Lifelong Learning for Engineers: A Literature Review

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Abstract: Lifelong learning has become an integral part of educational approaches, aiming to promote continuous learning throughout an individual's life. The purpose of the current literature review is to assess the trends, themes and gaps in lifelong learning for engineers. A comprehensive search was conducted in Google Scholar, ScienceDirect, and Scopus for aticles published from 1990. Specific search terms were used to retrieve relevant articles and were determined based on a combination of keywords. The abstracts and titles of the retrieved articles were screened to determine their eligibility for inclusion in this study. A total of 5,342 studies were initially identified. After removing duplicates, the number of studies was reduced to 2,217. Subsequently, the studies were further filtered based on the predefined qualification criteria, resulting in 1,779 studies that underwent abstract and title screening. Ultimately, a total of 28 articles were identified as meeting the predefined eligibility criteria and were considered for the research. These selected articles formed the basis for the thematic analysis and further exploration of the research topic. The studies emphasized the significance of both formal and informal learning and training. Problem-based learning is a crucial component of lifelong learning. This approach encourages deeper understanding, independent thinking, and the development of teamwork and essential skills. Self-directed learning is a prominent competency for lifelong learning. It involves self-reflection, self-regulation, and proactively identifying areas for improvement. A group-based approach is suggested to complement technical knowledge with personal skills and non-technical competencies. Five themes including self-directed learning, coaching and mentoring, problem-based learning, formal and informal learning, and group-based approaches were identified. These concepts should be integrated into the education system and the workplace to support lifelong learning for engineers.

Keywords: literature review, engineering, lifelong learning

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Introduction

According to the Oxford English Dictionary, lifelong learning can be described as an educational approach designed to promote continuous learning throughout the life of an individual. (Naimpally, Ramachandran & Smith, 2011). Before formally receiving instruction, a person's competence, abilities, comprehension, and awareness were evaluated based on that person's regular training and education (Guest, 2006). This paradigm

has evolved in the global society with the metrics of measuring a person's skills and general competence that encompasses knowledge-based lifelong learning, which is a necessity and not an option, especially in the field of engineering (Guest, 2006). By allowing the individual to build their knowledge and skills in their specialized field in a personal or professional capacity (Guest, 2006), According to Naimpally, Ramachandran, and Smith (2011), the continuous learning method guarantees that the individual has the expertise and abilities required to continue their learning journey after completing their higher education.

When contrasted to other academic disciplines, the usefulness of information acquired in the sciences and technologies, notably in the field, is greatly reduced, A lot of money needs to be put into the development of people through lifelong learning to avoid obsolescence (De Grip, & Smits, 2012). The investment in human capital in question does not only include formal training programs but also informal learning in the work environment (De Grip, & Smits, 2012). Since the engineering field is based on skills and knowledge that are conventionally tacit, the need for lifelong learning, which is ineffective in its current state, is quite significant for engineers. Considering the revolutionary nature of the engineering field, especially concerning technology (Naimpally, Ramachandran & Smith, 2011).

In precisely the same way as they require initial instruction and licensing, engineering workers also need to keep up their education (Bowman, 1997). To preserve safety for everyone, a safe environment, an efficient national economy, a highly regarded profession, an effective employer, and a happy career, ongoing growth in one's profession is essential (Bowman, 1997). Engineers have a common difficulty, but different disciplines have different strategies for maintaining individual and collective skills (Bowman, 1997). Maintaining expertise is crucial for advancement in your career, and engineers who work for large corporations frequently have access to internal training and professional development programs (Bowman, 1997).

Since numerous problems hinder the development and implementation of lifelong learning (Table 1), the objective of our study was to review qualitative research examining lifelong learning for engineers that focused on specific themes and analyze the trends, gaps, and significance of the practice.

Table 1. Problems associated with lifelong learning for engineers and proposed resolutions

Author	**Problem with Lifelong Learning**	**Resolution**
(Martinez-Mediano & Lord, 2012)	Although the education system plays a significant role in the promotion of lifelong learning for engineers, it has failed to integrate lifelong learning competencies.	Lifelong learning competencies must be sufficiently understood and implemented in learning institutions through formal and informal training as well as self-directed learning.
Uden & Dix (2004)	Unfortunately, engineers are not properly equipped with the problem-solving skills required for their careers.	Problem-based learning can be integrated into lifelong learning to better equip engineers with the

Author	Problem with Lifelong Learning	Resolution
		required skills.
Skrentny & Lewis (2022)	There is an assumption that the STEM pipeline that includes engineers begins and stops at specific stages.	Training is an important aspect of lifelong career growth and development that can go on for years.
Latinopoulos (2005)	There are basic issues associated with the participation of engineers in lifelong learning activities.	Formal and informal learning should integrate self-sufficient learning skills.
Lenschow (1998)	Teaching is evaluated by learning institutions, which is different from the evaluation of the competence of engineers in the global market.	Lecturing should be reduced in formal learning and project-based learning should be increased to promote teamwork and learning critical engineering skills.
Peat, Taylor & Franklin, (2005)	Engineering classroom instruction prepares students for the organizations they will work for.	Comprehensive online resources should be developed to promote independent learning and self-directed learning, asynchronous and synchronous communication, and the content learned should be delivered to the real-world environment. Learning should promote teamwork and independent thinking.
Saxe, Mahmoud & Razavinia, (2022)	The formal education system fails at some level to integrate lifelong learning in the fast-changing technological world.	The course design should align with the outcomes of lifelong learning.

Research Question

The existing research works based on lifelong learning in engineering education reveal a significant research gap that calls for further research studies. While these discussed research works have explained several fundamental issues surrounding the integration of lifelong learning principles in engineering, there is a requirement for a comprehensive investigation that extends these visions.

Table 1 highlights some key issues associated with lifelong learning for engineers, including the failure of education systems to integrate lifelong learning competencies, lack of problem-solving skills, basic issues associated with participation, and the need for evaluation of competence etc. Moreover, the discussed existing research works suggest resolutions, including integrating lifelong learning competencies in formal and informal training, using problem-based learning to equip engineers with necessary skills, reducing lecturing in formal

learning, increasing project-based learning to promote teamwork and critical thinking, developing comprehensive online resources to promote independent and self-directed learning, and aligning course design with lifelong learning outcomes. However, there is still a lack of a holistic framework that integrates these facets cohesively and it highlights a significant research gap in this lifelong learning for engineers. Thus, a new research endeavor should aim to bridge this research gap by developing a unified model or strategy for embedding lifelong learning seamlessly into engineering curricula, addressing the multifaceted challenges identified by previous studies, and providing actionable recommendations for educators and institutions to enhance the lifelong learning experiences of engineering students.

Methodology

Study Design

The research methodology is a systematic framework that leads the overall research study. This research has several key steps in its methodology, including the literature search strategy, visualization of author keywords co-occurrence, eligibility criteria, inclusion criteria, exclusion criteria, and the approach of inquiry. Figure 1 illustrates the research methodology flowchart, and collectively, these components specify how the research issue will be investigated, what sources will be taken into account, and how data will be gathered and analyzed.

