First-Year Students in Experiential Learning in Engineering Education: A Systematic Literature Review

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Abstract

This complete theory paper is a literature review that outlines the introduction of experiential learning in undergraduate engineering education. Using a population-intervention-comparison framework and PRISMA flow diagram, we investigated how experiential learning was implemented in undergraduate engineering education between 1995-2020. This paper is part of a larger review highlighting engineering education research findings that apply to the first-year experience.

From a total of 220 studies that were synthesized, 45 studies purely involved first-year students and 39 studies pertained to a combination of first-year students and second-year to fourth-year students. These 84 studies examined what students learned in their first-year and addressed the nature of preparation and composition of students entering engineering. Experiential learning was mostly measured through the lens of student performance (89%) through different forms of evaluations including performance checks, surveys, and individual interviews. A second lens was faculty evaluations (7%) including instructors' observations, feedback, and reflections of students' performance and experience. Finally, a third lens was industry feedback (4%), obtained to inform capstone design courses where students work at industrial sites on company based projects with industry mentors.

From our literature survey, we identified four key elements with corresponding insights that described successful implementation of experiential learning that might serve as consideration for future implementation for engineering educators and researchers. These four key insights include: 1.) Relevance and collaboration with stakeholders, students, academe, industry, and society, 2.) Students engagement and ownership, 3.) Scaffolding and integration across levels, and 4.) Importance of assessment.

Introduction

While experiential learning has long been considered part of engineering education since the mid-1950s [1] systematic review articles have been limited in their scope and coverage years. One of the most comprehensive studies documenting experiential learning in engineering education was published in 1976 by Harrisberger, et al. [2]. The study examined models of experiential learning from six pioneering experiential engineering programs including the University of Cincinnati Professional Practice Program; the Harvey Mudd College Clinic; the Kansas State University Mechanical Engineering Design Laboratory; the Worcester Polytechnic Institute PLAN; the West Virginia University PRIDE (Professional Reasoning Integrated with Design Experience); and the University of Massachusetts ESIC (Engineering Services for Industry and Community). Over the last forty years, the use of experiential learning in undergraduate engineering education has increased exponentially; concurrently a significant body of pedagogical research has been presented in the literature. The present article explores and documents experiential learning in the field of engineering within an inclusive period between 1995-2020.

Since Harrisberger's study in 1976, much has changed in undergraduate engineering education. It is clear that the use of experiential learning has increased exponentially over the past forty years, as has pedagogical research in the topic. Our choice of studying the period 1995-2020 for this research article stems from two important points. First, our research showed that critical developments between the early 1970s to late 1980s (Table 1), both in North American and in Europe, facilitated a great spread of engineering education research across higher education institutions (HEIs) in this time-period. This spread would have impacted curricular, pedagogical, and institutional changes in engineering education across HEIs by the early 1990s, resulting in (by our estimation) a proliferation of research articles beginning in about 1995. Second, Jesiek et al.'s 2009 article on a similar topic summarized nicely much of the relevant literature in the 1970s and 80s.

Table 1. Critical Developments in Experiential Learning in Engineering in the 1970's and 80's

Critical Developments	Relevance in Engineering Education
1.) Creation of the European Society for Engineering Education in 1973 [4]	Contributed to the development and improvement of engineering education in Europe.
2.) 1975 World Congress on Educating Engineers for World Development (Harrisberger et al., 1976).	Emphasized the crucial role of experiential learning in the future both in the US and developing countries.
3.) Review of Experiential Learning in Engineering Education (Harrisberger et al., 1976).	Examined models of experiential learning from six pioneering experiential engineering programs in the US.
4.) Creation of the National Commission on Excellence in Education in 1981 [5]	Investigated the quality of education in the US' schools and universities.
5.) The signing of the Washington Accord in 1989 [6]	Outlined a standard of assessment in the professional practice of engineering.
6.) Establishment of the Engineering Education Coalitions funded by National Science Foundation in 1989 [6].	Provided wider linkages among U.S. engineering institutions and dramatic increase in the quality of engineering education and degrees awarded in engineering

