizzes than on delayed quizzes. Therefore, contrary to the common belief that students effectively utilize the time between lectures and examinations to bolster their learning, Brannan et al.'s research suggests that administering immediate quizzes may be more effective in facilitating student learning.

A SoTL approach was implemented by Nesbit et al. (2012) to support the development of beliefs among students about the role of civil engineers in society (this work was included because it discusses how challenging it is to develop students' beliefs while teaching subjects such as calculus, mechanics, and numerical analysis, subjects which commonly are taught to structural engineering students). Nesbit et al. argued that metacognition and self-regulated learning (SRL) can be used as enabling activities for such purposes. Metacognition refers to the awareness and understanding of one's own cognitive processes and the ability to regulate and control those processes. SLR refers to the ability to manage one's own learning and take responsibility for one's academic success. SRL involves not only thinking about one's thinking (metacognition) but also actively regulating and controlling your one's learning behaviors. SRL normally is associated with students' approach to learning both in and out of the classroom, and motivation constructs (Nelson et al. 2015). The methodology implemented in this study was based on a series of community service learning (CSL), a teaching and learning strategy that emphasizes active participation in real-world community projects or activities as an integral part of a student's academic curriculum, ultimately leading to the solution of engineering-based problems for charities, schools, and other not-for-profit organizations experiences dealing with the type of work performed by civil engineers and the broad impact of their knowledge (Coyle et al. 2006). Through an assessment involving a Likert-scale survey, which gauged students' perceptions of the role of civil engineering in society, they identified enhanced levels of knowledge, skills, attitudes, and identities among the student participants. These outcomes underscore the efficacy of their approach in fostering a deeper understanding of the societal contributions made by civil engineers.

By implementing a SoTL study on a statics and dynamics course, Lura et al. (2015) determined the negative effects of short in-class quizzes used to assess students' understanding of homework assignments on both students and educators (this paper was deemed eligible for inclusion because the case study of a statics and dynamics course corresponds to a course typically taught in CaSE programs). The delayed quizzes, which consisted of one of the assigned homework problems that was rephrased and/or had different numbers, were administered at the start of class, and students were given 15–20 min to complete them. From most students' point of view, this activity represented a source of anxiety and stress, whereas only a few students saw it as a beneficial approach to reviewing the learning material. From the instructor's perspective, this course modification did not alter students' behavior; students continued to attempt to memorize homework solutions to solve problems newly presented in quizzes. Lura et al. used quantitative data directly from students' performance on exams, quizzes, and homework to draw their conclusions, along with a qualitative perceptions survey completed by the students involved in the study.

Awange et al. (2017) implemented a SoTL approach through a collaborative learning environment method to enhance industry-based skill acquisition and overall learning among students of a surveying course in Australia (although this work mainly discusses the case study of a surveying course in civil engineering, it was included in this systematic literature review because one of its main learning outcomes is that students "interpret civil engineering drawings, including the use of plans, elevations, and sections and details for structures," which is of relevance for CaSE educators). A distinctive characteristic of such learning environments is the fact that through sharing and group-based discussion, knowledge is generated and reinforced (Rojas 2002). Awange et al. collected qualitative data from validated anonymous questionnaires and determined that face-to-face discussions, project-based learning, and workshop-based learning contributed to the development of the learning attributes that CaSE students need to acquire.

An alternative application of SoTL in CaSE was exemplified by Beier et al. (2018) (their study clearly is relevant to this systematic literature review because it presents a SoTL project for the enhancement of the learning experience of students in structural dynamics, which is a significant CaSE subject). They conceived an e-learning concept tailored to give students studying structural dynamics an opportunity for active engagement in research endeavors.

The efficacy of this e-learning concept was assessed across several dimensions, including (1) the achievement motivation of the students, (2) the degree of acceptance of the concept, and (3) its effectiveness during the first year of implementation. Students who interacted with the e-learning tool displayed notably elevated levels of motivation and exhibited a strong grasp of the subject matter. From the perspective of educators, this e-learning approach facilitated the supervision of a greater number of student projects, thus enhancing its pedagogical utility.

