Challenge Based Learning

A Comprehensive Survey of the Literature

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Abstract

Challenge Based Learning (CBL) is a relatively new contribution to the pedagogical landscape, emerging in the early 2000s. Recently the interest in CBL and, correspondingly, the amount of published literature has increased significantly. This document builds on existing literature reviews and identifies additional publications to provide deeper and more comprehensive insight into CBL. Starting with a focused review of the academic databases: Scopus and WoS, a broad collection of CBL publications were identified and analyzed. The survey then identifies and reviews additional documents connected to these publications, resulting in an extensive review of the existing CBL literature.

Through the review, a series of themes emerged, providing a structure for the document. The themes include:

- the definition, origins and components of CBL;
- motivations for adoption and implementation;
- current strategies for implementation and potential barriers;
- the impact of CBL.

These themes are investigated by exploring and connecting a global set of publications. In addition, the document includes future research recommendations, a Bibliometrics and Scientometrics literature analysis, and a comprehensive bibliography. A goal of the document is to consolidate the current CBL literature, expand networks and increase conversations to support adoption, implementation and further research.

This literature survey presents an informative perspective of the global CBL landscape. The published literature presents CBL as a unique and promising pedagogical approach used effectively in transformative large-scale implementations and classroom integration. However, a range of new questions arise, and additional rigorous research is needed to deepen the knowledge base and gain a broader perspective on the effectiveness and role of CBL.

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Introduction

Challenge Based Learning (CBL) is a relative newcomer to pedagogical approaches, emerging in the early 2000s (Baloian et al., 2006; Giorgio & Brophy, 2001; Nichols & Cator, 2008) and expanding in usage over the last several decades. The approach has gained popularity in recent years as a means of promoting student engagement, ownership of learning, critical thinking, problem-solving abilities, external partnerships and the development of professional skills.

The number of published papers on Challenge Based Learning has grown significantly over the past five years. Publications include conference proceedings, journal articles, books, and literature reviews. This literature survey combines, builds on and extends existing higher education-focused literature reviews (Gallagher & Savage, 2020; Leijon et al., 2022; Moresi et al., 2018; Sukackė et al., 2022) and additional publications, especially in pre-university education. The goal of consolidating a broad set of publications is to provide deeper and broader insight into CBL.

The survey provides insights into the fundamental components of CBL and perspectives on origins, definitions, implementations, and effectiveness. Finally, the document identifies gaps in the research and makes recommendations for future efforts.

Overall, the literature survey aspires to support new and current CBL implementations and spur additional research at all levels.

Methodology

The academic databases: Scopus and WoS served as a starting point for the literature survey. Using Challenge-Based Learning in Title, Abstract or Keyword fields, 426 matching documents emerged.

An initial review of the dataset removing duplicates and non-relevant items resulted in 383 documents, including articles, conference papers and book chapters. Quantitative and qualitative approaches were applied to analyze the identified documents.

For the quantitative approach, a bibliometric analysis was conducted based on science mapping methodology (Börner et al., 2003) on the entire collection of documents retrieved using the bibliometrix software packages (Aria & Cuccurullo, 2017). This analysis provided a big picture of the current state of published research and identified macro-trends, most relevant sources and authors, conceptual clusters of keywords, most active countries and collaboration networks, and co-citation networks. A series of graphs in this document's Bibliometrics and Scientometrics Analysis appendix visualize this information.

Screening and filtering were conducted based on inclusion criteria for a more in-depth and qualitative approach. A screening of the initial data set of 383 documents using a matrix made of a predefined set of relevant themes plus other themes that emerged during the analysis resulted in a final set of 172 documents for the qualitative part of the survey. The predefined themes included CBL origins and definitions, examples of different implementations, the effectiveness of CBL, and other emerging themes such as the CBL alignment with global sustainability goals, CBL and soft 21st-century skills, and the hybridization of CBL with other frameworks.

Additional articles and book chapters not indexed by the two primary sources (Scopus and WoS) were identified and considered relevant to the research goal during the screening process. These documents were retrieved, added to the list for a more in-depth review, and included in the comprehensive bibliography (Appendix B).

Finally, the initial collection of materials revealed minimal information about CBL in pre and non-University settings. Through a search of additional databases, an additional set of documents focused on CBL in primary and secondary education was retrieved and reviewed.

State of the Research

The number of publications focused on CBL remained low until 2017 when publications significantly escalated. This growth includes research across various academic disciplines, with engineering as the most prominent.

The vast majority of publications document research on CBL implementations in higher education. Although one of the initial sources of CBL focused on implementations in primary and secondary education, more research is needed.

The published research spans a broad geography, indicating a global interest in CBL. Most publications (in the dataset used for the analysis) are from Mexico and USA, followed by the Netherlands, Spain, Brazil, Indonesia and Italy. The research concentration in specific geographic locations identified a University (Mexico) and a consortium of Universities (Netherlands) adopting CBL. There is also evidence that the growth in research and publications mirrors the opening of the Apple Developer Academies in Universities (Brazil & Italy). The Apple Developer Academies include a systematic implementation of CBL.

The most common methodologies in the surveyed literature are descriptive case studies, followed by quantitative (quasi-experimental), mixed methods, and qualitative. However, research on CBL is nascent and could benefit from more rigorous methodological approaches.

Various publications detail successful case studies, experiences, and implementations in higher education (HiEd). However, despite the increasing interest among HiEd, the research landscape of CBL remains vaguely defined and fragmented. Most papers on CBL are descriptive, offering minimal or no conceptualization of the CBL framework and its ideas.

Quantitative studies on the effectiveness of CBL implementation are limited and few, with most studies remaining at a case-based, descriptive level. However, some articles reference robust studies on active learning strategies, supported by large data sets and quantitative study design, as scientifically grounded evidence of the effectiveness of non-traditional learning approaches as opposed to traditional, lecture-based, hierarchical, and teacher-centered approaches.

To address the nascent nature of CBL research, some researchers have tried to answer how CBL is scientifically grounded. For example, Leijon et al. (2022) identified different themes with CBL as a background frame for educational interventions. The themes include a descriptive level, a background frame for the intervention and to discuss/interpret the intervention results, and a background frame for intervention used analytically and discussed concerning other disciplines and theoretical approaches.

While there is evidence of successful case studies, experiences, and implementations of CBL, the research landscape is still emerging, with limited longitudinal and quantitative studies. Researchers have sometimes addressed this gap by combining CBL with other theoretical approaches to offer analytical depth.

Findings and Discussion

The discussion follows a set of overarching themes and sub-themes that emerged from the survey.

Section 1: What is CBL? This section explores the origins, definitions, theoretical foundation, and components of CBL as addressed in published literature. The components discussion addresses key elements of CBL that make it a unique educational approach.

Section 2: Why is CBL implemented? This discussion explores the range of motivations for the adoption and implementation of CBL.

Section 3: How is CBL Implemented? This section reviews approaches used to implement CBL, barriers to implementation, and ideas for avoiding them.

Section 4: What is the impact of CBL? This section focuses on the effectiveness of CBL implementations, as reported in the literature.

What is CBL?

Origins

The literature traces the earliest mention of CBL to academics at Vanderbilt University and later to researchers affiliated with the VaNTH ERC Engineering Research Center, a collaborative effort between the universities of Vanderbilt, Northwestern, Texas, Harvard, and MIT (Birol et al., 2002; Giorgio & Brophy, 2001; Giorgio et al., 2002; Rowe & Klein-Gardner, 2007). This concept of CBL connects to the How People Learn (HPL) pedagogical framework (Bransford et al., 2000) and aims to enhance student learning experiences in higher education. The collaboration resulted in the STAR Legacy Cycle, a six-stage cycle including a challenge, idea generation, multiple perspectives, research and revision, assessment and going public (Giorgio & Brophy, 2001). More publications documenting several case studies and early evaluations on the effectiveness of this approach were published mainly in engineering and biotechnology (Jansen, 2003; Martin et al., 2007; Rowe & Klein-Gardner, 2007).

Another early appearance of Challenge-Based Learning in literature, apparently unrelated to the STAR Legacy Cycle, appeared in 2004 (Baloian et al., 2006). Here CBL is mainly rooted in Vygotsky's sociocultural theory and is proposed by the authors as a unique form of problem-based learning, in which the problems are of realistic, open-ended nature, for which the word "Challenge" is proposed in place of "problem." In addition, experiential and project-based learning elements claim to be included in the framework (Baloian et al., 2006).

In 2007, a large collaborative project, "Apple Classrooms of Tomorrow - Today," was initiated by a team within the education division of Apple Inc. The project focused on helping American high schools create the learning environment a new generation of students needed to stay engaged and in school. The project resulted in a set of "design principles" for the 21st Century High School (Apple Inc, 2008).

Following the ACOT2 project, Apple Inc. published a white paper proposing a Challenge Based Learning framework (Nichols & Cator, 2008). A 2008 pilot study which applied the Apple-defined version of CBL was designed to extend and test the framework in K12 middle/junior high education and run in six schools across the US (Johnson et al., 2009). In 2011 the results were published from another more extensive study, including a broader range of institutions from elementary to HiEd and international sites (Johnson & Adams, 2011).

The definitions from the Star Legacy project and the Apple-related publications (Johnson & Adams, 2011; Johnson et al., 2009; Nichols & Cator, 2008; and Nichols et al., 2016) appear in subsequent publications in the literature. Over time the Apple definition progressively became the most frequently cited.