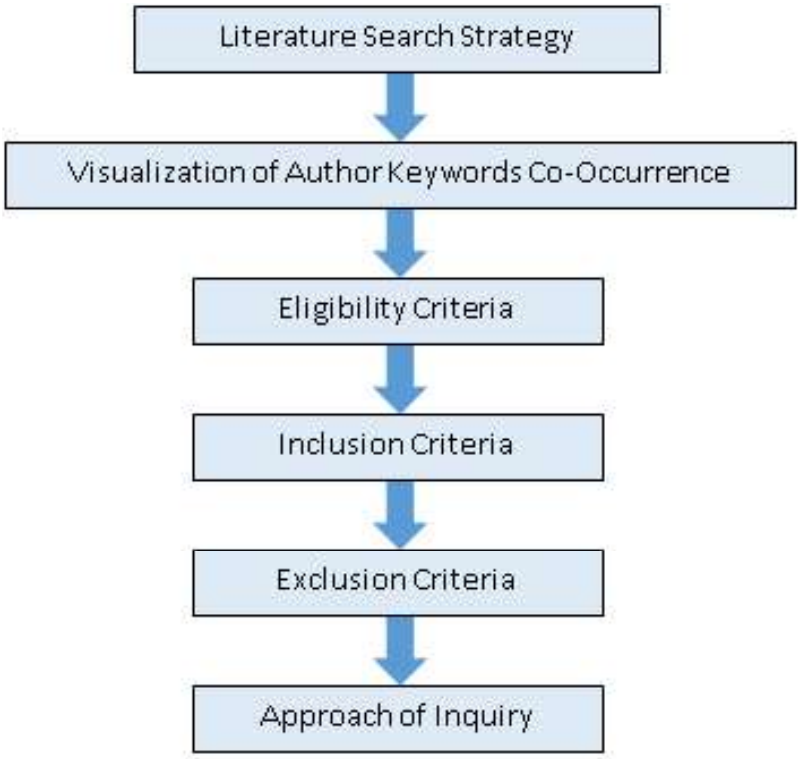

Figure 1. Research Methodology Flowchart

Search Strategy

A literature search in various engineering literature domains within numerous online databases published between 1st October 1990 and 31 October 2022 was performed. Published articles available in Google Scholar, ScienceDirect, and Scopus online databases were queried using search terms with a combination of keywords listed in Table 3. Implementing a search using the databases resulted in hits listed in Table 3 that were subjected to a process of elimination by screening abstracts and titles to determine whether the studies were eligible for inclusion in the current research. The remainder of the papers' entire contents were perused, and any articles that did not pertain to the subject of the study were excluded. The MORISE structured literature review framework was employed in this article as explained in Figure 3 (Sabri, Lædre and Bruland, 2022).

Visualization of Author Keywords Co-Occurrence

The keywords listed in Table 3 were used in the search string for Scopus (Figure 2) and ScienceDirect (Figure 3) databases.

Figures 2 and 3 show the most common keywords for the articles included in the analysis. Engineering education, lifelong learning, continuing education, and practical characteristics were the most often used words for ScienceDirect. Engineering education, lifelong learning, engineering graduates, employee education, and development for professionals are among the most popular search terms on Scopus.

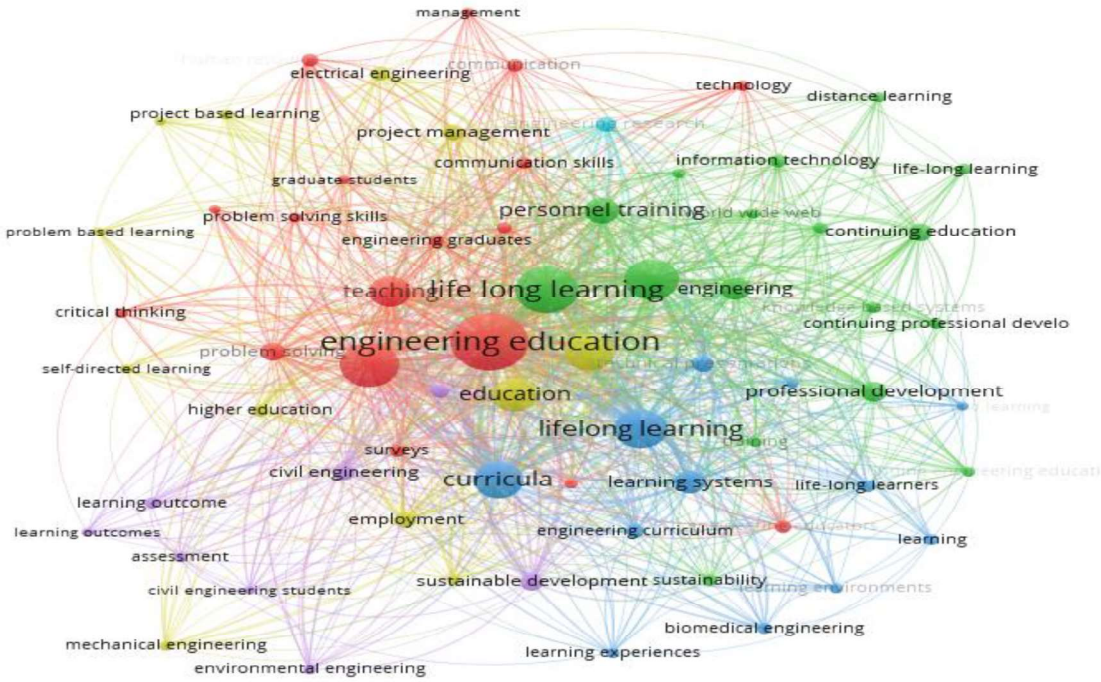

Figure 2. Retrieved Keywords (Scopus)

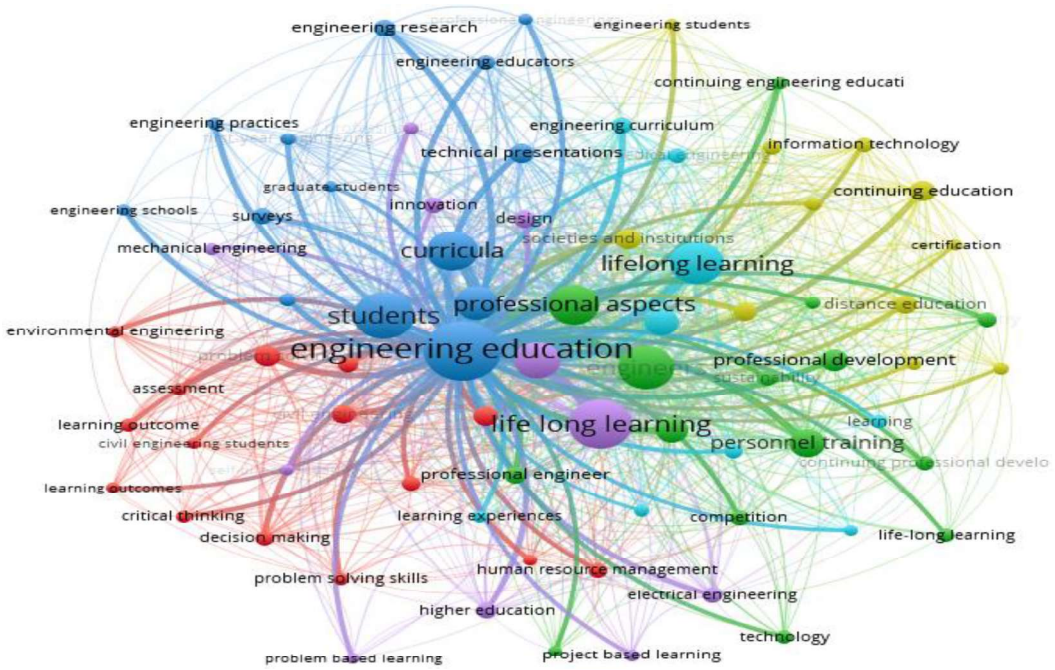

Figure 3. Retrieved Keywords (ScienceDirect)