University engineering programs have a history of delivering experiential learning in two ways: authentic and simulated [2]. Authentic experiences consist of activities that immerse students in real situations with open-ended outcomes (e.g., co-ops, internships and project-based designs). Simulated experiences involve carefully designed, controlled, and guided design and programming. Authentic or simulated, the concept of experience is "one of the most obscure that we have" [7] and "of all the words in the philosophic vocabulary [it] is the most difficult to manage" [8]. Even John Dewey, whose educational philosophy was considered the core theoretical base for the practice of experiential education [9], "almost gave up on the concept out of frustration with the way his notion of experience was misinterpreted" (Roberts, 2012, p. 13). When Dewey encouraged his teachers to provide children with experiences such as gardening, cooking, etc., he was communicating an educative process that would lead to the creation of a school system that went beyond academic subjects [10] and would bring transformative change to both individuals and society. Smith et al. [11] emphasized that “the richness of Dewey’s concept of experience is lost if it is reduced to simply learning by doing” (p. 8).

Definition of Experiential Learning

Engineering education’s experiential learning was premised on “learning by doing,” drawn in part from Dewey’s educational philosophy [12]. Experiential learning can be defined as “the change in an individual that results from reflection on a direct experience…” [13]. Learning is an individual experience and it represents a knowledge or skill acquired by an individual in formal schooling or informal settings. The knowledge or skill acquired through experiential learning changes the individual’s way of thinking, feeling, perceiving, and behaving [14].

Experiential education has been called by different names. Roberts (2012) citing Priest and Miles [15] and Adkins and Simmons [16], identified at least four different names for experiential education. It has been referred to as “adventure education,” “outdoor education,” “challenge education,” and “environmental education” (p. 3). The formal definition of experiential education has changed throughout the years. Classically, Smith & Knapp [9] defined experiential education as “a *philosophy* and *methodology* [emphasis added] in which educators purposely engage learners in direct experience and focused reflection in order to increase knowledge, develop skills and clarify values” [9]. However, its most recent form, the definition of experiential education has been refined to being “a teaching philosophy *that informs many methodologies* [emphasis added] in which educators purposely engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, clarify values, and develop people’s capacity to contribute to their communities” [17]. It is this last definition that we have utilized in this review article.

Experiential learning, on the other hand, can be defined as “the change in an individual that results from reflection on a direct experience…” [13]. Learning is an individual experience that represents a knowledge or skill acquired by an individual in formal schooling or informal settings. The knowledge or skill acquired through experiential learning changes the individual’s way of thinking, feeling, perceiving, and behaving [14]. Experiential learning can also be viewed as a set of methods or approaches (e.g., lab design, experiments, a poem, a field trip) employed—for instance—in engineering or language class to achieve certain learning outcomes of the course [18]. So, while experiential learning as a methodology involves “learning by doing” or learning through experience, it does not encompass the more comprehensive philosophy of education, like experiential education that involves a broader scholarship or worldview that centers individuals’ knowledge on their participation in shaping society in thoughtful ways [12].

Systematic Literature Review Methodology

Our review follows three crucial steps as outlined by the work of Borrego, Foster, and Froyd [19] on systematic literature reviews in engineering education. The steps include (a) identifying research questions, (b) defining inclusion criteria, and (c) finding and cataloging sources with four crucial review stages as suggested by the PRISMA flowchart [20].

a.) Identifying Research Question

We aim to explore an overarching question: *How has experiential learning been implemented within undergraduate engineering education for the last 25 years (1995-2020) that might inform advances in first-year engineering education?*

The PICO (population-intervention-comparison-outcome) framework from the National Institute for Health and Clinical Excellence (NICE) [21] (Table 2) was used to clarify relevant parameters for our research question.