Since then, a wide variety of case studies and research literature emerged which refers to CBL - either in its Apple original definition or in some more derivative and hybridized versions of it. However, as the definition section illustrates, it is challenging to quantify the extent publications track back to specific origins.

Definitions

The literature includes a range of definitions for Challenge Based Learning. A confounding factor in identifying definitions is the presence of related terms such as Challenge-Based Learning, Challenge-Based Education (Charosky et al., 2018), Challenge-Based Instruction (Crown et al., 2015), Challenge-Driven Education (Högfeldt et al., 2019; Leijon et al., 2022; van den Beemt et al., 2023a), and Challenge Based Innovation (Kurikka et al., 2016). Recent, comprehensive literature reviews and studies about CBL (Gallagher & Savage, 2020; Leijon et al., 2022; Sukackė et al., 2022; van den Beemt et al., 2023b) provide some clarity in identifying the most recurrent definitions across the surveyed literature or proposing new, encompassing ones.

Johnson et al. (2009), in one of the first systematic longitudinal studies on the results of the implementation of CBL, define it as “a new teaching model that incorporates the best aspects of problem-based learning, project-based learning, and contextual teaching and learning while focusing on real problems faced in the real world .”

The definition from Nichols and Cator (2008) is the most often quoted in the literature:

> "Challenge Based Learning is an engaging multidisciplinary approach to teaching and learning that encourages students to leverage the technology they use daily to solve real-world problems. Challenge Based Learning is collaborative and hands-on, asking students to work with peers, teachers, and experts in their communities and worldwide to ask good questions, develop deeper subject area knowledge, accept and solve challenges, take action, and share their experience."

Leijon et al. (2022) use this definition to identify the relevant keywords used to define the key components of CBL, which are: multidisciplinary, teaching and learning, technology, real-world problems, collaborative, communities, ask good questions, subject area knowledge, solve challenges, take action, and share.

The 2008 definition by Nichols and Cator evolved in the CBL User guide (Nichols et al., 2016) to include the concept of a learning framework, a deeper emphasis on subject area content and 21st Century Skills.

> "Challenge Based Learning provides an efficient and effective framework for learning while solving real-world Challenges. The framework is collaborative and hands-on, asking all participants (students, teachers, families, and community members) to identify Big Ideas, ask good questions, identify and solve Challenges, gain in-depth subject area knowledge, develop 21st-century skills, and share their thoughts with the world."

According to Gallagher and Savage (2020), at the highest level of abstraction and, or conceptualization, CBL has been defined in a wide range of ways: as a “framework,” an “approach,” a “methodology,” a “model,” and as a “learning experience.” However, the authors prefer the term “approach.” Based on the reviewed definitions, they identify another set of defining keywords: global themes, real-world challenges, collaboration, technology, flexibility, multidisciplinarity and discipline specificity, creativity and innovation, and challenge definition.

Another often-cited definition is the one found in Malmqvist et al. (2015):

> "A learning experience in which learning takes place through the identification, analysis and design of a solution to a socio-technical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find collaboratively developed solutions that are environmentally, socially and economically sustainable."

According to van den Beemt et al. (2023a), this definition positions CBL in the broader scope of "Grand Challenges" aligned to the increasingly relevant (in higher education) themes of global goals and sustainability, thus gaining traction in publications that connect CBL to educational initiatives strategically aligned with such themes. For instance, the European Consortium of Innovative Universities (ECIU), one of the leading promoters of CBL in Europe, defines challenge-based learning that mixes the two widely accepted descriptions, characterizing CBL as a pedagogical approach that actively engages students in a genuine, pertinent, and contextually relevant situation. The process entails identifying, analyzing, and designing a solution to a problem which is both socially and technologically relevant. The educational experience is typically interdisciplinary, incorporates diverse stakeholder viewpoints, and aims to achieve a jointly created solution that is environmentally, socially, and economically sustainable (Kohn Rådberg et al., 2020; Sukackė et al., 2022).

In this perspective, other recent attempts to develop a more comprehensive definition are found in the literature (Reymen et al., 2022). A significative example is how De Stefani and Han (2022) define CBL in the context of an initiative by the Arqus alliance, a trans-European challenge-based learning (CBL) project involving seven European Universities from many disciplinary fields, including social sciences and natural sciences. The authors of the study discuss the two definitions by Apple and Malmqvist, considering all relevant keywords and proposing a new synthetic one:

> "CBL is conceived as a learning framework that allows participants to navigate local and global "societal challenges" identified autonomously or responding to a challenge provider while gaining multi/inter-disciplinary awareness and cultivating disciplinary knowledge and professional and social skills. CBL allows to develop concrete and feasible socio-technical projects, based on a scientifically controlled research pattern and in dialogue with local and global stakeholders, that integrate a technological component and are likely to be communicated, implemented and disseminated, producing effects compatible with the SDG agenda" (De Stefani & Han, 2022).

While there is considerable overlap among the definitions, one interesting distinction between the prevailing definitions is the locale and focus of the Challenges. In the definitions connected to writing by Nichols et al. (2016), the focus is real-world challenges, but no assertion that these must be "societal challenges." They certainly can be, but they could also be less aspirational and more personal. The definition discussion naturally leads to exploring the components of CBL discussed later in this paper.

A related and less explored area is the definition of a Challenge. Most published documents do not definitively differentiate between what is considered a challenge vs. a problem vs. a project vs an opportunity, and understanding of these concepts and their differences is generally taken for granted.

Efforts to define Challenges include a "call to action" - charging participants to learn about the subject and develop a solution (Nichols et al., 2016). Another definition can be found in the EduTrends (2015) report by Tecnológico de Monterrey: A challenge is an activity, task or situation representing an incentive and an obstacle to overcome (EduTrends, 2015). In other literature, Challenges are specifically derived from societal issues and, in particular, the United Nations Sustainable Development Goals (Dieck-Assad et al., 2021; Membrillo-Hernández et al., 2018; Pérez-Rodríguez et al., 2022). A similar definition of societal-based challenges is the "Grand Challenges," a set of global initiatives traced back to the Bill & Melinda Gates Foundation. In this case, challenges are opportunities to focus innovation on making an impact.

Another definition of Challenges that emerges within the CBL literature is as a "unit" of learning or instruction. Challenges are specific learning opportunities of varying lengths and intensities. From this perspective, Challenges are specific implementations of Challenge Based Learning (Nichols et al., 2016; Recke & Perna, 2021a; Vilalta-Perdomo et al., 2022a) that can be part of a larger scope and sequence.

A final definition of a challenge emerging from the literature is a software development process. These papers merge CBL with Agile methodologies such as scrum to become a software development process (Binder. et al., 2017; Santos et al., 2015), particularly as part of a learning experience. A Challenge becomes a time-blocked learning and development process for mobile application development.

Theoretical / Pedagogical Foundations

In general, the CBL literature does not thoroughly articulate the learning theories and pedagogical foundations that serve as the theoretical underpinnings of the approach.

For example, Baloian et al. (2006) refer to Vygotsky's sociocultural theory as the foundational thinking in their presentation of Challenge-Based Learning. In particular, they reference the importance of social interaction, authentic learning activities, creating and sharing artifacts within their community and close collaboration between learners and experts. Additionally, the authors state that elements of CBL draw from experiential, project-based and decision-based learning approaches.

The original Apple CBL paper (Nichols & Cator, 2008) does not explicitly provide a theoretical or pedagogical foundation for the framework. The 2016 CBL Guide acknowledges that "Challenge Based Learning builds on the foundation of experiential learning and leans heavily on the wisdom of a long history of progressive ideas" (Nichols et al., 2016, p. 7) but does not elaborate.

Tecnológico de Monterrey roots Challenge-Based Learning in Experiential Learning with references to a tradition of philosophers and educational theorists that contributed to theories of learning through experiences, such as Dewey, Piaget, Kilpatrick and Kolb. In particular, there is attribution given to Kolb's model of experiential learning, highlighting the importance of the cycle between concrete experience and reflection (EduTrends, 2015).

CBL shares characteristics of progressive, constructivist, sociocultural, experiential, service, critical, and constructionist learning theories. These theories emphasize active, experiential, relational, contextual, self-regulated, and practical learning within individuals, communities, and organizations. Furthermore, these qualities appear in various historical and current pedagogical approaches. In some of the literature, there is the accurate assertion that CBL was not a wholly original method and instead developed through "aligned pedagogies" and a synthesis of learning theories and pedagogical approaches. From this perspective, CBL selects key ideas from various theoretical stances to address societal changes, the needs of a new educational landscape and the emerging needs of students (Gallagher & Savage, 2020). A similar assessment holds for almost all education approaches.

Relationship to Problem and Project-Based Learning

CBL and related approaches like project-based learning (PjBL), problem-based learning (PBL), and inquiry-based learning (IBL) are frequently referenced interchangeably as generic active learning frameworks, potentially leading to confusion about the similarities and differences (Sukackė et al., 2022). The question of how and where CBL varies from PBL and PjBL is common in the literature when presenting or discussing CBL. While some studies have attempted to compare and contrast these approaches

(Chicharro et al., 2019; EduTrends, 2015; Gaskins et al., 2015; Sukackė et al., 2022; van den Beemt et al., 2023b), there is value in further clarifying the unique features of each pedagogy.