Table 2. Search strings and keywords

SEARCH NUMBER	ADDITION to SEARCH STRING	Science Direct	SCOPUS	Google Scholar
1	TITLE-ABS-KEY (“LIFELONG” AND “LEARNING” AND “ENGINEERS”)	3897	342	35,100
2	TITLE-ABS-KEY (“LIFELONG” AND “LEARNING” AND “ENGINEERS” AND “FORMAL” OR “NON-FORMAL”)	3897	32	7620
3	TITLE-ABS-KEY (“LIFELONG” AND “LEARNING” AND “ENGINEERS” AND “SELF-DIRECTED LEARNING”)	110	10	5750
4	TITLE-ABS-KEY (“LIFELONG” AND “LEARNING” AND “ENGINEERS” AND “TEAMWORK”)	468	29	21700
5	TITLE-ABS-KEY (“LIFELONG” AND “LEARNING” AND “ENGINEERS” AND “PROBLEM-BASED”)	247	12	9360
6	TITLE-ABS-KEY (“LIFELONG” AND “LEARNING” AND “ENGINEERS” AND “GROUP-BASED”)	166	1	2450

Table 3 provides a summary of the search strings and keywords used to gather relevant literature on lifelong learning for engineers from ScienceDirect, Scopus, and Google Scholar, that is in all search strings,

ScienceDirect produced the most hits, with Google Scholar generating the most results for search string 2. Search strings that included terms like "self-directed learning," "teamwork," and "problem-based" yielded fewer results but were more specific to the research question.

Eligibility Criteria

Eligibility criteria were applied to assess whether articles fulfilled the requirements for admission or rejection.

Inclusion criteria

Learning issued between 1990 and 2022; authored in English; included primary and secondary sources; peer-reviewed; published through proper channels; focused exclusively on lifelong learning for engineers; online availability.

Exclusion criteria

Publications that were distributed using unorthodox or grey means; articles that are not peer-reviewed; studies irrelevant to the research topic; evidence syntheses, editorials, and commentaries; sources authored before 1990; articles with abstracts only.

Approach of Inquiry

An inductive approach of inquiry was applied as opposed to a deductive one and, especially in the case of primary literature sources, was mostly rooted in grounded theory. Based on the collected data related to the topic of lifelong learning for engineers, theories were developed inductively. The thematic analysis was carried out in phases —the familiarization phase comprised an overview of general information related to the research topic; the selection phase comprised identifying themes after coding data from the 15 selected sources based on trends, research gaps, and patterns; and review phase comprising a review of selected articles and proper definition of selected themes.

Results

Literature Search

The Database search identified 5342 hits. Removal of duplicates resulted in 2217 studies and applying the qualification criteria resulted in 1779 studies, whose abstracts and names were looked over to see if they had any relevance to the thematic analysis. After 21 articles had been eliminated, they were reviewed for eligibility using the time-span criterion, and seven articles were added after the timespan restriction was lifted. Finally, 28 articles were found to successfully satisfy the predetermined qualifying requirements (see Figure 4).

Morise flowchart for researching databases and choosing literature

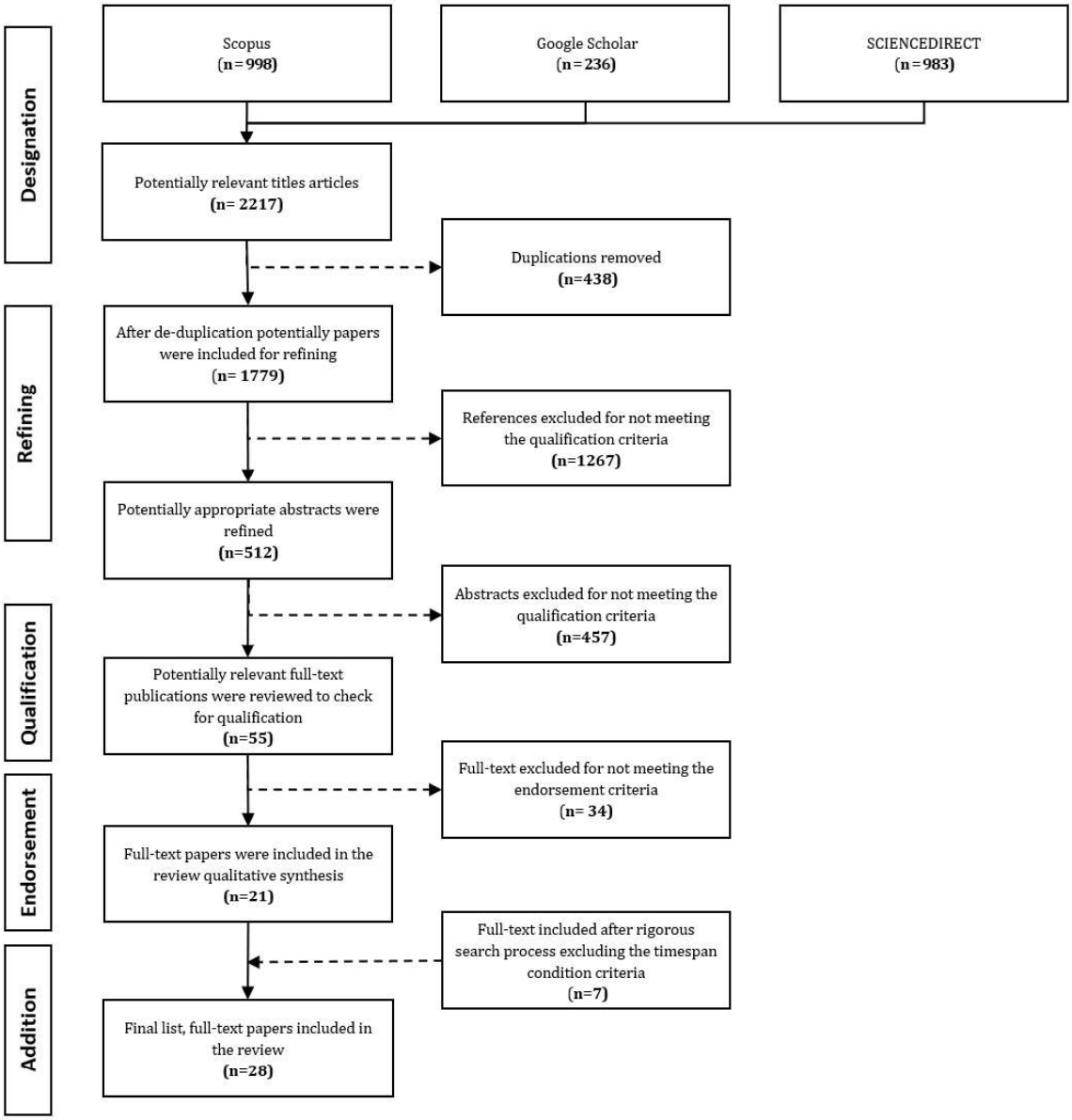

Figure 4. Morise flow chart

Data Extraction

Table A1 contains data and conclusions from 28 research that satisfied the qualifying requirements, including the writer's name, year of publication, results, nation, technique, and objective. The findings in all the featured research emphasized the suggested remedies for professionals' continuous education. There was no unclear information, and no assumptions were made. Detailed data extraction information is attached to the appendix (Refer Table A1).

Research on continuous development in architecture is included in the table of contents, along with a few research studies on education and career advancement. It includes information such as the author, year of publication, purpose of the study, methodology used, country of origin, and outcomes. The studies were conducted using a variety of methodologies, including content analysis, Tobit analysis of survey data, thematic analysis of interview transcripts, qualitative analysis, module analysis, group-based project analysis, survey analysis, program analysis, review, and systems theory framework.