A pedagogical methodology that has been popularized recently is the flipped classroom (Lo and Hew 2019). In a standard flipped classroom model, students acquire a portion of the course material in advance of the class through instructional media such as videos or written materials. As a result, classroom time is no longer devoted to traditional lectures, and instead focuses on promoting more interactive learning experiences, including group discussions. Cleary (2020) applied this model to the junior level Structural Analysis engineering course aiming at increasing student success rates and learning quality (this study clearly was relevant work for this systematic literature review because it presents a SoTL project to enhance the learning experience of students in structural analysis, which is a significant CaSE subject). Clearly found mixed results. Although the flipped classroom allowed faculty to identify problematic topics for students earlier in the learning process and address them before exams, there was a lack of student preparation before lectures, which hindered the effectiveness of the approach. Nevertheless, Cleary argued that the model serves to improve student engagement and learning experience, and should be investigated further and adopted.

Another study case of a SoTL methodology put into practice is related to experiential learning (EL), which is based on a process of learning through doing and has been deemed to be particularly suitable for engineering education because engineering is an experiential field of science (Abdulwahed and Nagy 2009). Jamison et al. (2022) used a systematic and critical review to examine how EL has been implemented and evaluated in previous undergraduate engineering education works (this systematic literature review was considered to be suitable for inclusion in this paper because it includes two references to case studies of SoTL projects implemented within a CaSE contex, which may be of interest for CaSE educators). Their results indicated a close relationship between SoTL and the implementation of EL practices. The impact of problem-based learning (PBL) pedagogy on teaching critical methodology concepts in a civil engineering course was used as an example in this work. This pedagogical methodology normally is perceived as a more learner-centered teaching approach than the traditional lecture-based teaching methods pervasive in engineering education (Yadav et al. 2011).

A massive open online course (MOOC) is an online course designed to be accessible to a large number of participants over the internet, typically is open to anyone who wants to enroll, and often offers course materials in the form of video lectures, reading materials, quizzes, and assignments (Joksimović et al. 2017). Al-Mekhlafi et al. (2022) observed a significant impact a SoTL study on the continuation intention after a MOOC methodology was implemented to deliver the course Engineer in Society to CaSE students (this study as included because was funded under a SoTL grant and presented a case study of relevance for CaSE education). Al-Mekhlafi et al. assessed the overall quality and effectiveness of the online learning experience using a six-variable model. Their questionnaire evaluated student attitudes, course quality, information quality, service quality, system quality, and students' intention to continue learning through MOOCs. The study's findings indicated that MOOC-based online learning can effectively promote active learning among students by fostering increased course participation and enhancing the overall educational process.

Benefits, Incentives, and Outcomes of Implementing SoTL for CaSE Educators

The role of SoTL in the current academic system was discussed in detail by Wankat and Oreovicz (2003) (this study included due to the insightful discussion of the role of SoTL in faculty promotion, including CaSE educators). Wankat and Oreovicz argued that although different stakeholders (students, parents, legislators, and universities) claim the importance of teaching in engineering departments, other factors (research output and attracted funding) are prioritized by decision makers when granting faculty promotion. Although this situation has started to change slightly in recent years and the role of teaching has been increased in the tenure decision process, this has occurred as a complementary requirement, not as a balancing one (i.e., teaching duties have not replaced other aspects; rather, they have been added to the already heavy burden placed on engineering scholars). Moreover, Wankat and Oreovicz argued that faculty promotion based mainly on teaching and the scholarship of teaching is hampered further by the lack of importance given to and the lack of actual understanding of the SoTL by engineering departments, as well as the lack of proper metrics that allow the measurement of teaching quality in general. Wankat and Oreovicz suggested promoting the adoption of the SoTL among engineering educators by including teaching as an important component in the tenure promotion criteria and by granting the necessary resources not only for the sake of the SoTL, but because of the inherent benefits this would bring to the learning experience of engineering students based on the pedagogical content knowledge possessed by engineering educators.

Drawing from their experiences within the CASTLE program, Brannan et al. (2004) concluded that SoTL commonly is met with skepticism among CaSE educators. This skepticism stems from the perception that SoTL offers limited opportunities for professional development within their domain. Furthermore, the formidable demands currently placed on CaSE faculty, coupled with the perceived lack of influence or significance of SoTL activities in the context of promotion and tenure processes, act as deterrents to the widespread adoption of the SoTL within this academic setting. To address these challenges, Brannan et al. suggested further administrative support in terms of conference funding, physical space to conduct SoTL activities, administrative task assistance, teaching load reduction, and support in tenure and promotion decisions. These measures were proposed as essential components in fostering a more receptive attitude toward the integration of SoTL practices among CaSE educators.