The literature includes a variety of approaches to articulating the differences and similarities between CBL, PBL and PjBL. Tecnológico de Monterrey notes that the approaches share similarities in engaging students in problem-solving and encouraging participation, active inquiry and collaboration in developing solutions. However, they differ in the presentation, typology of problems, and approach to solving them, with CBL more oriented towards real and open problems rather than fictional or purely scholastic ones (EduTrends, 2015). According to Gaskins et al. (2015), the primary distinctions between PBL and CBL include: PBL concentrates on a solution to a specific project, while CBL encompasses a broader scope for the investigation.Moreover, CBL aims to link students with actual issues existing in their communities, which can enhance their involvement and drive. Another point that Gaskins et al. (2015) highlight as a crucial difference is that CBL fosters the practice of reflecting on one's learning and the consequences of their actions.

Binder et al. (2017) point to CBL not including an externally created and predefined course of study, content, or challenge, like PBL and PjBL. Instead, learners and community members participate in co-creating the challenge. Membrillo-Hernández et al. (2019) extend this difference to the fact that CBL confronts students with authentic challenges without any pre-conceived solution. Due to this uncertainty, the students become more self-directed and drive the content learning while the teacher facilitates and supports the learning process (Sukackė et al., 2022). Similarly, Nizami et al. (2023) state that PBL uses designed problems while CBL starts students with developing the challenge. This different starting point results in the students developing deep and new knowledge because of the lack of pre-conceived constraints.

Vilalta-Perdomo et al. (2022a), in their introduction to The Emerald Handbook of Challenge Based Learning, point to the ability of CBL to extend learning beyond the classroom as a differentiator from other approaches. They state that:

> CBL is less constrained by conceptual, physical, or time boundaries; there is an expectation that sustainable engagements, between students and the community, will continue after the academic period is formally over. (p.3)

They continue that this interaction with an external fluid environment where simple answers are rare introduces the students to “out-of-the-box” thinking as they deal with the uncertainty of an open challenge and interact with various stakeholders.

Sukackė et al. (2022) conducted a systematic literature analysis of research on PBL, PjBL, and CBL. Based on previous studies, authors compared these methods in terms of five dimensions: learning focus, the type of solution and its potential implementation, implementation outcome, and the teacher's role. Regarding learning, PjBL gives a task to complete a project, PBL applies specific content to solve problems, and CBL deals with real problems to finish the Challenge. The focus changes from tackling real (PjBL & PBL) or imaginary problems (PjBL & PBL) to addressing real and open problems (CBL). The product varies from the presentation of project completion (PjBL), outlining the procedure and reaching the results (PBL), or generating and implementing actionable solutions (CBL). The process includes various activities, such as producing learning materials (PjBL), assessing learners' capacity to think and employ their knowledge (PBL), or inspiring students to examine, create, develop, and execute the best solution to the Challenge (CBL).

Lastly, the fifth dimension, teachers, defines the teacher's role in the process - from project manager in PjBL to being a professional mentor in PBL or a coach and collaborator in CBL (Sukackė et al., 2022). The same study also focuses on implementation strategies and the instructional design implications. The authors evaluate and compare the three approaches through the lenses of the ADDIE instructional design model (Branch, 2009) and how they conceptualize the roles and attitudes of the student and the teacher. In related publications, Garay-Rondero et al. (2019) found that CBL involves stakeholders from multiple settings to support students rather than rely solely on professors or project managers. These stakeholders act as co-researchers and designers rather than mere facilitators (Membrillo-Hernández et al., 2018). Nizami et al. (2023) also point to the role of teachers as a key difference between PBL and CBL. In CBL, teachers move into the roles of coaches and co-researchers rather than professional advisors. Nichols et al. (2016) propose that the teacher moves from an "expert dispenser of knowledge" to a co-learner and collaborator. Other documents speak of the teacher assuming the role of coach and consultant (Juárez et al., 2022) and co-creator (Käyhkö et al., 2021; Maya et al., 2017),

Another unique aspect of CBL, increasingly highlighted in recent literature, is its focus on sustainability issues and the need for a verifiable and urgent solution instead of a final product-oriented approach, as in PjBL (Garay-Rondero et al., 2019). Furthermore, CBL is grounded in socially engaged pedagogy, emphasizing global challenges, ethical dimensions, and environmental issues (Sukackė et al., 2022). Some literature reviews argue that a critical element of CBL is lost when employed solely for educational interventions without a component of societal impact or engagement (Leijon et al., 2022).

Therefore, it is crucial to understand CBL as a pedagogy that goes beyond educational objectives and aims to address real-world and authentic concerns.

Components of CBL

The discussion on the definition, pedagogical background, and relationship between CBL and the "other-based learning" approaches leads to an investigation of the key components of CBL. This investigation is closely related to the above discussion about the differences between CBL and other approaches but seeks to define CBL at a structural and component level.

To further conceptualize the components of CBL, a recent study by van den Beemt et al. (2023a) proposed a "CBL compass" - a general framework to define and identify the main components of CBL. This framework can be used as a planning tool for practitioners looking to implement CBL or as an analytical tool to evaluate existing courses or programs. The framework is organized into a high-level conceptual framework and accompanying dimensions and indicators for each concept, allowing for the identification of educational processes at the levels of vision, teaching and learning, and support.

According to the authors: vision, teaching and learning support are the key macro-dimensions. In order to successfully implement CBL in an educational program, a clear vision is necessary to provide a foundation for its goals and motivations. The vision should include elements such as real-life open-ended challenges, global themes, and the involvement of stakeholders for real-world collaboration.

Teaching is the means of putting this vision into action, while learning is a parallel process that reinforces it. The dimensions of teaching and learning in CBL include T-shaped professionals, self-directed learning, assessment, teaching, interdisciplinarity, collaborative learning, and learning technology. As CBL involves more active and self-directed learning, support in terms of facilities and teachers is essential and differs from traditional education.

In their systematic literature review, Gallagher and Savage (2020) highlight the recurring characteristics of CBL interventions used as the main components of CBL. First, using a "challenge" to encourage students to address educational criteria, fulfill competencies, and complete learning objectives is a fundamental aspect of CBL. However, differences and gaps exist in the definition of challenges among different approaches, such as Apple and STAR, with the latter involving educators determining the challenge for students.

Second, CBL promotes real-world challenges and out-of-the-building experiences that involve validating the challenges and solutions with extra-academic actors, such as industry partners and community members. Additionally, thematic content areas addressed in CBL often relate to global issues such as sustainability.

Third, collaboration between students, educators, and extra-academic actors is at the forefront of the design of CBL interventions and as a means for developing solutions. The importance of the involvement of external stakeholders, such as industrial partners and other organizations, is a recurring theme in the literature (Chanin et al., 2018; Jordán-Fisas & Mas-Machuca, 2022; Membrillo-Hernández et al., 2019; Pérez et al., 2019; Ruiz-Cantisani et al., 2022). Mayer et al. (2022) present the different roles external stakeholders might play in a CBL educational setting and explore the opportunities, risks and benefits.

Fourth, technology is a recurring theme in the literature, with many CBL interventions employing technology in students' daily lives. Conde et al. (2017) categorize technology tools used during CBL, including information access, editing and publishing, documentation process, collaboration and communication, specialized tools depending on the domain, and learning platforms that may include a collection of these tools. Similarly, Barynienė et al. (2022) classified technology appropriateness and use by phase (Engage, Investigate, Act).

Fifth, flexibility is also a common characteristic of CBL. Integrations and hybridization between CBL and other frameworks not necessarily in an educational context are also common. For example, the literature reveals instances of CBL integrated with Design Thinking (Gama et al., 2018, October; Gerardou et al., 2022; Ma, 2022; Motschnig et al., 2018), lean start-up (Cardoso et al., 2021; Chanin et al., 2018; Detoni et al., 2019), Hackathons (Gama et al., 2018, July), Agile (Nascimento et al., 2022; Nicola et al., 2019; Oliveira & Araújo, 2021; Santos et al., 2015), Concurrent Engineering (López-Fernández et al., 2020), and Game Design and Narrative Design (Capone et al., 2019; Cuevas-Ortuño & Huegel, 2020; Recke & Perna, 2020; Recke & Perna, 2021b; Siqueira da Silva, 2018).

Sixth, multidisciplinarity is present both as a feature of the approach itself, with CBL being multidisciplinary in its combination of multiple approaches, methods, and procedures from different domains, and as a characteristic of specific course design and case studies fostering the interaction between different subject domains/disciplines.

Finally, innovation and creativity are module descriptors, key competencies, or general values within CBL interventions, with students encouraged to use these values to develop solutions to their Challenges.

A CBL characteristic not identified by Gallagher and Savage (2020) but found across some of the literature is ownership or self-efficacy. Nichols et al. (2016) identified the importance of the students taking ownership of the process and destination of their learning as a critical factor in CBL. Other publications, including Chanin et al. (2018) and Hendrickx et al. (2022), reinforce the role of co-ownership.

At the structural level, the recent literature points to a defining component of CBL as having three phases: Engage, Investigate and Act (Carlos et al., 2022; Ettema et al., 2020; Farizi et al., 2023; López-Fraile et al., 2021; Price et al., 2022; Stahlberg et al., 2022; Vilalta-Perdomo et al., 2022a). These phases are not in the original descriptions of CBL (Baloian et al., 2006; Giorgio & Brophy, 2001; Nichols & Cator, 2008) or early literature but emerged in 2016 with the publishing of the CBL User Guide (Nichols et al., 2016). The phases organized the original elements from the CBL whitepaper (Nichols & Cator, 2008). While not all of the literature after 2016 references the three phases, where there is a reference to structure, it is the dominant description. Literature not referencing the three phases often uses the included elements (e.g. Big Idea, Challenge, Guiding Questions) in the process description (Chanin et al., 2018; Chapel et al., 2021; Santos et al., 2015; Santos et al., 2018; Susilawati & Suryadi, 2020). An interesting observation is that when there is no reference to the phases and the related elements, there is little discussion about the structure and process of CBL.