Table 2. PICO Framework Adapted for the Current Review

PICO Framework	Description
Population: Which populations are we interested in? How can they best be described? Do any subgroups need to be considered?	Undergraduate engineering students in any HEIs as described in engineering education journals and published in English only between 1995-2020. To include first-year students and/or a combination of upper-year students, graduate and non-engineering students, faculty, staff, and/or other HEIs or community and industry stakeholders.
Intervention: Which intervention, activity, or approach should be used?	Examination on the nature of experiential learning in terms of: a.) definition: either authentic or simulated (as defined in Section 1) and/or involve direct experience (as defined in Section 2) b.) location (classroom, community, industry-partner's facilities) c.) curriculum (undergraduate engineering course) d.) pedagogical approach (teamwork, individual, hands-on, use of technology, etc.)
Comparison: What is/are the main alternative/s to the intervention being considered?	Compare and contrast study designs not limited to control groups but including any alternative groupings in qualitative, quantitative, and mixed method studies.
Outcomes: How are outcomes measured in terms of students' improvement?	How did experiential learning improve students'? a.) satisfaction with the course b.) academic outcomes (scores, performance) c.) learning experiences (engagement, reflections)

b.) Modified PRISMA

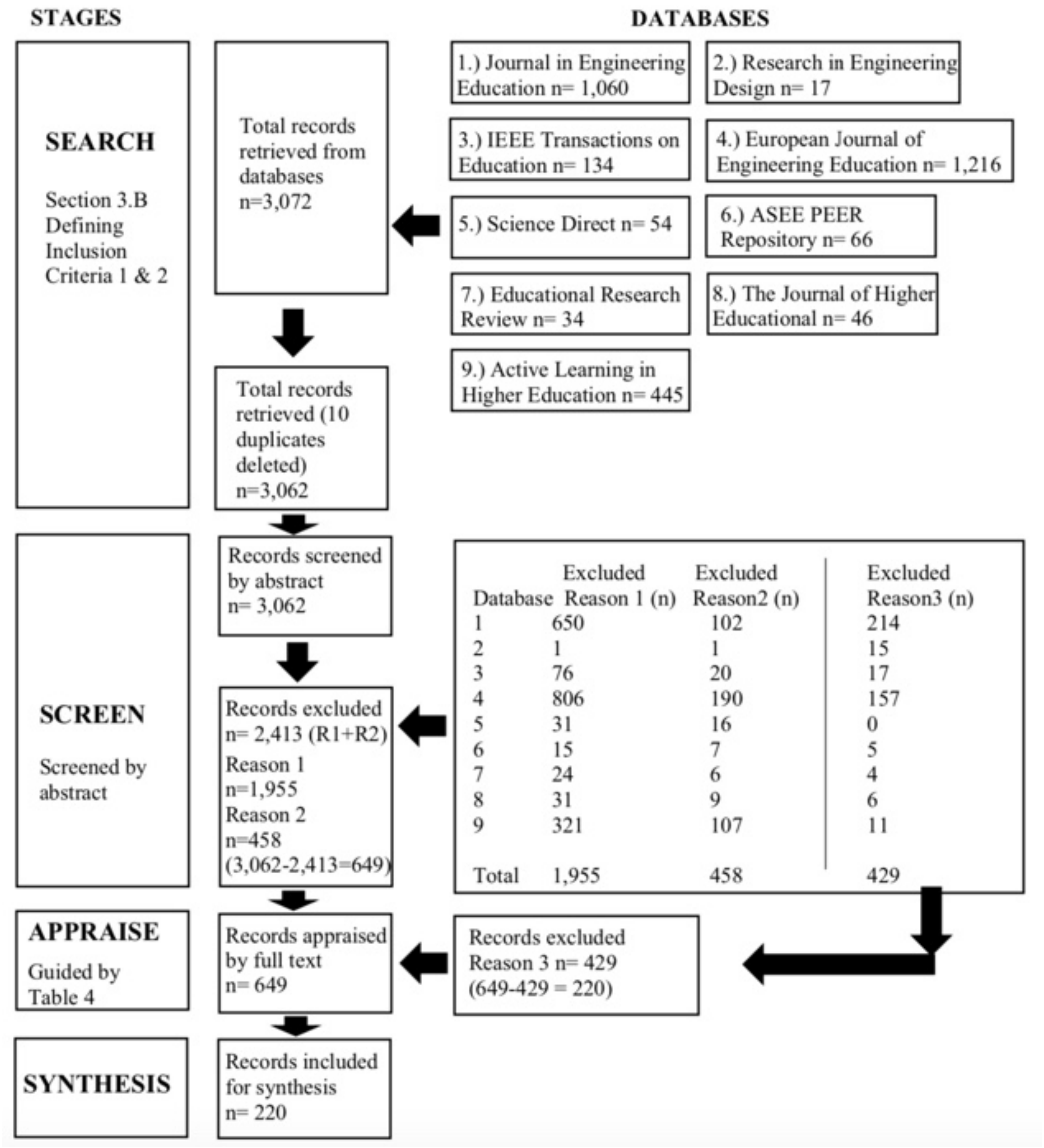
We followed the PRISMA flowchart (Figure 1) with four critical steps to search, screen, and appraise 3,072 studies, followed by synthesize of the remaining 220 articles.