Adams et al. (2007) examined the various pathways, opportunities, and challenges of the SoTL through narrative testimonials from three engineering educators, including a CaSE faculty member. This study was included as a case study because it reflects the SoTL experience of a civil engineering educator while also providing a broader perspective by comparing it with the experiences of educators from general engineering education and educational psychology. One of the main factors hindering the implementation of SoTL in the CaSE context (and in STEM in general) is the fact that it is perceived as pseudoresearch due to its qualitative character and misperceived lack of rigor. Conversely, the positive lessons learned from the implementation of the SoTL include the opportunity of using research for reflective teaching practice, building community, and personal satisfaction.

Smith et al. (2008) explored the implementation of faculty learning communities (FLCs) as a way of enhancing SoTL practices in

STEM disciplines, including the CaSE field (this study was deemed relevant for this systematic literature review because it discusses the impact of a SoTL approach in several case studies, including a course called Introduction to Civil Engineering, which was attended by CaSE students). Smith et al. expected that the FLC would begin to institutionalize the use of new pedagogies to support STEM instruction and enhance the achievement of underrepresented and disadvantaged students. Their approach was based on, among other activities, a classroom innovation case study of the Introduction to Civil Engineering course through peer teaching. The incentives put in place to motivate CaSE faculty to join the FLC initiative consisted of (1) appropriate acknowledgement for promotion; (2) a small stipend (ranging from $500 to $1,000); and (3) the subjective satisfaction of enhanced student interest, retention, and achievement. Overall, the results suggest that FLCs are an effective mechanism for positively impacting teaching and learning in STEM disciplines.

Shrivastava (2013) identified the need for research in the SoTL to support and adequately conduct civil engineering curriculum updating while accounting for global and specific geographical and cultural context factors (this study was considered to be relevant work due to the emphasis given to the structural engineering component of the undergraduate civil engineering capstone design project presented as case study following a SoTL approach). Following Wankat and Oreovicz (2003), Shrivastava also identified the lack of recognition of SoTL in faculty assessment and promotion processes as the main challenge for its adoption in engineering education. Shrivastava concluded that the required curriculum improvements in civil engineering would not be achieved until the SoTL is formally acknowledged as an equal study field within civil engineering.

Bielefeldt (2015) and Bielefeldt et al. (2015) argued that younger faculty are more interested in SoTL and that with time, the value of the SoTL could be increased naturally due to a generational change. Conversely, this also may mean that people who dedicate time to the SoTL struggle more to achieve seniority and progress to higher ranks because other competing priorities (such as research output and amount of funding) have a heavier weight toward achieving seniority in academia.

Swart et al. (2017) sought to enhance and redefine the concept of the SoTL using the analogy of a unicycle, and delineated eight foundational principles: (1) awareness, (2) reflection, (3) discernment, (4) development, (5) application, (6) evaluation, (7) sharing and (8) crystallization. (This work was included because it surveyed two CaSe educators and presented their experiences implementing SoTL.) Swart et al. emphasized the importance of encouraging engineering scholars to actively engage in the practice of SoTL. However, Swart et al. (2017) also found that factors such as the fear of change or potential discrimination could act as barriers to participation in SoTL activities. Drawing insights from a focus group interview involving four academics representing diverse engineering disciplines (two from the CaSE field), Swart et al. concluded that newcomers to SoTL principles may require additional effort to acquaint themselves with these principles. In addition, seasoned scholars must remain committed to actively embracing the eight principles, because failure to do so may result in a loss of balance, akin to falling from a unicycle. Ultimately, Swart et al. (2017) argued that a proficient mastery of SoTL practices can yield profound personal satisfaction, particularly through the achievement of the ultimate SoTL objective, which is the enhancement of student learning outcomes.