In summary, CBL has evolved from its early origins to become a recognized approach to teaching and learning. Its emphasis on real-world issues, collaboration, and technology integration has made it a valuable pedagogical approach in various educational contexts. As the field of CBL continues to evolve, further research and exploration of its unique features and impact on student learning will contribute to its ongoing development and implementation in education.

Why is CBL Implemented?

In higher education institutions (HEIs), adopting CBL is a response to the increasing complexity of societal challenges and the need for new competencies and skills to address them. The belief is that traditional teaching and learning models struggle with meeting these needs, and CBL has the potential to be a transformation method for adult learning (Leijon et al., 2022). HEIs, driven by an increased focus on STEM, have navigated towards active student-centered learning methods in the last half of the 20th century, including problem-, project-, design-, and challenge-based learning. The desire is to equip students with the necessary competencies and skills to take on challenges and find solutions (Gudonienė et al., 2021). Therefore, CBL is strategically relevant as it supports learning experiences that include embracing authentic, active learning, offering choice in problem-solving and learning practices, enabling training in multidisciplinary teamwork and decision-making, and integrating sustainability in engineering education (Bernard et al., 2016; Enelund et al., 2013; Graham, 2017; Kohn Rådberg et al., 2020).

In HEIs, implementing CBL is perceived as a practical approach to equipping students with the necessary competencies and skills to take on complex societal challenges. It aligns with the strategic goals and policies of many HEIs and promotes learning through inquiry, multidisciplinary teamwork, technology and sustainability. In addition, CBL supports acquiring transversal skills and competencies, such as collaboration and innovation, commonly integrated into institutional policy and curricula to improve student employability and post-university life (Gaebel et al., 2018). A report on large-scale implementation of CBL in HiEd points to CBL as a flexible model "in which education focuses on creating lifelong learners who are knowledgeable about their discipline, but also have broader views, as well as focus on environmentally and socially responsible consumption and production" (Reymen et al.,2022).

CBL also enhances students' sense of meaning in their education (Bernard et al., 2016; Gallagher & Savage, 2020), promotes student reflective practice, self-regulation and metacognition (Bohm et al., 2020; Doulougeri et al., 2022; Tang & Chow, 2020) and is effective in increasing student engagement, motivation and participation, all elements that are considered of paramount importance by contemporary educational institutions. CBL also aligns with institutional goals of industry and community collaboration, advancing knowledge, innovation, solving trans-disciplinary societal problems, and sustainability (Gallagher & Savage, 2020).

In pre-university education, the motivation for implementing CBL centers on increasing student engagement and content comprehension but also includes acquiring the durable skills needed to succeed in school and beyond. For example, one key motivation for developing the CBL framework by Apple Inc (Nichols & Cator, 2008) and the initial pilot studies (Johnson & Adams, 2011; Johnson et al., 2009) stemmed from the belief that schools no longer engaged or met the needs of modern learners. In addition, several other smaller studies explored using CBL to engage learners and increase their learning motivation (Bledsoe & Pilgrim, 2015; Marin et al., 2013; Simón-Chico et al., 2023; Swiden, 2013).

Additional motivations for introducing CBL into pre-university education included developing a deeper understanding of subject area concepts (Bohori et al., 2022; Gaskins et al., 2015; Haqq, 2013; Haqq, 2017; Junita, 2016), STEAM curriculum implementation (Lockwood, 2023), improving critical thinking (Nawawi, 2017), developing soft skills (Tajuddin & Jailani, 2013), and leveraging technology (Bledsoe & Pilgrim, 2015; Bohori et al., 2022; Marin et al., 2013; Yoo & Hong, 2009).

Overall, the adoption of CBL in higher education institutions (HEIs) and pre-university education stems from recognizing society's changing needs and complexities. CBL offers a transformative approach to learning, equipping students with the competencies and skills necessary to tackle real-world challenges. In HEIs, implementing CBL aligns with strategic goals and policies, promoting active and student-centered learning that fosters collaboration, innovation, and sustainability. It also enhances students' sense of meaning in education, reflective practice, and engagement while addressing institutional demands. Similarly, in pre-university education, CBL is motivated by the desire to increase student engagement, comprehension, and the acquisition of durable skills. Overall, CBL emerges as a pedagogical approach that responds to the evolving educational landscape and equips students with the skills needed to thrive in the complex challenges of the future.

How is CBL Implemented?

Authors in the literature found that while CBL can be implemented across various contexts and scales and can cater to both small and large student cohorts, until recently, it was still mostly on the periphery of the curriculum as a supplement to already existing structures rather than embedded curriculum practice (Gallagher & Savage, 2020; Malmqvist et al., 2015). In addition, Doulougeri et al. (2022) noted that empirical research on CBL mainly focuses on describing single learning environments or comparing small-scale CBL interventions with traditional teaching and learning approaches, making it difficult to generalize results across different contexts or disciplines.

However, as discussed, some studies have shown how positive results from initial isolated CBL projects and pilots have led CBL to be expanded to other courses within universities, used for multiple cohorts of students, or planned integration into core curricula (Gallagher & Savage, 2020). Merks et al. (2020) proposed a blended approach to course redesign that combines challenge-based learning and a modular curriculum approach. Mesutoğlu et al. (2021) suggested scaling up this approach to help teachers and faculties redesign their courses at a broader level.

Van den Beemt et al. (2023a) state that educational institutions should rather consider using CBL as a strategic framework to make their educational programs more open, flexible, and learner-centred, which requires a developmental perspective.
De Stefani and Han (2022) introduce the term "strategic CBL," which is designing and carrying out CBL activities as a CBL practice. The authors noted that CBL benefits not only students at the outcome level but also teachers and faculty stakeholders who plan and execute CBL initiatives and courses undergo a process of rethinking education at a deeper level, suggesting that CBL might ignite institutional transformation at a large scale.

In recent years several institutions initiated a process of implementation of CBL as an embedded framework in their overall educational models, such as the Tec21 educational model in the Tecnológico de Monterrey (Membrillo-Hernández et al., 2022), Universidad Politécnica de Madrid (Sánchez et al., 2022), the Faculty of the European University of Madrid (Pérez et al., 2019), the University of Twente (Loohuis & Chapel, 2021), and the TU/e Innovation Space at Eindhoven University of Technology (Reymen et al., 2022). At TU/e, CBL is part of the institutional strategic vision to make the framework a "substantial" part of the programs at the Bachelor's and Master's levels (Lazendic-Galloway et al., 2021). In addition, Gunnarsson and Swartz (2021) discuss a comprehensive project aimed at including a CBL framework in engineering courses within a large consortium of European Universities; similarly, the Arqus alliance, a trans-European challenge-based learning (CBL) project involving seven European Universities from many disciplinary fields, including social sciences and natural sciences, has been initiated to implement CBL for large multidisciplinary projects (De Stefani & Han, 2022).

According to Membrillo-Hernández et al. (2022), the Tec21 educational model is a pioneering implementation of CBL into all undergraduate programs. The model requires the adoption of CBL as a core teaching and learning approach to foster student skills development.

Van den Beemt et al. (2023b) contributed to the discourse on implementing CBL at the Eindhoven University of Technology. They developed a conceptual tool called the "CBL compass" to assist educators, curriculum designers, and faculties in implementing CBL as a core component of the university curricula. This initiative is part of a larger effort to scale up CBL as a primary component of the university's educational ecosystem. According to the authors, CBL needs to be integrated into the core of the university curricula to make a significant impact, and faculty and staff need guidelines to effectively transition their courses to CBL or develop new CBL courses. In addition, the CBL compass can serve as a tool for teachers and as a managerial instrument to evaluate and map the implementation of CBL at a curriculum level.

Part of the same effort toward making CBL an embedded and transformative curriculum practice at the institutional level is the TU/e learning hub at Eindhoven University, which promotes collaboration among students, industry, research, and societal organizations to develop, sustain, and disseminate research-informed CBL practices for curricular and extracurricular activities (Reymen et al., 2022). Doulougeri et al. (2022) further illustrate the adoption of CBL as an educational framework at a curriculum level by discussing the E3 initiative at Eindhoven University, including the CBL compass and CBL design principles. The compass and design principles guide teachers, faculties and curriculum developers in imagining and implementing CBL interventions by providing an evidence-informed set of concepts and practices. Following the famous Sinek "Start with Why" approach, authors discuss the framework as a tool that provides the overall vision behind the educational innovation - the "why" -, concrete and practical indications on ways to organize teaching and learning - the "how" - and how to approach learning domain-specific contents - the “what."

Van den Beemt et al. (2023) conducted a comparative case study analyzing the different efforts in implementing CBL at the institutional level across three continents, examining examples from Mexico, Netherlands, China and Ireland. The study analyzed the different implementation strategies across the countries and the challenges implied in the transformation process. According to the authors, universities and educational institutions need the ability to adapt and innovate to prepare themselves and their students for an uncertain future. Implementing CBL can be crucial to developing professionals with the necessary skills to meet current world requirements. Moreover, CBL has the potential to transform universities into crucial elements of society further, creating a cooperative ecosystem where students can choose and manage their learning, guided by experienced professors and stakeholders who provide them with the necessary tools for success while developing solutions that are meaningful and that can have an impact on the ecosystem itself.