The countries of origin for the studies varied and included the United Kingdom, the Netherlands, the United States, Belgium, Greece, Spain, and Norway. The outcomes of the studies suggested a variety of approaches to lifelong learning and professional growth, including the use of coaching and mentoring, the numerous advantages of instruction based on problems, the significance of autonomous learning, and the need for continual updating of knowledge and skills. The studies also highlighted factors that can influence training participation, such as the use of innovative production methods in companies, industry competitiveness, and the characteristics of employees and their jobs.

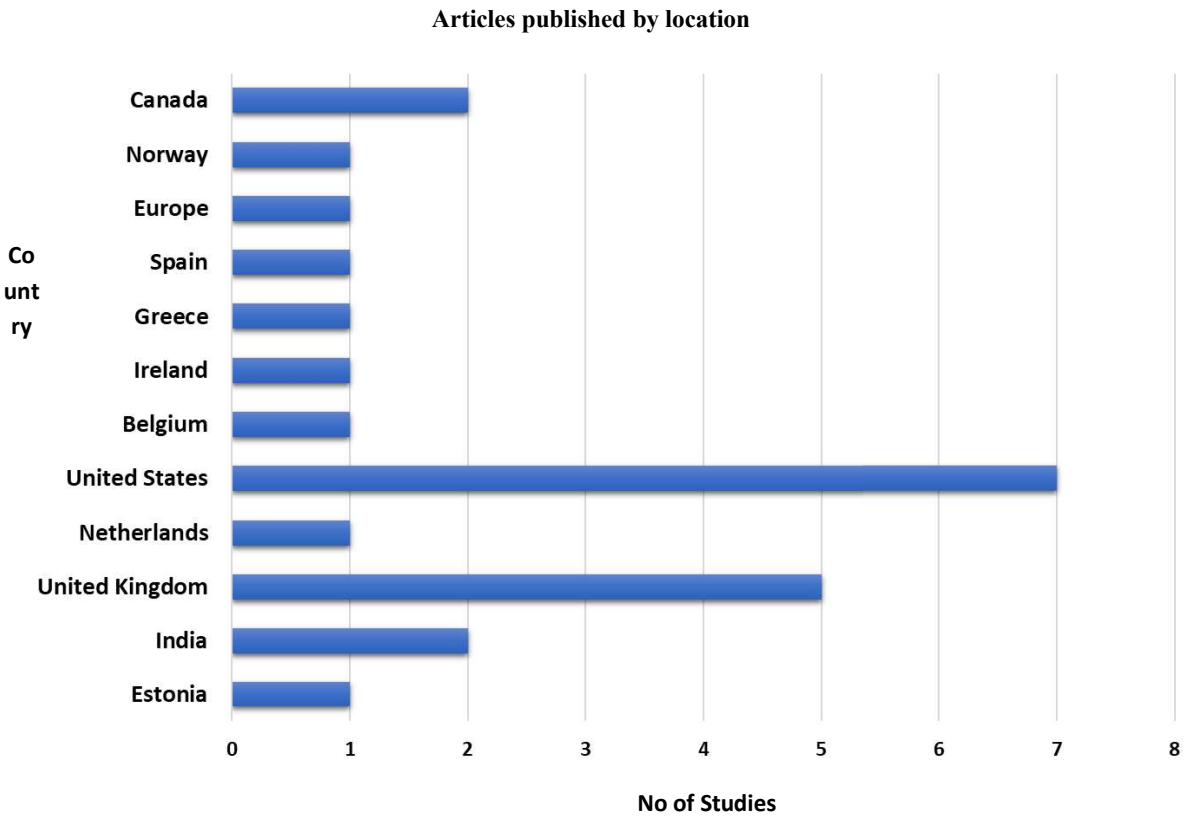

Figure 5. Articles Published by Country

Most articles were published in the United States followed by the United Kingdom. There is limited research on the topic in developing countries such as those in Africa. Additionally, there may be an immediate connection connecting the quantity of publications released by a nation and the amount of money spent on engineers'

ongoing education.

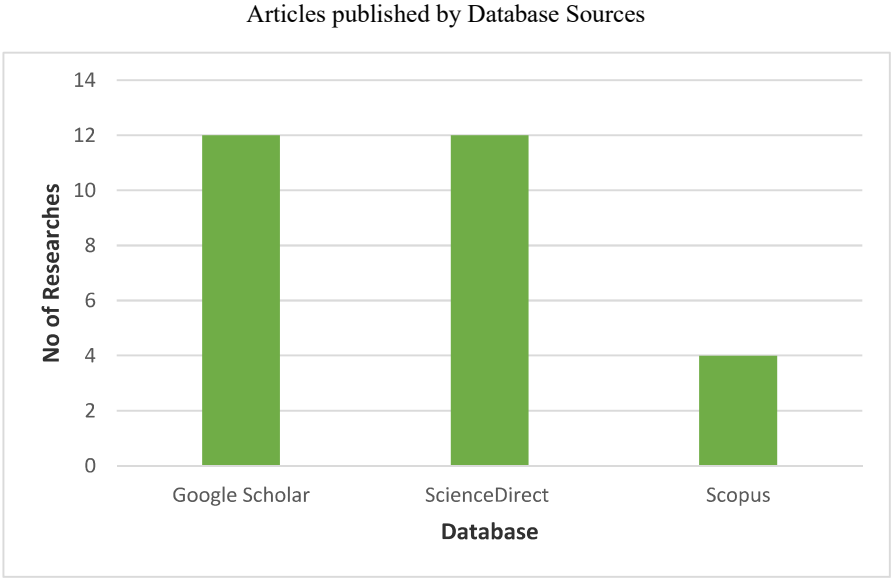

Figure 6. Count of Sources by Databases

As shown in Figure 6, more articles on lifelong learning were retrieved from Google Scholar and ScienceDirect than Scopus. Google Scholar and ScienceDirect had a wider scope and index a larger number of academic journals than Scopus, which specializes in scientific, technical, medical, and social sciences literature.

Methods used for procurement in the project environment

As shown in Figure 7 and Table 5, more articles on statistical and descriptive analyses were retrieved than other methods.

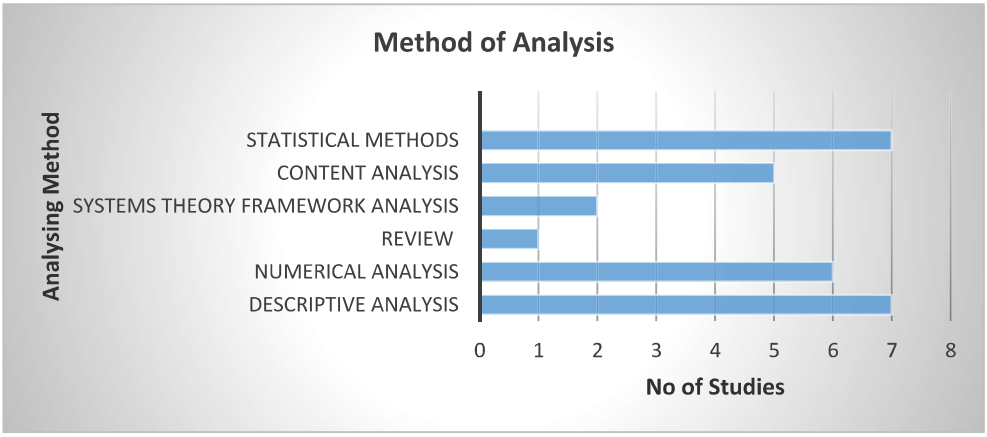

Figure 7. Count of Authors by Method of Analysis

Table 5. Methods of analysis of data used for each study included.