A comprehensive examination of the implementation of the SoTL within the context of a Dutch university was documented by Poortman et al. (2020) (this study was deemed relevant for this systematic literature review because it discusses the role of SoTL within the Senior University Teaching Qualification in the Netherlands, which is a topic of interest for university educators in the Netherlands, including CaSE faculty). At the University of Twente, the Senior University Teaching Qualification (SUTQ) program is offered to seasoned educators who have a keen interest in educational innovation and the design of pedagogical practices within their teaching milieu. The primary objective of this program is to cultivate an environment that encourages collaborative reflection, the exchange of knowledge, and the pursuit of practice-based research among its participants. To facilitate these goals, enrolled educators are provided with comprehensive support mechanisms, including guidance from a dedicated coach, constructive peer feedback from colleagues, and participation in seminars focusing on educational research and design. Noteworthy among the observed outcomes among SUTQ participants were their reports of feeling inspired and appreciative of the lucidity, utility, and feedback derived from SUTQ sessions. However, Poortman et al. reported an insufficient community-building activity and further support requirements in terms of teaching rewards and recognition in career advancement, as well as allocation of both time and monetary resources to participate in the program. Addressing these challenges is imperative in order to realize the overarching objective of implementing a genuinely student-centered engineering education.

As supporting evidence to suggestions by Smith et al. (2008), Wolff et al. (2021) identified a series of disciplinary, discursive, and contextual challenges for the implementation of the SoTL in STEM (this study was included because it presents a relevant SoTL implementation, and a case study focused on a civil engineering integrated cognitive–affective–systemic model, which may be of interest to CaSE educators). Wolff et al. proposed the implementation of a community of practice (CoP) approach to overcome such challenges and enhance SoTL development in engineering education. They justified their proposal by stating that without proper systemic support, academics consider the extra effort required for the involvement of the SoTL to be a heavy burden with marginal benefits, and the intrinsic motivation of the individual is the only reason to engage in it. Their CoP proposal was founded upon a peer learning environment, which fosters collaborative practice-sharing of scholarly theories and a more holistic development of academics in their teaching role. Their concept was tested using a novel EL approach applied in an introductory transport science course (part of a civil engineering curriculum). They concluded that the CoP approach enabled "a deeper sense of being part of a whole," with opportunities to strengthen individuals' "sense of identity and belonging."

Finally, Jamison et al. (2022) concluded that faculty need additional support for conducting research on EL opportunities. This support includes training, funding, and facilitating research collaborations, which could be implemented through the establishment of centers for research on learning and teaching (CRLTs) at educational institutions.

Conclusions

In contemporary academia, scholarship encompasses a multifaceted spectrum, comprising teaching, service, and research endeavors. However, within the context of academic career progression, these facets do not receive uniform consideration, nor are they assessed with equal weight. This paper presents the findings of a systematic literature review focused on the SoTL within the realm of CaSE. The primary objectives of this study were to delineate the various methodologies and approaches adopted by educators in the

CaSE field and to illuminate the challenges and incentives that may either foster or impede engagement in SoTL activities. The results of this investigation are presented through both bibliometric analysis and narrative synthesis methodologies.

It can be inferred that the interest of the community of CaSE educators in SoTL has had a notable upward trend in recent years, as evidenced by the increasing number of publications within the searched databases. However, it is apparent that the academic output in this domain could be enhanced further by fostering greater collaboration among individuals and research groups involved in SoTL endeavors. Additionally, the predominant focus of the identified SoTL records seems to be closely aligned with a student-centered vision, because these two keywords had more counts. This trend is particularly prominent in recent publications, as revealed through the bibliometric analysis.

The implementation of SoTL within CaSE contexts exhibits considerable diversity. It spans a spectrum from innovative e-learning and experiential learning methodologies to more-conventional problem-based learning and peer learning environments. A noteworthy approach within this field is the incorporation of service-learning contexts, which underscore the pivotal role that engineers play in society. This addresses the first question of the systematic literature review.

However, the integration of SoTL in CaSE contexts is accompanied by a set of challenges. These challenges encompass a dearth of adequate training, funding, and support for research collaborations, as well as a prevailing perception among engineering educators that their substantial efforts yield marginal benefits. Moreover, apprehension about change and potential discrimination, coupled with a lack of comprehension of SoTL within engineering departments, presents formidable obstacles. However, it is unequivocal that the most significant challenge hindering the successful implementation of SoTL in CaSE contexts is the absence of recognition for teaching activities in faculty promotions.