In conclusion, while CBL has initially been viewed and practiced as a supplementary teaching approach, recent literature suggests that significant steps toward making it an embedded and transformative curriculum practice at an institutional level have already been taken. By adopting a strategic approach to CBL, institutions can transform their educational programs into more open, flexible, and learner-centered models, benefiting students, faculty, other stakeholders, and society. However, to effectively implement CBL, faculty and staff need guidelines, tools, and support.

While the literature did not reveal specific publications on obstacles to adoption and implementation, several themes emerged across the literature. These themes, although anecdotal, provide a rich starting point for a conversation about obstacles when implementing CBL and ways to avoid them. In most cases, identifying obstacles included ideas to overcome them and recommendations for managing them in future implementations.

General uncertainty and a change in the structure of the learning environment appeared as a concern for both students and teachers. The uncertainty stemmed primarily from the move to a less rigid structure where students make decisions about processes and the resulting products (Membrillo-Hernández et al., 2019; Scroccaro & Rossi, 2022). Chapel et al. (2021) found that the lack of structure was sometimes "far outside the comfort zone of students and teachers." Oliveira & Araújo, 2021 also found that student and teacher management in a complex learning environment could be an obstacle.

Other literature identified a general resistance toward non-traditional approaches to teaching (Félix-Herrán et al., 2019; Lam, 2016; Lin & Chen, 2017). Sources for this resistance included teachers and students being accustomed to traditional forms of teaching and not wanting to change (Johnson & Adams, 2011) or being unwilling to leave their comfort zones (Membrillo-Hernández et al., 2022). Some researchers contend that the issue is less outright resistance and more about the inherent inertia of traditional teaching methods among teachers and students (Félix-Herrán et al., 2019; Lam, 2016; Lin & Chen, 2017). In addition, the unfamiliarity of students with values such as openness, independence, and self-responsibility, which are integral to CBL, add to a general resistance to change (Johnson & Adams, 2011).

The relationship of CBL to the overarching curriculum expectations can also be problematic. For example, the multidisciplinary nature of the Challenge creates potential issues with the current subject area-driven curriculum (Malmqvist et al., 2015) and the generalizability of challenges to curriculum design (Yang et al., 2018). Additionally, Price et al. (2022) identified the difficulties of managing the CBL process learning objectives while also presenting solutions in a way that is accessible and useful for external stakeholders.

Various other obstacles to implementing CBL in a traditional learning setting appear in the literature. Assessment appeared as an area of difficulty and a potential barrier to adoption. Teachers struggled with formal assessment in a novel environment (Bledsoe & Pilgrim, 2015; Scroccaro & Rossi, 2022), and the students struggled with the structure of the assessment (Vilalta-Perdomo et al., 2022b). Limited time presents an obstacle, with the need for additional time for students to work on challenges (Detoni et al., 2019) and for teachers to do evaluations (Díaz Martínez, 2019). Shakila et al. (2021) identified the unequal distribution of workload and different perspectives across disciplines as causing student tension. Kasch et al. (2022), while documenting their experience with implementing CBL in online education, identified a similar range of barriers, including a lack of openness towards other disciplines, a lack of self-regulating learning skills, difficulties formulating challenges in a group and getting lost during the investigation.

Another area presenting potential barriers is the participation of external stakeholders. A logical consequence of extending learning beyond the classroom and working on authentic challenges is the participation of external partners. While there are positives to working with external stakeholders, the literature identified various issues and potential obstacles. Mayer et al. (20220 points to difficulties when the external partners do not participate as expected, including blocking student creativity and making them afraid of failing. Price et al. (2022) add that a potential issue with external stakeholders is that they may lead students to pre-conceived solutions. The Challenge shifts from discovery and learning to production and development in these cases. They continue that this relationship can become negative for all parties as the students cannot learn and be creative, and the partners do not get what they expect.

The literature has recommendations for overcoming the barriers, including setting a solid foundation for CBL, adequately preparing teachers and students for the experience, and supporting all stakeholders during the process. For example, Lin and Chen (2017) stated that with institutional implementations of CBL that there needs to be policy-level communication. Others extended this need for clear communication between all internal and external stakeholders (Mayer et al., 2022) to consider all of the specific needs and expectations (Price et al., 2022) and to develop a shared vision (Doulougeri et al., 2022). Additionally, there is a need to communicate with the students about the purpose and expectations (Tang & Chow, 2021) for CBL, especially concerning assessment (Scroccaro & Rossi, 2022; Valencia et al., 2020).

A key area for avoiding or mitigating potential obstacles is the ongoing support for teachers and students, including professional development before and during the implementation (Caratozzolo & Membrillo-Hernández, 2021; Tissenbaum & Jona, 2018; van den Beemt et al., 2023a). Carlos et al. (2022) recommend creating a network of partners who can support the process and the work with outside partners. Ongoing "social support, coaching, and scaffolding practices" are identified as key supports for successful implementation (Doulougeri et al., 2022). The students can not be "left alone” in the process; scaffolding and support are needed throughout the process (Scroccaro & Rossi, 2022).

In conclusion, the literature reveals that the implementation of Challenge-Based Learning (CBL) as an embedded and transformative curriculum practice at the institutional level has gained significant traction. By adopting a strategic approach to CBL, educational institutions can create more open, flexible, and learner-centered models that benefit students, faculty, and other stakeholders. However, the literature also highlights several obstacles to the adoption of CBL, including uncertainty and resistance to change, curriculum alignment, assessment difficulties, limited time, workload distribution, interdisciplinary perspectives, and external stakeholder involvement. The literature presents various recommendations for overcoming obstacles, including the importance of solid foundations, clear communication, shared visions, and ongoing support through professional development, coaching, scaffolding, and networking. By addressing these challenges proactively, educational institutions can successfully implement CBL and create transformative learning experiences for their students.

What is the Impact of CBL?

The literature surveyed identifies various ways CBL benefits students and teachers, including increased engagement and motivation, self-directed learning, autonomy, technical skills, problem-solving skills, creativity, and deeper understanding and application of knowledge.

Several longitudinal studies have investigated the perception of CBL among teachers and students, indicating that both parties found the CBL in the curriculum effective. Johnson et al. (2009) and Johnson and Adams (2011) reported positive results with teachers and students from primary through Higher education, where teachers believed that CBL significantly improved collaboration, creativity, problem-solving, critical thinking, and communication skills. Moreover, most students reported learning more than anticipated and were motivated to work harder than usual.

Other shorter-term studies have also reported positive results across educational levels and content areas. For example, Gabriel (2014) examined the effect of CBL on senior biochemistry students and noted a significant improvement in communication and problem-solving skills. A quasi-experimental study by Tang and Chow (2020) found that CBL facilitated deep learning among nursing students. In addition, a study by Suwono et al. (2019) revealed that CBL was more effective than traditional teaching methods in improving students' scientific literacy. Ardiansyah and Asikin (2020), in a quasi-experimental research project with adolescents, found that CBL improves mathematical creativity, a quality critical to learning math. Haqq (2013 - 2019) reported in two quasi-experimental studies that students using CBL increased their ability to understand mathematical concepts compared to traditional classes. Susilawati and Suryadi (2020) found in a study of prospective elementary school teacher candidates that CBL improved their mathematical spatial abilities and positively impacted social interaction and metacognition.

Additionally, Susilawati et al. (2018), through a quasi-scientific study with 73 pre-service math teachers, learned that CBL "can facilitate conflict processes, invention processes, social interaction processes and the students' reflective processes so that the students' lateral thinking." (p.95) In another study, Cheung et al. (2011) observed increased interest in cybersecurity and improved computer and security skills among computer science undergraduates.

Martin et al. (2007) conducted a quasi-experimental study and found that students who received CBL intervention improved innovative thinking more than those in the control group. Junita (2016), also using experimental and control groups, demonstrated increased creative mathematical problem-solving with CBL. Using experimental and control classes, Nawawi (2017) found that CBL fostered critical thinking about environmental issues more effectively. Working with middle and high school students, Gaskins et al. (2015) noted that teachers reported positive impacts on outcomes, attitudes and knowledge acquisition. Bohori et al. (2022), working with 15-17-year-old vocational students, found that CBL effectively improved content mastery. Membrillo-Hernández et al. (2019) demonstrated that students who participated in CBL outperformed their peers who remained in traditional classroom education, with higher achievement indicators and student engagement. Research has also indicated that CBL positively impacts academic performance, student engagement, and entrepreneurial skills. For instance, a study by Colombelli et al. (2022) analyzed the academic and business outcomes of a doctoral entrepreneurial education program, revealing a positive effect of the program on students.

Colombelli et al. (2022) conducted a study analyzing the effect of a CBL program on the entrepreneurial skills, mindset, and intentions of 127 university students. Results indicated that the program positively and significantly affected students' entrepreneurial mindset and skills, including financial literacy, creativity, and planning. Similarly, Martínez and Crusat (2020) highlighted how entrepreneurship is a natural outcome of CBL. In a project with over 200 university-level engineering students, Caratozzolo et al. (2021) found that CBL is highly effective for developing thinking skills in relation to sustainability.