Method	Authors
Descriptive Analysis	Martinez-Mediano & Lord (2012), Uden & Dix (2000), Guest (2006), Uden & Dix, (2004), Parkinson, (1999), Porter, Patil, & Dutta (2012), Evans (2018)
Numerical Analysis	Skrentny & Lewis (2022), Vardiambasis et al. (2007), Patterson, Labun, & Eikenaar, (2016), Marra, Camplese, & Litzinger (1999), El Mawas et al. (2017), Nimmi, Zakkariya, & Rahul (2021)
Review	Latinopoulos (2005)
Systems Theory Framework Analysis	Saxe, Mahmoud & Razavinia (2022), Berzina et al. (2019)
Content Analysis	Andries de Grip (2012), Franklin, S., Taylor, C. E., and Peat, M. (2005) Lenschow (1998), Patterson, L., Labun, C., & Eikenaar, J. (2016), Deveci & Nunn (2018)
Statistical Methods	Froehle,et al. (2022), Aerts, (2020), Stolk & Martello (2015), Litzinger et al. (2001), Witt, E., & Lill (2012), Das (2011), Williams, Blowers & Goldberg (2004)

Table 5 and Figure 6 show the analysis method utilized for qualitative research. Descriptive analysis and statistical methods were the most used methods, with several authors utilizing this approach. Review, systems theory framework analysis, and other methods were used less frequently.

Analysis of Themes

Specifically, there are five main areas: learning on your own, coaching and mentorship, formal and informal learning, and group-based approaches) (Table 6) were identified from 28 articles that were fully derived inductively.

Table 6. Themes analysis

Theme	Articles
Formal and Informal Learning and Training	Saxe, Mahmoud & Razavinia, (2022), Lenschow (1998), Latinopoulos (2005), Graham Guest (2006), Martinez-Mediano & Lord (2012), Skrentny & Lewis (2022), Martinez-Mediano & Lord (2012), Andries de Grip (2012), Aerts et al. (2020), Porter, Patil, & Dutta (2012), Parkinson, (1999), Marra, Camplese, & Litzinger (1999), Deveci & Nunn (2018), Berzina et al. (2019), Litzinger et al. (2001), Witt, & Lill (2012), Das (2011), Williams, Blowers & Goldberg (2004), Nimmi, Zakkariya, & Rahul (2021)

Problem-based Learning	Lorna Uden & Alan Dix (2014), Peat, Taylor & Franklin (2005), Ioannis Andries et al. (2007), Patterson, Labun, and Eikenaar (2016), Uden & Dix (2004), Litzinger et al. (2001)
Self-directed Learning	Aerts et al. (2020), Froehle et al. (2022), Andries de Grip (2012), Graham Guest (2006), (Uden & Dix, 2004), Marra, Camplese, & Litzinger (1999), El Mawas et al. (2017), Litzinger et al. (2001), Evans (2018), Bowman (1997).
Group-based Approach	Gavin Duffy & Brian Bowe (2010), Patterson, Labun, and Eikenaar (2016)
Coaching and Mentoring	Froehle et al. (2022), Graham Guest (2006), Stolk & Martello (2015)

Table 6 provides a comprehensive analysis of the themes identified in the studies reviewed for the research question on the trends, themes, and gaps in lifelong learning for engineers. The table presents five main themes, namely Formal and Informal Learning and Training, Problem-based Learning, Self-directed Learning, Group-based Approach, and Coaching and Mentoring, alongside the studies that discussed each theme. Formal and Informal Learning and Training is the most frequently discussed theme in the table, with 18 studies mentioning it. This indicates that the concept of lifelong learning for engineers is being considered in both formal and informal contexts. Several studies, including Nimmi, Aerts et al. (2020), & Martinez-Mediano & Lord (2012) Zakkariya, & Rahul (2021), focused on the importance of continuous learning through formal training programs, workshops, and courses. In contrast, other studies, such as Graham Guest (2006) and Lenschow (1998), emphasized informal learning through on-the-job training and learning from colleagues.

Uden & Dix (2014) and Peat, Taylor & Franklin (2005) identified that professionals' ability to solve problems is improved by training based on problems, leading to lifelong learning in practice. Aerts et al. (2020) and Andries de Grip (2012) found that self-directed learning is necessary to bridge the gap between formal education and the rapidly changing demands of industry. Three studies discussed group-based learning, indicating that group-based learning facilitates teamwork and collaboration among engineers, leading to lifelong learning. On the other hand, two studies discussed the importance of coaching and mentoring, indicating that mentoring programs help to transfer knowledge and skills from experienced engineers to the younger generation.

The table shows that various approaches can be used to facilitate lifelong learning for engineers, with formal and informal learning and training being the most frequently discussed theme. The studies reveal the importance of engineers being proactive in their learning through self-directed learning and taking charge of their learning to bridge the gap between formal education and the rapidly changing demands of industry. The table highlights the need for organizations to consider different learning approaches, to support scientists' continuous education, tutoring, and mentorship programs as well as problem-oriented instruction, collaborative instruction, and mentoring are included.

Themes

Theme 1: Formal and Informal Learning and Training

Initially, competence, knowledge, and skills were measured based on educational background mostly depending on formal learning and training history. According to Andries de Grip (2012), "Academic scholarship on the establishment of outstanding durability organizations is also centered on unstructured education." According to the author, informal learning is very significant especially for engineers because the accumulation of technology takes place through diverse learning processes and may depreciate if the processes are absent leading to stagnation. Graham Guest (2006) cited provision as one of the facets associated with the continuous professional development of informal learning in the workplace. Organizations should assess to what extent they offer lifelong learning opportunities to their employees and consider collaborating with other bodies to promote the process. Universities have a responsibility to promote lifelong learning through education programs and online learning (Latinopoulos, 2005). Training is an important aspect of lifelong career growth and development that can go on for years (Skrentny & Lewis, 2022).

According to Andries de Grip (2012), one's level of education is not complementary to their history of participation in formal training. The research identified certain behavioral patterns among engineers with bachelor's degrees wherein they take part less often in formal or informal training from which they can learn, and female engineers have a different informal learning pattern compared to men; they spend a limited amount of time self-teaching (Andries de Grip, 2012). The gap in formal or informal learning and training based on educational background is a major issue.

Aerts et al. (2020) highlighted the evolution of lifelong learning in terms of technology to meet current needs. According to the authors, formal and informal training should remain practice-oriented and remain specific and relevant to the field of profession. Aerts et al. (2020) suggested that learning from peers through platforms such as LinkedIn and podcasts should be encouraged. The existence of alternative strategies such as online platforms eases access to the process of lifelong learning. There is a shift of focus towards more informal learning owing to the development of technology and the fact that in many cases formal learning is not sufficiently tailored toward existing practical needs. Both formal and informal learning and training are significant and should be promoted, especially in workplaces.

Theme 2: Problem-based Learning

According defined by Uden & Dix (2014), problem-centered education is "...the knowledge that emerges from striving for the comprehension of, or settlement of, an issue." and is a significant component of lifelong learning for engineers. Uden & Dix (2014) created and executed an end-of-course information technology module to help students appreciate the value of problem-based instruction. According to the findings, problem-based learning encouraged deeper and independent comprehension of the learning material as opposed to the conventional superficial understanding of course material. In their research, students were placed in small

groups to encourage teamwork and appreciation for diversity. Students gained significant skills such as self-management, information retrieval, proper communication, and time management. Engineers need to learn continuously throughout their work life both as part of learning teams and independently, the requirement for the incorporation of problem-based instruction into educational programs. A growing trend in education is the use of projects in education, which is related to problem-centered education in the engineering industry faster compared to the slower rate in educational institutions (Peat, Taylor & Franklin, 2005).