Despite the introduction of several incentives, such as modest stipends and the establishment of research centers dedicated to learning and teaching, faculty learning communities, and community of practice groups, to encourage SoTL among CaSE educators, this systematic review reveals that the pivotal factor required to attain this objective is the proper acknowledgment of teaching activities in faculty promotions. This recognition should be integrated as an equitable component alongside the existing criteria of teaching, learning, and service requirements, rather than imposing an additional burden on the already demanding responsibilities of CaSE educators. The expected benefits identified through this systematic literature review that could be observed if these challenges were overcome and if more CaSE educators adopted a SoTL approach include (1) enhanced teaching practices, because educators using SoTL rely on research and evidence to guide their teaching practices, ultimately leading to the adoption of methods that have been proven to be effective, resulting in better student comprehension and retention; (2) improved student engagement, because SoTL promotes active learning techniques, such as problem-based learning and collaborative projects, which are particularly beneficial in engineering education; and (3) strengthened curriculum design, because SoTL encourages the integration of interdisciplinary knowledge and perspectives, enriching the curriculum and broadening student learning. This addresses the second question of the systematic literature review.

The limited number of records included in this systematic literature review is not due to a lack of educational research conducted by CaSE academics. Instead, it may indicate that authors are not familiar with the concept of SoTL and thus do not label their work as such. This observation is based primarily on the authors' personal experiences and their knowledge of existing literature that could be categorized as SoTL but was not recognized as such by the original authors. This underscores the importance of offering training on SoTL to CaSE academics or increasing their awareness through other means, so that future educational research can be identified correctly.

The significant insights presented in this paper that can help advance engineering education research and practice are (1) the identification of teaching methods implemented and tested by CaSE educators; (2) the presentation of implications for faculty

Table 3. Full list and details of records included in systematic literature review

No.	Source	Title	Reference
1	Scopus	An e-learning-concept for research-based learning in structural dynamics	Beier et al. (2018)
2	Scopus	Characteristics of engineering faculty engaged in the scholarship of teaching and learning	Bielefeldt (2015)
3	Scopus	Evaluating the impact of a faculty learning community on STEM teaching and learning	Smith et al. (2008)
4	Scopus	Experiential learning implementation in undergraduate engineering education: a systematic search and review	Jamison et al. (2022)
5	Scopus	Learning through service engineering faculty: characteristics and changes over time	Bielefeldt et al. (2015)
6	Scopus	Tenure and teaching	Wankat and Oreovicz (2003)
7	Scopus	The senior university teaching qualification: engaging in research, design and building community in engineering education	Poortman et al. (2020)
8	Scopus	Scholarship of teaching and learning: 'what the hell' are we getting ourselves into?	Swart et al. (2017)
9	Scopus	ASCE Vision 2025 and the capstone design project	Shrivastava (2013)
10	Scopus	A cumulative learning approach to developing scholarship of teaching and learning in an engineering community of practice	Wolff et al. (2021)
11	Web of Science	Enhancing civil engineering surveying learning through workshops	Awange et al. (2017)
12	Web of Science	Modeling the impact of massive open online courses (MOOC) implementation factors on continuance intention of students: PLS-SEM approach	Al-Mekhlafi et al. (2022)
13	Web of Science	Using the flipped classroom model in a junior level course to increase student learning and success	Cleary (2020)
14	Google Scholar	Becoming an engineering education researcher: intersections, extensions, and lessons learned among three researchers' stories becoming an engineering education researcher: intersections, extensions, and lessons learned among three researchers' stories	Adams et al. (2007)
15	Google Scholar	Facilitating cross-disciplinary scholarship of teaching and learning at The Citadel	Brannan et al. (2004)
16	Google Scholar	Homework methods in engineering mechanics	Lura et al. (2015)
17	OsloMet Library	Influencing student beliefs about the role of the civil engineer in society	Nesbit et al. (2012)

development, including areas in which professional development opportunities are needed; (3) fostering a culture of research in engineering education by encouraging CaSE educators to engage in scholarship related to their teaching practices, contributing to a more evidence-based and research-informed educational environment; and (4) the synthesized presentation of primary sources that can inform educational policies and institutional practices by highlighting successful approaches and identifying areas in which improvement is needed.

Appendix. Full List and Details of the Records Included in This Systematic Literature Review

This appendix includes a full list and details of the finally included records in the presented systematic literature review. Table 3 provides details about the source, title, and reference of the records.

Data Availability Statement

Some or all data, models, or code generated or used during the study are available in a repository online in accordance with funder data retention policies (Jiménez Rios et al. 2023a, 2024).

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