Ruiz-Cantisani et al. (2022) examined programs at three University campuses. They found that CBL and a connection with external partners confirmed that students successfully developed disciplinary and transversal competencies in industrial engineering. Additional research shows that CBL effectively facilitates industry networking, industry-specific training, start-up creation skills, and multidisciplinary teamwork (Chanin et al., 2018; Detoni et al., 2019; Gudonienė et al., 2021; López-Fraile et al., 2021). Detoni et al. (2019), in a case study of an undergraduate course on entrepreneurship, found CBL to positively impact collaborative work, reflection, active searching for knowledge, and motivation.

Additionally, several studies have shown that CBL improves soft skills, such as critical thinking, problem-solving, creativity, and communication (Colombelli et al., 2022; Ettema et al., 2020; Johnson et al., 2009; Martínez & Crusat, 2020; Palma-Mendoza et al., 2019). Chapel et al. (2021), in a case study of undergraduate engineering students using CBL, found that the framework increased the ability to take ownership of their learning and "think for themselves." Chanin et al. (2018) noted that student engagement and learning increased when placed at the center of the learning process through CBL. Portuguez Castro and Gomez Zermeno (2020) found that CBL helped students find personal meaning in education. Farizi et al. (2023) found through a quasi-experimental study that CBL significantly improved the critical thinking skills of pre-University students studying history. In a study that included over 900 students participating in Communication Bachelor degree courses, López-Fraile et al. (2021) found that CBL improved academic performance due to a deepening of their knowledge caused by being actively involved in solving challenges.

In a quasi-experimental study Simón-Chico et al. (2023), CBL was implemented in physical education classes for 13-15-year-old students to explore the impact on motivation, engagement and performance. The results showed improvement in all areas and the belief that CBL is a promising approach to physical education. A small case study by Briede-Westermeyer et al. (2017) supports the ability to effectively use CBL for acquiring theoretical knowledge, innovation skills and the competencies needed for the healthcare product market.

In conclusion, the literature provides extensive evidence supporting the benefits of CBL for both students and teachers. Longitudinal studies and shorter-term research consistently highlight positive outcomes, including increased engagement, motivation, self-directed learning, autonomy, technical and problem-solving skills, creativity, and deeper understanding and application of knowledge. Teachers perceive CBL as significantly improving collaboration, critical thinking, communication, and creativity among students. Students, in turn, report learning more than anticipated and being motivated to work harder. CBL has been found effective across various educational levels and content areas, such as biochemistry, nursing, mathematics, computer science, and environmental studies. It fosters innovative thinking, deep learning, critical thinking, scientific literacy, mathematical creativity, spatial abilities, metacognition, and entrepreneurial skills. Furthermore, CBL positively impacts academic performance, industry networking, multidisciplinary teamwork, and the development of soft skills, including critical thinking, problem-solving, creativity, and communication. It has also shown the potential to transform learning environments at the institutional level, leading to institutional recognition and the achievement of sustainable development goals.

However, many of the the studies' anecdotal nature and small sample sizes raise the need for further evaluation of the framework's effectiveness. Currently, the primary evidence is from case studies or surveys that measure the participants' perception of CBL without using validated instruments to measure outcomes (Tang & Chow, 2020). There is a need for additional longitudinal and more rigorous studies.

Summary

Building on existing HiEd literature reviews and research databases, this survey explored the full p-20 CBL landscape. The result shows a broad and growing interest in CBL. However, there is a need for additional longitudinal and rigorous research across the spectrum but especially in pre-university settings.

Although a relatively young pedagogical approach with an eclectic origin story, there is enough shared definition and agreement on components to consider the approach unique. The literature revealed connections to PBL, PjPL and other active pedagogies but also identified clear areas of differentiation. There is a need for a better articulation of the theoretical and pedagogical foundations.

The specific motivations for adopting and implementing CBL varied at different educational levels—however, the themes of engaging students and preparing them for a complex and rapidly changing world emerged as driving reasons. Due to the immediacy of the real world and the need to evolve to be relevant to students and communities, Universities gravitated to the contextual, real-world, open-ended and social impact-directed components of CBL.

In the literature, there are examples of CBL implemented as both a supplementary teaching approach and a transformative approach to education. For example, several high-profile University settings include CBL as a component of a larger strategic approach to structural transformation. However, in pre-university education, CBL is more often a supplemental approach. The literature presents barriers to implementing CBL, but these seem manageable and, in many cases, are followed by recommendations for mitigation.

A substantive collection of publications present the positive impacts of CBL for content acquisition and the development of transversal knowledge and skills seen as necessary for future success. This evidence substantiates the effectiveness of the CBL approach, but additional, more in-depth and rigorous research is needed.

The hope is that this literature survey creates a foundation for future efforts to implement, research and evaluate the CBL approach.

Suggestions for Future Research

The literature survey identified a wide range of areas for further investigation. While there is evidence that the implementation of CBL is continually increasing and that the method is effective in acquiring content knowledge and soft skills, the research's scope and quality leave a range of unanswered questions. The following includes specific recommendations for future research to support the ongoing implementation and growth of the CBL framework.

Challenge Definition and Impact
At the heart of CBL is the supposition that starting with a Challenge creates a fertile learning environment, but there needs to be more research on how Challenges impact learning. In much of the literature, the definition of challenges and their elements gets limited attention. Areas of Interest: What makes a challenge a challenge? Are there specific elements of challenges that result in more effective learning?

Pre-University
A vast amount of the CBL literature focuses on higher education. The studies that emerged from pre-university education are small-scale case studies, short term and of limited rigor. These factors do not question the findings' validity; rather, they open the door for follow-up and deeper, more long-term, rigorous efforts. Areas of interest: CBLs impact on younger learners and knowledge acquisition. The implementation of CBL in traditional school settings.

Non-Stem Implementation

Much of the CBL literature focuses on implementation in STEM and a lesser degree, STEAM environments. The STEM focus ranges from professional schools (engineering and medical) to undergraduate programs (engineering, science, mathematics) and vocational focus. There is a need for implementations and investigations in a broader range of content areas, especially the humanities. Areas of interest: CBL implementations in traditional humanities courses. Interdisciplinary implementations of CBL crossing the boundaries between the humanities and STEM.

Longitudinal Studies

Besides some initial pilot studies, there is minimal research involving long-term implementations of CBL. Areas of interest: The long-term impact of CBL on learners' academic performance. The transferral of CBL knowledge and skills from the school and university settings to personal and work decision-making. The barriers and support for institutional adoption of CBL.

Technology Use

Some foundational CBL ideas can be tracked to increased access to technology and, by extension, information. Also, the growth of CBL implementations paralleled increased access to technology by teachers and students. However, in the literature survey, few studies focused on the role of technology in implementing CBL. Areas of interest: The impact of technology access on CBL implementations and the use of technology for supporting the implementation of CBL, especially in the areas of reflection, documentation and sharing.

Reflection/Metacognition

Reflection is a critical element of the CBL framework, but this topic has minimal investigation. One exception is a recent study by Andrade et al., 2023 that reflective practice and CBL helped students to map new ideas and acquire valuable hard and soft skills. Further investigation into the importance of reflection in the process of CBL is needed. Areas of interest: The role of reflection in and on action in Challenges. The barriers to effective reflection for students and teachers and the timing and structure of reflection in the CBL process.

Brain-Based Learning

Since the formulation of the CBL framework, there have been considerable advancements in understanding the learning process through neuroscience and brain-based learning research. A fertile area for future research is how these emerging concepts connect with The CBL process. Areas of interest: The role of pattern making in CBL.

The importance and role of emotion in the engagement phase of CBL. How can challenges be structured to create an environment for optimal learning effectively.

Barriers

The literature survey surfaced some barriers to the adoption and implementation of CBL and possible ways to mitigate them, but there is a need for a deeper dive. Areas of interest: The relationship between perceptions of formal learning and learning through CBL. The specific areas that prevent teachers from adopting CBL and structural barriers to institutional adoption.

Assessment

Assessment for CBL in formal learning environments needs further investigation. The work of Scroccaro and Rossi (2022) provides a foundation for further research. Areas of interest: A deeper investigation of formative and substantive assessment to meet institutional expectations. The impact of self and peer assessment on learning within Challenges.

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Appendix A: Bibliometrics and Scientometrics Analysis

Searching the Scopus and WoS databases resulted in an initial set of published research. The query used to retrieve articles was "Challenge-Based Learning" OR "Challenge Based Learning" in the Title, Abstract or Keywords fields for both repositories. It resulted in a total of 426 matching documents. Refining and removing overlapping items, duplicates, and non-relevant items resulted in a dataset of 383 documents.

A quantitative analysis was conducted using science mapping and bibliometrics methodology (Börner, Chen, Boyack, 2003; Aria & Cuccurullo, 2017). This type of analysis helps to get a big picture of the current state of published research and to identify macro-trends, most relevant sources and authors, conceptual clusters of keywords, most active countries and networks of collaboration, and co-citation networks.