Firstly, we defined and adopted three types of inclusion criteria (Search Stage). The Search Stage included conducting journal and database selection. We selected four highly rated engineering education journals like Journal of Engineering Education (JEE), European Journal of Engineering Education (EJEE), two major journal databases and other prominent journals like Educational Research Review, all published in English only. We used the combinations of experiential learning AND/OR experiential education only for our search parameters.

Secondly, the Screen Stage examined 3,702 articles by abstract. From the abstract, articles that did not involve any engineering students (target population as described in Table 2) in the study were eliminated (Reason 1, n=1,955). Abstracts that were retained were further examined using descriptions related to intervention and comparison, particularly on how experiential learning was defined and concretized in study's method or design. Abstracts that did not fall on both descriptions were deleted (Reason 2, n=458).

Thirdly, studies that do not have in-depth presentation of experiential learning were eliminated (Reason 3, n=429) (Appraise Stage). We defined studies that have in-depth approached as studies that have deep focused on explicit use and sufficient description of experiential learning, and provided sufficient data (qualitative, quantitative, mixed) for analysis and reporting. The number of studies retained after Appraisal stage was 220 (649 – 429) (Figure 1).

Finally, our review compared the similarities and differences of each individual study (n=220) as to their implementation of experiential learning and key insights for future implementation and recommendation (Synthesis Stage) which include variables like the outcome measures of the interventions, relevant outcomes (students' satisfaction with the course, academic achievements, learning experience and reflection). To reduce bias in the selection, validity, and reliability of the primary studies under review, the authors discussed and agreed to all the coded variables. Any article that either one or all of the authors opposed to its inclusion or exclusion was re-visited. The first author provided the rationale for each of the article's inclusion and exclusion (based on the research questions and inclusion criteria) and the second author (including one research colleague) reviewed their notes and reached a final decision.



Database	Excluded Reason 1 (n)	Excluded Reason2 (n)	Excluded Reason3 (n)
1	650	102	214
2	1	1	15
3	76	20	17
4	806	190	157
5	31	16	0
6	15	7	5
7	24	6	4
8	31	9	6
9	321	107	11
Total	1,955	458	429

Figure 1. Modified PRISMA Flow Chart

Results and Discussion

How has experiential learning been implemented within undergraduate engineering education for the last 25 years (1995-2020) that might inform advances in first-year engineering education?

We identified three critical findings extracted from a broader review that pertained to first-year engineering education and research. These findings include:

1. First-year Students: The Heart of Experiential Learning

One of the most important findings of the review was that experiential learning studies in engineering education were primarily designed and implemented to involve first-year students (N=45, 20%) and in combination with upper-year students (N=39, 18%), and the rest as mixed combinations of undergraduate and graduate students, faculty, and other HEIs (Table 3). The worry and "concern for attrition in engineering students has motivated many engineering schools to revise their undergraduate curricula and, particularly, to take a closer look at what students learn in their first-year" [22]. These experiential learning studies on first-year students were also conducted to understand and address the nature of the preparation and composition of students entering engineering. Moreover, students have been entering the discipline from many different levels of society and educational backgrounds, some of whom are experts and some amateurs. Some have little exposure to machines and devices [23], while some have no background at all in coding; still others have never soldered or understood the color coding of a resistor [24].

Table 3. Engineering Students and Number of Studies

Classification of Engineering Students Involved in the Study	No. of Studies
First-year	45
First-year in combination with upper-year	39
Fourth-year	27
Upper-years combination (2nd year – 4th year)	19
Undergraduate and graduate	18
Third-year only	16
Second-year only	15
Third and fourth-year only	13
Undergraduate, graduate, and faculty with other HEIs	11
Second and third-year only	9
Undergraduate and graduate engineering and non-engineering	8

Studies specific to first-year engineering students involved (for example) an integrated course in writing [25], helping students navigate their first tertiary level research tasks [26], hands-on design for team work experience [27], multidisciplinary teamwork with real customers [28], and project-based learning in combination with other pedagogical approaches [29].