Vardiambasis et al. (2007) reported the results of the Technical Educational Institute of Crete (TEIoC) student survey, which demonstrated that the introduction of problem-based learning benefited the students who became more academically and adequately trained to meet the needs of the engineering job market. Patterson, Labun, and Eikenaar (2016) reported the significance of problem-solving processes in lifelong learning, which help learners in the identification of information gaps, fill the gaps efficiently to develop a full perspective of the problem, and come up with an effective solution. Therefore, educational institutions, as well as workplaces, should consider integrating more problem-based approaches and processes to promote lifelong learning.

Theme 3: Self-directed Learning

The most significant and prominent competencies for lifelong learning are self-reflection and self-regulation, both of which, according to Aerts et al. (2020), allow students to identify aspects that require improvement and acquire the discipline to act. The importance of self-directed education through experiences and one-on-one contacts like mentoring and coaching was emphasized by Froehle et al. in their study from the year 2022. Independent education has become a crucial part of continuing education since it encourages freedom and originality in personal development.

Andries de Grip (2012) identified a pattern of self-directed teaching based on gender and the type of employment, according to which, female engineers generally spend less time on self-teaching compared to their male counterparts. Additionally, engineers who identify a gap in their skills have a significant chance of investing in self-directed learning. There is a correlation between the types of employment and self-directed learning; those who work in positions that demand advanced skills in leadership are more inclined to engage in independent education. Andries de Grip (2012) also reported that certain categories of engineers do not sufficiently invest their time in self-directed learning.

It is important for engineers to document their major achievements in engineering, such as successful technical projects and significant contributions to management and administration. This can help them recognize their strengths and demonstrate their capabilities to others. Engineers should aggressively pursue self-directed lifelong learning activities, such as attending formal credit and non-credit courses, workshops, seminars, and other learning experiences (Bowman, 1997). They should maintain comprehensive records of their successful completion of these activities to ensure Professionals keep apprised of the most recent developments in their specific field and learn fresh abilities to increase their general competency (Bowman, 1997).

According to Graham Guest (2006), in the future, all lifelong learning will be characterized by self-directed learning to promote individuality and independence during the continuous professional development process. Therefore, self-directed learning is inevitable and should be integrated into learning institutions as well as in employment training to promote lifelong learning for engineers (Uden & Dix, 2004).

Theme 4: Group-based Approach

Currently, greater significance is placed on the comprehension of engineering knowledge and possession of the necessary abilities at the cost of elements like initiative, collaboration, interaction, and learning by yourself. Standards for accreditation have changed and are now characterized by increasing abilities in the required skills for undergraduate engineering students. Duffy and Bowe (2010) argued for the necessity of a shift from the conventional approach to a more group-based approach, which is quite compatible with simultaneous technical as well as non-technical learning outcomes' development.

Practical and personal skills are equally significant for lifelong learning for engineers; the latter is often ignored. According to Duffy & Bowe (2010), technical skills, personal skills should also be developed in a progressive and structured manner. In their research, the authors found that a group-based approach helped the student become an independent individual, well-equipped with the personal and technical skills required in the market.

Duffy & Bowe (2010) proposed the implementation of an approach where students learn to work Extremely difficult, flexible assignments that depend on subject-specific content are worked on both in groups and individually. An integrative understanding of learning, which encourages students to create their autonomous understanding of the material being learned, is the foundation of the approach that puts the student first. Patterson, Labun, and Eikenaar (2016) proposed the use of peer assessment of learners' group participation to promote the development of personal skills through structured activities. Personal skills are significant lifelong learning for engineers and can be developed through implementing a group-based learning approach.

Theme 5: Coaching and Mentoring

Providing coaching and mentoring are underutilized forces in continuing education. According to the findings of the investigation conducted by Froehle et al. (2022), approximately 86% of the participants recognized learning from a second party as a significant component of their development. Additionally, some participants in the study reported that formal programs involving the placement of new hires with mentors contributed to their growth. Froehle et al. (2022) highlighted peer mentorship and experience as primary learning methods; they emphasize team learning and general teamwork. According to Graham Guest (2006), the trends show that conventional management, training, and other mechanistic techniques are being replaced by mentoring and coaching that is based on dialogue as opposed to instruction. The individualistic nature of the strategy is among the most significant merits of coaching and mentoring.

Discussion

Lifelong learning is a never-ending process of continuous learning of skills and knowledge throughout one's life. The emphasis has evolved to continuous education as opposed to the use of educational background as a metric of measuring the capacity of an individual in terms of their proficiency. Many elements of lifelong learning highlight the significance of continuous professional development in a knowledge economy through vocational and educational organizations (Naimpally, Ramachandran & Smith, 2011).

the paradigm changes in learning about engineering from conventional educational methods to more practical methods are necessary to prepare learners for the changing demands of the engineering profession (Lenschow, 1998). Unfortunately, informal learning patterns revealed an inverse relationship between an engineer's level of education and the probability of participating in informal learning activities (Andries de Grip, 2012), which indicates that individuals with higher levels of education have a lower probability of participating in informal learning. Because there is a need to fill the gap in perceived differences between educational background and informal learning, organizations should consider introducing programs that encourage every individual, regardless of their educational background, to participate in learning activities, whether formal or informal (Aerts et al., 2020; Andries de Grip, 2012; Saxe, Mahmoud & Razavinia, 2022). Additionally, formal, and informal learning and training should remain practice-oriented, relevant, and tailored according to the profession (Aerts et al., 2020; Andries de Grip, 2012). Uden & Dix (2000; 2004) suggested that organizations should consider implementing an effective learning culture to create a supportive environment that promotes self-directed learning and on-the-job training.

Problem-based learning is among the most impactful techniques that promote and allow students to gain important personal skills. Unfortunately, greater importance is placed on understanding engineering knowledge at the expense of one's abilities and capabilities (Duffy & Bowe, 2010). However, modifications in accreditation requirements with an increased focus on personal interaction and resolving issues competencies were used. Integration of a problem-based approach will promote a deeper and independent understanding of the learning material, and learning skills such as self-management, information retrieval, proper communication, time management, and problem-solving capabilities (Vardiambasis et al., 2007; Patterson, Labun, and Eikenaar, 2016; Uden & Dix, 2014) that are crucial for lifelong learning in the engineering domain (Deveci & Nunn, 2018). Integration of a group-based approach enables the promotion of both technical and non-technical abilities improvement necessary for lifelong learning for engineers (Vardiambasis et al., 2007; Patterson, Labun, and Eikenaar, 2016; Uden & Dix, 2014).

In this regard, learning and vocational institutions should consider the implementation of an approach where the learners can operate both individually and in groups to solve multifaceted flexible problems with content that is specific to the engineering field. Additionally, they should invest in the development of non-technical skills of their employees or students as much as they do for technical skills; both aspects are equally significant.

Institutions can demonstrate their commitment to lifelong learning by integrating it into their internal and external departmental reviews and accreditation procedures (Bowman, 1997). This can help to ensure that the institutions remain up to date with the most recent research in the area and can provide its pupils with the most comprehensive instruction feasible (Bowman, 1997). Institutions can offer courses tailored for engineers who have graduated more than ten years ago or those who are transitioning into a new career (Bowman, 1997). These courses should focus on senior undergraduate topics in areas experiencing rapid technological changes (Bowman, 1997). This approach can help to update the skills and knowledge of practicing engineers and ensure that they are equipped with the latest tools and techniques in their field (Bowman, 1997).