Figure 1

Document production over time

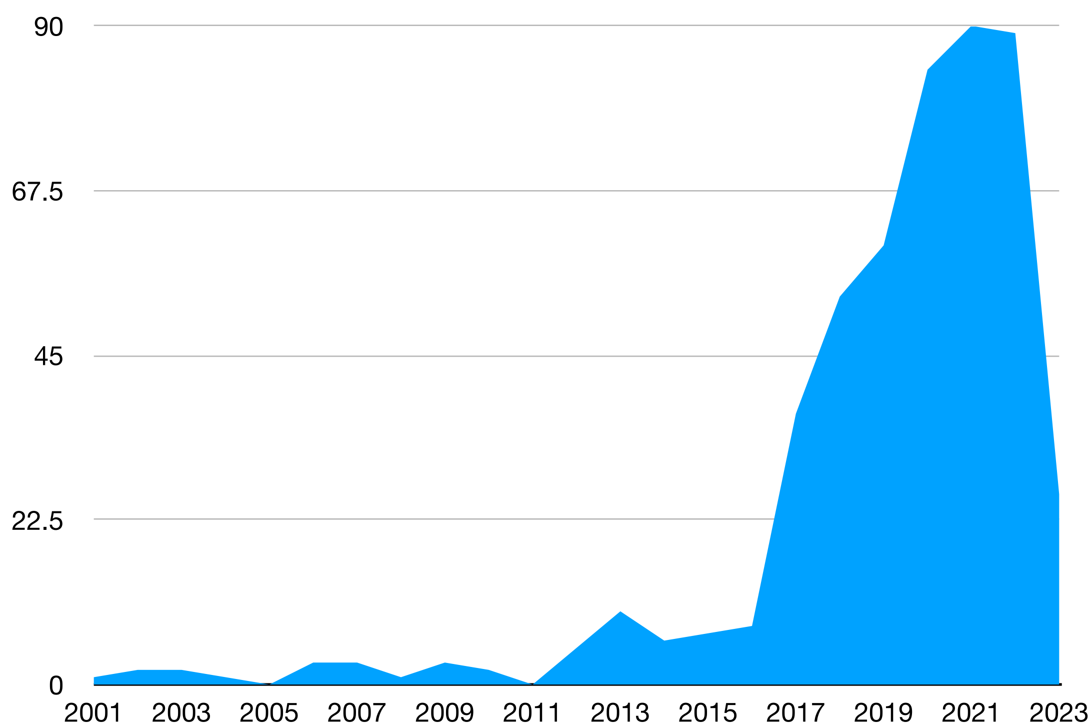


Figure 1 presents a year-by-year overview of the number of scientific documents related to Challenge Based Learning (CBL). The number of articles increased steadily, from

1 in 2001 to 90 in 2021. In 2016, there was a significant increase in the number of articles published compared to the previous years, with 37 articles published, followed by a notable increase in 2018, with 53 articles. The trend continued in 2019, with a further increase to 60 articles published, with a peak of 90 articles in 2021. The table clearly shows the growing research interest in CBL, with an increasing number of publications each year.

Figure 2

Number of documents by Country

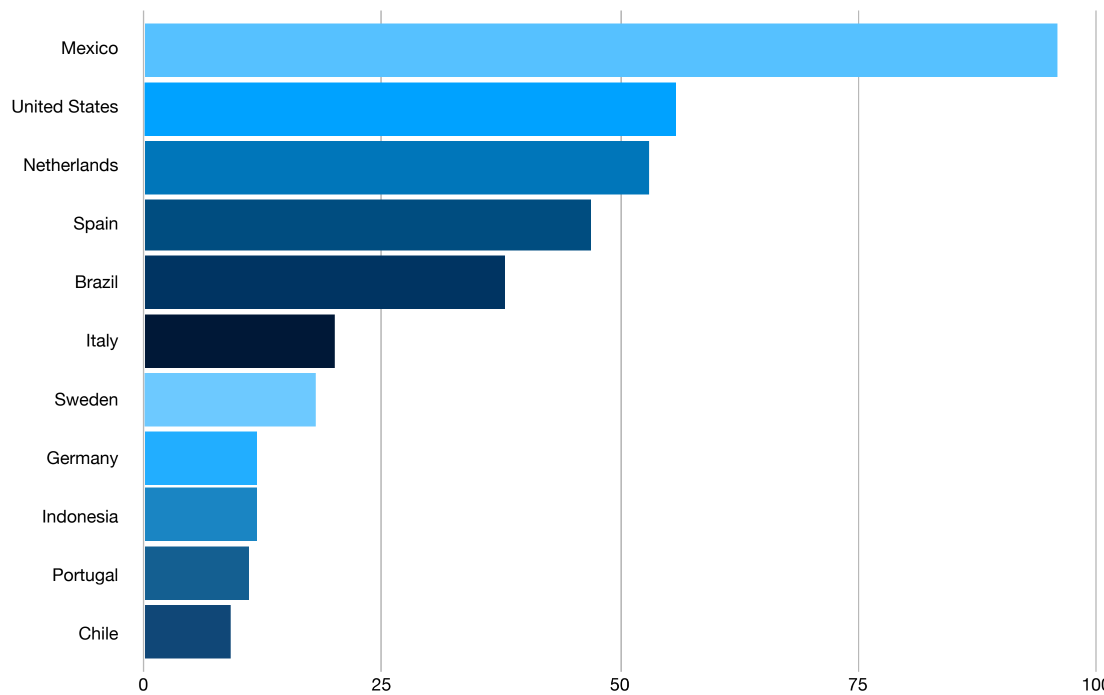
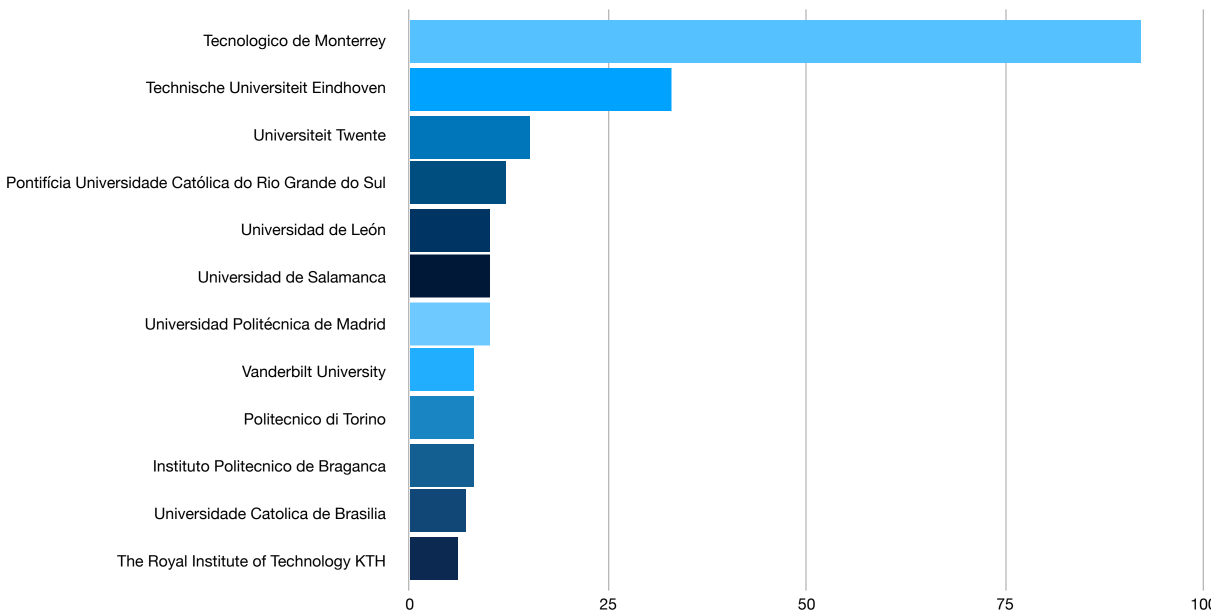


Figure 2 presents a country-based analysis of the scientific production of documents about Challenge Based Learning. Data indicates that Challenge Based Learning is a research topic of global interest, with a significant number of publications originating from a diverse range of countries. The numbers are also consistent, especially in most recent years, with the presence in the top-ranking countries of educational institutions and universities running large-scale initiatives that implement CBL as an embedded curriculum as one of the main objectives. Figure 3 confirms this connection with the most represented institutions by the number of publications.

Figure 3

Number of documents by Institution



Network Analysis

Network analysis techniques were applied to the dataset using the biblioshiny and bibliometrix tool (Aria & Cuccurullo 2017) and visualised with Gephi network visualisation tool (Bastian et al. 2009). Thanks to network analysis it is possible to uncover inherent structures of a scientific literature field, such as thematic clusters of keywords, the intellectual structure through the analysis of cited references of the documents, and the collaboration networks of the field.