Typical examples of studies that combined first-year students with upper-year students included an engineering clinic, an engineering education center and structure that promotes practice-oriented team experiences [30], and a multi-disciplinary laboratory course [31]. An example of a study that combined undergraduate and graduate engineering students was the Systems and Software Engineering Affinity Research Group, a non-hierarchical model that provides a socialization mechanism and infrastructure to support the development and management of students in small and large research groups [32]. One unique and highly successful collaboration among engineering students and faculty of three different universities was the Learning Factory, a new practice-based curriculum with physical facilities for product realization [33].

2. First-year Students' Performance: The Core of Experiential Learning Evaluation

Experiential learning was mostly measured using student performance (89% of identified studies, Figure 2) through different forms of evaluations. We categorized student evaluations consisting of different forms of performance checks, surveys, individual interviews, and focus group discussions. Student performance checks were evaluated through:

- module evaluation, written and oral assignments [34], team performance [35];
- working project design and oral presentation [36], post-quiz and post-design [37];
- direct assessment (course design notebook, oral presentations, etc.) or indirect assessment (class feedback forms, process checks) [38, 39]; and
- third party evaluation [40].

Surveys, standard student evaluation or adapted evaluation tools [41] or anonymous [42] were conducted to evaluate students' group dynamics with open-ended questions [43], provide post interventions [44], determine students gain in learning and self-efficacy [45], etc. Individual interviews and focus group discussions were conducted to identify successful practices and lessons learned in cross-disciplinary virtual teams [46], as well as to assess the effectiveness of the learning strategies [47].

A few studies (7% of identified papers) examined experiential learning through the lens of faculty evaluations. This involved instructors' observations, feedback, and reflections of students' performance and experience [48, 49]. Finally, industry feedback represented 4% of the total forms of evaluating experiential learning delivery. Industry feedback was obtained to inform capstone design courses where students work at industrial sites on company based projects with industry mentors [50], as well as to demonstrate how simulating multiple processor cores can be used in architecture [51], to name a few examples. Some individual studies involved several forms of evaluating experiential learning like student, instructor, and industry feedback [33, 52] or combination of performance checks and surveys like individual interviews, final presentations, and student survey [53].

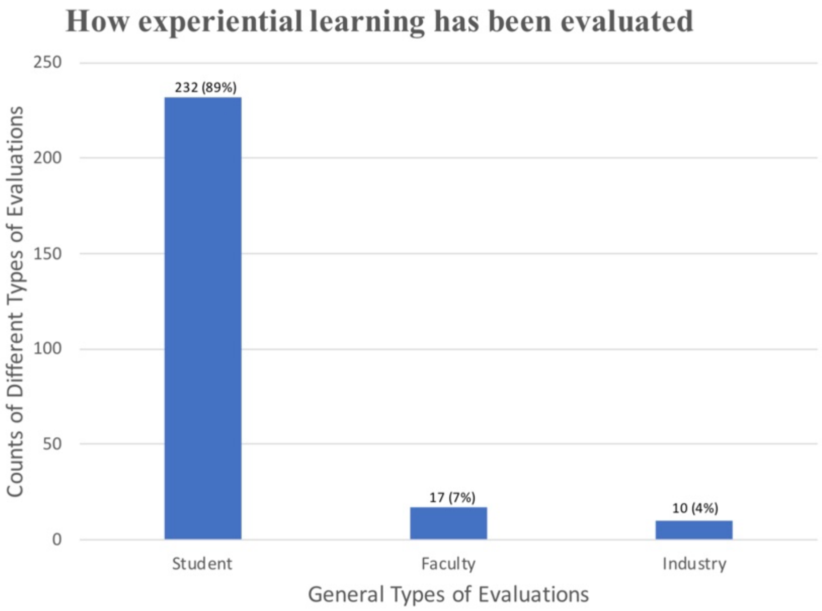


Figure 2. Evaluating experiential learning through student, faculty, and industry perspectives

3. Key Insights for Successful Implementation: Relevance and Significance for Educators and Researchers in First-Year Engineering Education.