Self-reflection and self-regulation are important skills required regarding architects' ongoing education (El Mawas et al., 2017) as these skills enable them to identify their traits, whether in terms of technical or non-technical skills that require improvement, allowing them to take the necessary steps to acquire the required expertise (Aerts et al., 2020). The gap identified by Andries de Grip (2012) where female engineers spend a limited amount of time on self-teaching in comparison to their male counterparts should be filled by developing programs that encourage all engineers, especially women and those in lower management levels, to take part in self-directed learning activities.

According to Graham Guest (2006) encompasses the most recent findings in the field and can give its students the most in-depth education possible (Bowman, 1997). The future will be characterized by self-directed learning to support individuality and independence during the continuous professional development process. Therefore, self-directed learning should be implemented in learning and vocational institutions to promote individuality in self-assessment and self-regulation.

It is crucial for practicing engineers to enhance certain essential skills such as delivering presentations, writing reports and memos, managing projects, and budgeting, as well as interpersonal communication (Martínez-Mediano & Lord, 2012). Studying scientific publications is an effective way to stay current on market developments. Collaborating with colleagues who share similar interests can also aid in professional development (Martínez-Mediano & Lord, 2012). When working in a team, all members can pool their strengths to accomplish the team's objectives, identify and solve issues, enhance their work, and foster innovation, resulting in valuable synergies (Martínez-Mediano & Lord, 2012).

Many consulting and management firms may offer in-house training programs, but most of the learning comes from participating in various initiatives with a range of clients (Bowman, 1997). Nevertheless, scientists who work for themselves or small companies frequently lack access to these programs, and their education is mostly restricted to on-the-job training with customers. As a result, all engineers must have an organized framework for ongoing development that could involve accredited colleges and universities to augment their on-the-job training (Bowman, 1997).

Professional licensing bodies should establish practical approaches and practices that support the lifelong

learning process for their members. To do this, they should develop and monitor guidelines that facilitate ongoing education and training (Bowman, 1997). Maintaining documentation that demonstrates designers' ongoing ability, particularly proof of attendance at official programs and acknowledgment of accomplishments in the industry, constitutes a best practice (Bowman, 1997). This can help ensure that engineers remain up to date with the latest developments and maintain their expertise throughout their careers. Establishing continuous education requirements for architects who hold managerial roles, especially those having monetary, monetary, and staffing duties, was another excellent practice (Bowman, 1997). Such guidelines can help ensure that engineers in leadership roles remain competent and able to make informed decisions that benefit their organizations and the wider profession (Bowman, 1997).

Lifelong learning is imperative for the continuous professional development of engineers. The principal obligation for professional development must ultimately rest with the specific engineer (Martinez-Mediano & Lord, 2012). Engineers have a responsibility to establish their occupational paths and ensure their technical and non-technical competencies develop to meet the challenges faced in their profession. The current literature review proposed the implementation of numerous approaches to promote lifelong learning for engineers including mentoring and coaching, group-based approach, self-directed learning, group-based learning, and formal and informal learning and training. Education and vocational institutions as well as workplaces should consider implementing these strategies.

Conclusions

Our database search identified 5342 hits of which 28 articles met the predefined eligibility criteria. Most of the hits were from the United Kingdom, USA, and Europe, as well as a substantial number from India, and more articles were retrieved from Google Scholar and ScienceDirect than Scopus. Statistical and descriptive analyses formed a major proportion of the total, which resulted in the identification of five themes - instructional methods such as mentoring and guidance, both conventional and unconventional learning, and team-based strategies. Our thematic analysis found a shift in focus towards more informal learning owing to the development of technology and the fact that in many cases, formal learning is not sufficiently tailored toward existing practical needs.

Both formal and informal learning and training are significant and should be promoted, especially in workplaces. Further, educational institutions, as well as workplaces, should consider integrating more problem-based approaches and processes to promote lifelong learning. In addition, self-directed learning is inevitable and should be integrated into learning institutions as well as in employment training to promote lifelong learning for engineers. Also, well, a group-based approach confers independence and equips the trainee or worker with the personal and technical skills required in the market. Lastly, conventional management, training, and other mechanistic techniques are being replaced by mentoring and coaching that are based on dialogue as opposed to instructions delivered in a one-way fashion. Our findings will provide a fillip to justify the need for continuous professional development of engineers.

Limitations

The number of studies included in the current literature review was a significant limitation. The inclusion criteria may have been too restrictive, leading to the exclusion of studies that may have been useful for the current thematic analysis. For instance, the time restraint and language limitation may have resulted in the exclusion of studies that would have been impactful for the current literature review. In some cases, there was incoherence in the available themes resulting in their exclusion from the thematic analysis.

Future research works based on lifelong learning for engineers should aim to overcome the limitations identified in this research and study detailed into key themes. A more thorough understanding will be ensured by extending inclusion criteria to cover a more expanded geographical and language range of studies. Comprehensive investigations into specific subjects like mentoring, problem-based learning, and the importance of self-directed learning should also be addressed using a variety of research approaches. Research ought to study the impact of new digital tools on engineering education as technology develops, and long-term studies should assess how the integration of lifelong learning concepts affects engineers' professional growth and career paths.

Implications

Particularly in organizations, only a few organizations support professionals' continuous education. Patterns discovered through the present thematic assessment brought to light shortcomings in the application of plans to support engineers' lifelong learning. The knowledge gained from the topical examination may help with the creation of strategies to support professional growth on an ongoing basis.

Author Contributions

The only relevant assignment selection, assessment, examination, data as well as details extraction process, analysis of themes, as well as data synthesis activities in which the author engaged fully, were those. The final draught was examined and authorized by the person who wrote it.

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Appendix.

Table A1. Data Extraction

Author	Year	Purpose	Methodology	Country	Outcomes
Graham Guest	2006	Think about what the 21st century has in store for continuing education and professional growth and include some relevant topics like coaching and mentorship.	Content Analysis	United Kingdom	Coaching and mentoring, which emphasize individual professionals and include communication rather than teaching, are replacing training, management, and other "mechanistic" techniques.
Andries de Grip	2012	To add to the conversation of what factors influence scientists' and engineers' training participation and informal learning (S&Es)	Tobit analyses of survey data	Netherlands	S&Es working for companies that use innovative production methods are more likely to take part in formal training programs and profit from the opportunity for on-the-job learning. In companies with lots of product breakthroughs, lifelong learning is not stimulated. S&Es work less frequently in formal training programs when they are engaged by companies in very

Author	Year	Purpose	Methodology	Country	Outcomes
					competitive industries. By analyzing employee characteristics, and job and business characteristics, the paper contributes to a reservoir of information on the elements impacting the growth of human resources, together with educational institutions and other types of informal education.
Froehle K. et al.	2022	Examine lifelong learning in engineering! Workplaces.	Thematic analysis of interview transcripts	United States	Understanding from knowledge, acquiring knowledge through coaches, and gaining knowledge through asking inquiries are all essential.
Aerts et al.	2020	Find the ideal learning environment for professionals and competencies that must be trained.	Qualitative Analysis	Belgium	As LLL is often spread around the curriculum and not directly named as such, its presence may be lost on some students.
Uden & Dix	2000	Examine the benefits of problem-based learning for learning (PBL)	Module analysis	United Kingdom	PBL may be used to develop abilities for lifelong learning.
Duffy & Bowe	2010	The results in all	Group-based	Ireland	A project-based,

Author	Year	Purpose	Methodology	Country	Outcomes
		the featured research emphasized the suggested remedies for professionals' continuous education.	project analysis		collaborative educational approach should be implemented to promote lifelong learning.
Vardiambasis et al.	2007	To determine the requirement for Greek engineers to continue their education	Survey Analysis	Greece	To support the industry's requirement to sustain high research and innovation potential, summer courses in "hot" engineering disciplines are organized using a more research-oriented approach.
Patterson, Labun, and Eikenaar	2016	Examine how the CEAB graduate qualities of "Lifelong Learning" can be provided with instruction and evaluation in the APSC 176 and APSC 201 communication courses, both of which are part of an engineering program at the UBC Faculty of Medicine.	Content Analysis	United Kingdom	Given the relatively limited enrolment in such courses, co-curricular programs like I2E and communication courses like SOE's APSC 176 and 201 offer chances for major effect among undergraduate engineering students. Additionally, communication training and practice serve as models for

Author	Year	Purpose	Methodology	Country	Outcomes
		Investigate the following stages in creating relevant criteria for judging if these courses successfully satisfy this accreditation requirement.			the continual and self-directed nature of lifelong learning.
Lords and Martinez-Mediano	2012	to emphasize the value of continuous education and competencies required in the engineering field.	Program Analysis	Spain	An engineering-specific program for the ongoing development of skills is described in the paper. This program is made to assist professionals in maintaining their understanding and abilities to stay relevant in their industry. The program focuses on five key competencies: critical thinking and problem-solving, communication, teamwork, leadership, and lifelong learning.
Uden & Dix	2000	To evaluate case studies of how PBL might be used to obtain lifetime learning	Program Analysis	United Kingdom	Students are being forced to use more autonomous and learner-centered strategies because of

Author	Year	Purpose	Methodology	Country	Outcomes
		skills			the decreasing resources available in higher education. After running the instructional software design program for two years, studies showed that students who took it improved academically and could apply what they learned to other courses and jobs.
Latinopoulos	2005	To examine the present state of lifelong learning practices for civil engineers in Europe, considering the historical evolution of general European policies, particular aims and target audiences, providers, and forms of provision, as well as teaching and learning methodologies.	Review	Europe	All higher education institutions should prioritize lifelong learning as they adjust their strategic objectives to encourage a larger and more effective involvement in these activities.
Skrentny & Lewis	2022	To statistically evaluate each factor related to	Survey Analysis	United States	The findings as a whole provide broader perspectives

Author	Year	Purpose	Methodology	Country	Outcomes
		the pipeline character of STEM education using data from the National Assessment of University Students.			on STEM education and employment and add to research on the diversity and workforce transitions in the sciences and engineering.
Lenschow	1998	To provide information about fresh measures implemented to support utilizing technology for information and communication enabling project-based learning in both small- and large-scale initiatives.	Content Analysis	Not Specific	In industry, project-based learning is growing, but more slowly in colleges and institutions.
Peat, Taylor & Franklin	2005	To assess the significance of project-based learning	Content Analysis	Norway	When PBL is used effectively in the correct courses, students learn more and become more competent, combining an appropriate mindset, ability, expertise, and skills is referred to as competency.
Saxe, Mahmoud & Razavinia	2022	A complete structure for continuing education in undergrad design	Systems Theory Framework	Canada	Self-directed learning promotes lifelong learning. Evaluation of the issue, research,

Author	Year	Purpose	Methodology	Country	Outcomes
		programs will be described.			creation, and application of technical instruments professionalism are all traits and skills that require constant amelioration throughout one's career. Lifelong learning transcends all graduate attributes because it is imperative for each of their development and improvement.
Parkinson, A	1999	Discuss how attributes required for lifelong learning can be developed	Descriptive Analysis	United States	The strategy being used is based on several fundamental principles, including setting clear expectations, expecting students to be accountable for their learning while enrolled in school, providing opportunities for learning outside of the classroom, motivating students, and teaching them how to learn.
Porter, Patil, & Dutta	2012	Analyze the significance of lifelong learning	Descriptive Analysis	Not Specific	Lifelong learning is significant for lifelong learning.

Author	Year	Purpose	Methodology	Country	Outcomes
		for engineers.			
Marra, R. M., Camplese, K. Z., & Litzinger	1999	Discuss ideas for evaluating students' lifetime learning while summarizing the findings of the first literature research on the topic as it relates to engineering education.	Numerical Analysis	United States	Engineers should be taught to learn independently in preparation for lifelong learning.
Deveci & Nunn	2018	Give an example of how engineering education uses intrapersonal communication as a lifetime learning ability.	Content Analysis	United States	Within a constructivist learning framework, reflective writing, visualization, and progress reporting can encourage intrapersonal dialogue and experiential learning, empowering students to take on the responsibilities of lifelong learning.
Berzina et al.	2019	Additionally, there is a brand-new continuing education program in substances, layout, and function for electrical and optical devices that is currently	Content Analysis	United Kingdom	Programs can be applied to help engineers in lifelong learning.

Author	Year	Purpose	Methodology	Country	Outcomes
		underway at the National Excellence Centre for Lifelong Learning in Electrical Engineering at RTU.			
Stolk & Martello	2015	If disciplinary integration fosters students' attitudes and abilities for lifelong learning in project-based engineering courses.	Statistical Analysis	Not Specified	All engineering students, particularly female students, can benefit from developing a feeling of social relatedness that fosters greater learning by placing human context at the core of technical instruction.
El Mawas et al.	2017	To emphasize the value of self-controlled learning for lifelong learning.	Numerical Analysis	Not Specific	From a lifetime learning viewpoint, the investigation provided an autonomous method of learning that incorporated technological, working, and aesthetic components.
Litzinger et al.	2001	To concentrate on assessing students' capacity for self-directed learning and making some early steps to improve the	Statistical Analysis	United States	Although the need for faculty and curricula to educate students for continuous learning is recent, the engineering

Author	Year	Purpose	Methodology	Country	Outcomes
		course to help students grow in this capacity.			profession places importance on lifelong learning, particularly continuing education. Independent instruction is essential for continuous development.
Witt, E., & Lill	2012	To explain the research of learner views on lifelong learning and Estonia's skill needs for the construction sector.	Statistical Analysis	Estonia	The results indicated a wide range in learners' perceptions of what constitutes present and future industrial requirements, a lack of satisfaction with how well HEIs are meeting those needs, and a reluctance to adopt the required position of lifelong learner—all of which pose challenges to the model.
Das, A. K.	2011	To assess critically the way open learning material (OER) activities have evolved in India, with a focus on how the OER movement	Statistical Analysis	India	The study provided examples of OER's role in democratizing venues for lifelong learning, which ultimately aid in skill development.

Author	Year	Purpose	Methodology	Country	Outcomes
		evolved from an open access revolution against the background of growth based on the information economy.			
Williams, Blowers & Goldberg	2004	To demonstrate how fostering information literacy in students will enable them to exercise greater control over their education, inside as well as outside of the classroom.	Statistical Analysis	United States	Developing information literacy skills is significant for lifelong learning.
Evans G.J.	2018	To promote the explicit teaching of metacognition as a means of promoting lifelong learning and self-directed learning.	Descriptive Analysis	Canada	There are simple ways to include metacognition education into current undergraduate engineering courses, which might have a significant positive impact on students.
Nimmi, Zakkariya, & Rahul	2021	to find out if continuous education makes human resources more valuable when assessing the likelihood of employment.	Numerical Analysis	India	The results support lifelong learning's position as a mediator in the relationship Because they reveal an advantageous connection between

Author	Year	Purpose	Methodology	Country	Outcomes
					human resources and one's perceived employment.
Bowman	1997	To determine the key issues faced by engineers during lifelong learning.	Content Analysis	N/A	Career success requires the maintenance of competence.