We identified four key elements with corresponding insights that described successful implementation of experiential learning that might serve as consideration and recommendation for future implementation for engineering educators and researchers. We defined 'successful implementation' of the 220 studies synthesized in this review as studies that indicated: a) students' satisfaction with the teaching strategy, b) students' achievements in their academic outcomes, and c) reinforced learning experiences and reflections according to surveys and interviews with students, instructors, and community and industry partners. These key insights include:

3.1) Relevance and collaboration with stakeholders, students, academe, industry, and society.

There was a need to match engineering curriculum with industries' holistic process from design to production to delivery [54, 55]. Additionally, an urgent call was put forward to educate future engineers regarding changing market demands and emerging technologies [56, 57]. Emphasis was placed on designs, projects, and content with social relevance [58, 59]. Finally, there was an urgent invitation to collaborate and listen to the changing needs and demands of stakeholders [30, 33, 60, 61].

3.2) Students engagement and ownership.

Autonomy enables students to take more responsibility, value learning, and attain a sense of ownership for their own learning, for example, by allowing students to collaboratively redesign the marking matrix [62], integrating students' original ideas in Venture Capital Fund projects [63], and having students identified the extent of their participation at every levels of "do, observe, think, and plan" learning cycles [64]. In doing so, students are also able to grasp the benefits of the experience in which they engage [65, 66].

3.3) Scaffolding and integration across levels.

It was seen that engineering disciplinary thinking blooms from multi-level (horizontal and vertical) integration and bridging of course design, projects, and content strengthened from first year to fourth year [31, 67]. Scaffolding, as explained by Carroll [68], should mean smooth transitioning from "seat-of-the-pants" first-year design courses to skills and competencies gained in second- and third-year courses to capstone projects—the peak of true engineering design experience for fourth-year students. In addition, feedback on explicit scaffolding, restructuring, and mentoring in team collaborations and projects promoted teamwork and engineering design in interdisciplinary or multidisciplinary settings [48, 69, 70].

3.4) Importance of assessment.

Multi-dimensional and multi-stage assessment of students' experiential learning was crucial to capture the complexity of students' experience in context [30, 39, 56, 71]. While assessment must be conducted for curricular and administrative purposes—for example, to provide empirical evidence on how experiential learning approaches support student learning—its conduct should also consider students' cultural identity and/or orientation [72].

Summary and Conclusions

This review adopted the definition of experiential learning as a methodology. The population-intervention-comparison (PICO) framework and PRISMA's four-stage review were employed to explore how experiential learning was implemented in engineering education between 1995 – 2020 and highlighted findings that might advance engineering education research as it applies to the first-year experience.

Most experiential learning studies in engineering education were primarily designed and implemented to involve first-year students. Many engineering schools revised their undergraduate curricula and, particularly, to examine what students learn in their first-year, understand and address the nature of the preparation and composition of students entering engineering. From 1995 to 2020, experiential learning was mostly measured to look at student performance with particular emphasis on first-ear students through different forms of evaluations. The four key elements we identified that described successful implementation of experiential learning might serve as consideration for future implementation for engineering educators and researchers, particularly to advance first-year engineering education.

However, our society-at-large and academic institutions are constantly evolving. As HEIs continue to be affected by the COVID-19 pandemic, there are profound implications for the nature of experiential learning being offered in engineering education especially for incoming first-year students. There is a need to explore the rich and varied theoretical and practical experiential learning paradigms that might bring unique perspectives to our evolving understanding of experiential learning and its relevance in engineering discipline.

Limitations of the Study

This systematic literature review of experiential learning in engineering education was only focused on studies published in English with particular focus on North America and Europe, and covered the period between 1995-2020. These restrictions, as forms of biases, limit the validity and reliability of this review. While the studies synthesized in this review were extracted from exemplary engineering and higher education journals and databases, Borrego, Foster, and Froyd [19] recommended that besides careful selection of different type of databases such as subject-specified, general, journal and gray literature, the review should also consider fields of interest such as psychology, communication, and computer science that might enrich the database's quantity and quality.

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