Co-Citation Network

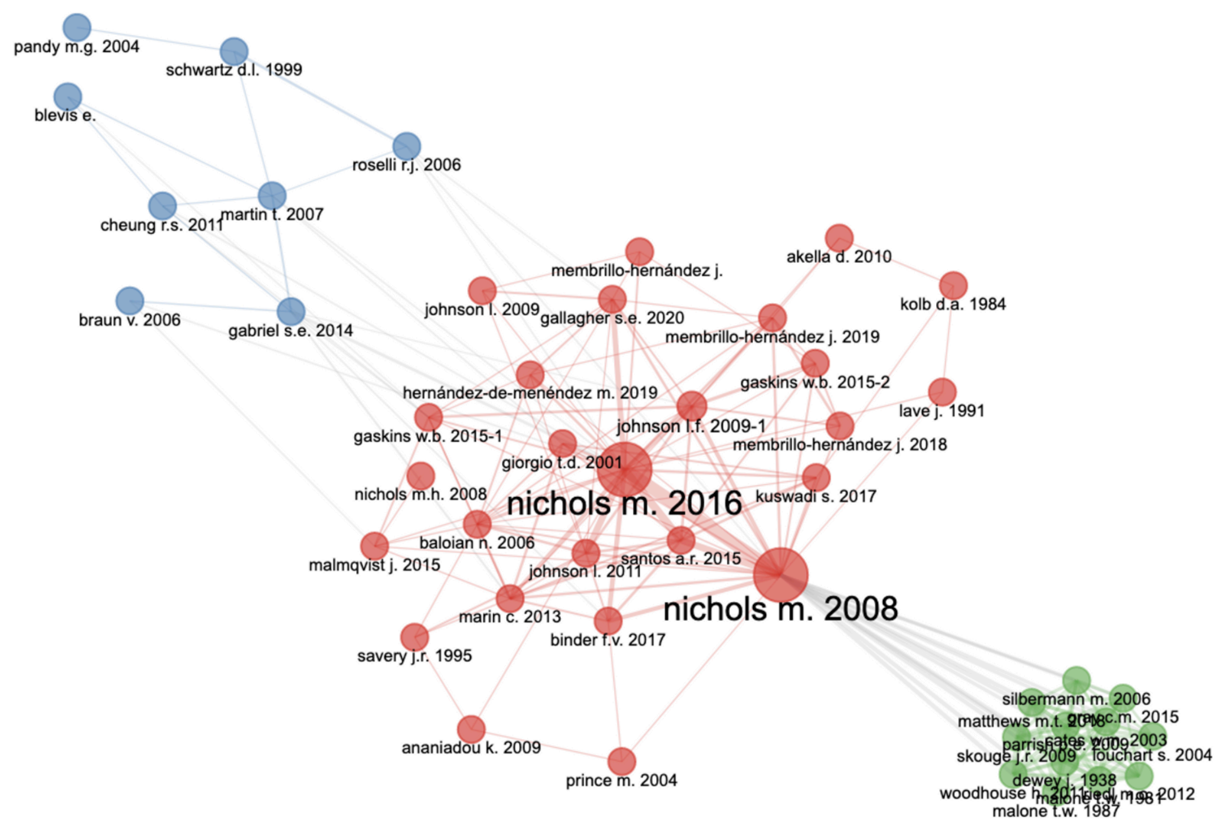
Co-citation analysis has been used in various fields to identify key intellectual references and understand scientific communities' intellectual structure. For example, Small and Griffith (1974) and Leydesdorff and Vaughan (2006) used co-citation analysis to identify core intellectual references in information science.

Co-citation analysis is a technique used to examine the connections among scientific papers or authors based on the co-occurrences of their citations within a given corpus of literature. When two papers or authors are co-cited in a third paper, they are linked.

The frequency of these co-citations is then measured and visualized using a network graph. The occurrence rate of these co-citations is quantified and visualized through a network. The size of each node in the graph corresponds to the level of interconnectivity that the paper or author possesses with other papers or authors within the network. Additionally, colors and spatial layouts are used to identify clusters of highly interconnected papers or authors using the Louvain clustering algorithm. These clusters represent groups of intellectual references that are often cited together, which can be considered core intellectual references for the field.

Figure 4

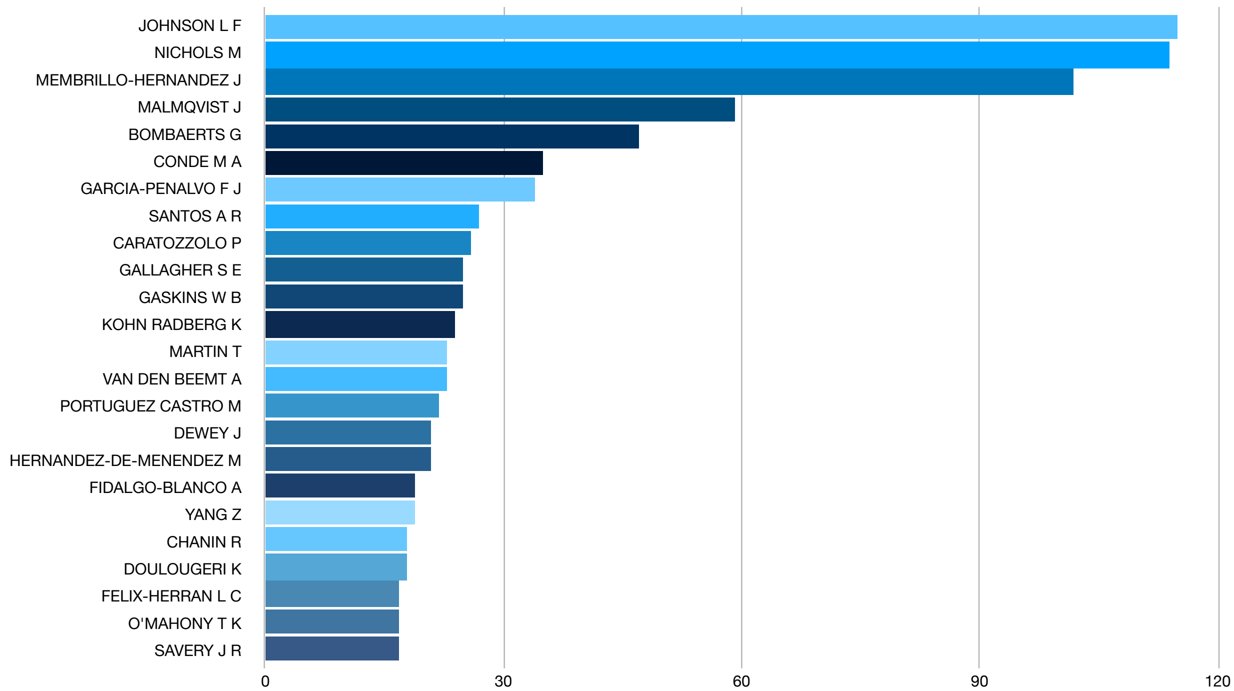
Co-citation Analysis



To complement the picture provided by the co-citation network about the intellectual structure, Figure 5 represents a simpler representation of the most cited authors within the analyzed corpus.

Figure 5

Most Cited Authors

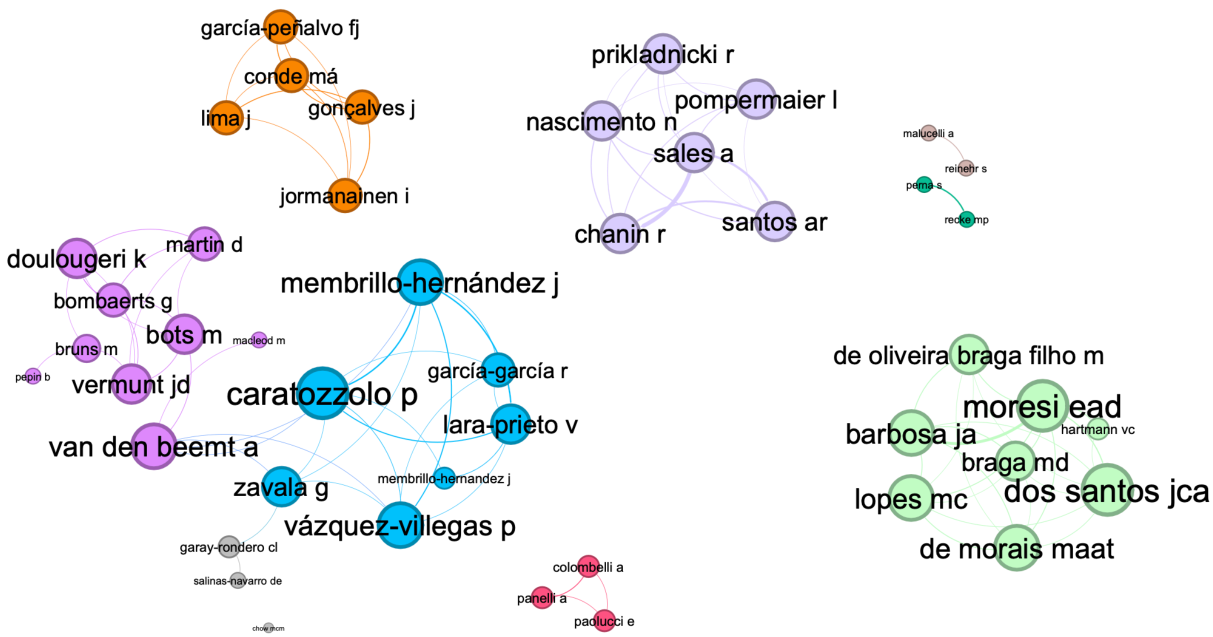


Collaboration Network

Co-authorship analysis appears in several scientific fields to identify key collaborative efforts and comprehend scientific communities' intellectual structure. For instance, Glänzel (2005) employed co-authorship analysis to unravel the underlying framework of scientific collaboration networks. In co-authorship analysis, the connections between scientific papers or authors merge based on their joint authorship of articles within a given corpus of literature. When two authors collaborate on a paper, a linkage between them is established. The rate of occurrence of these co-authorships is quantified and represented visually using a network graph. The relative size of each node in Figure 6 corresponds to the extent of interconnectivity that the author or paper shares with other authors or papers in the network. Moreover, clustering algorithms, such as Louvain, can identify groups of highly interconnected authors or papers based on co-authorship. These clusters signify central collaborative endeavors frequently occurring within the field.

Figure 6

Collaboration Network



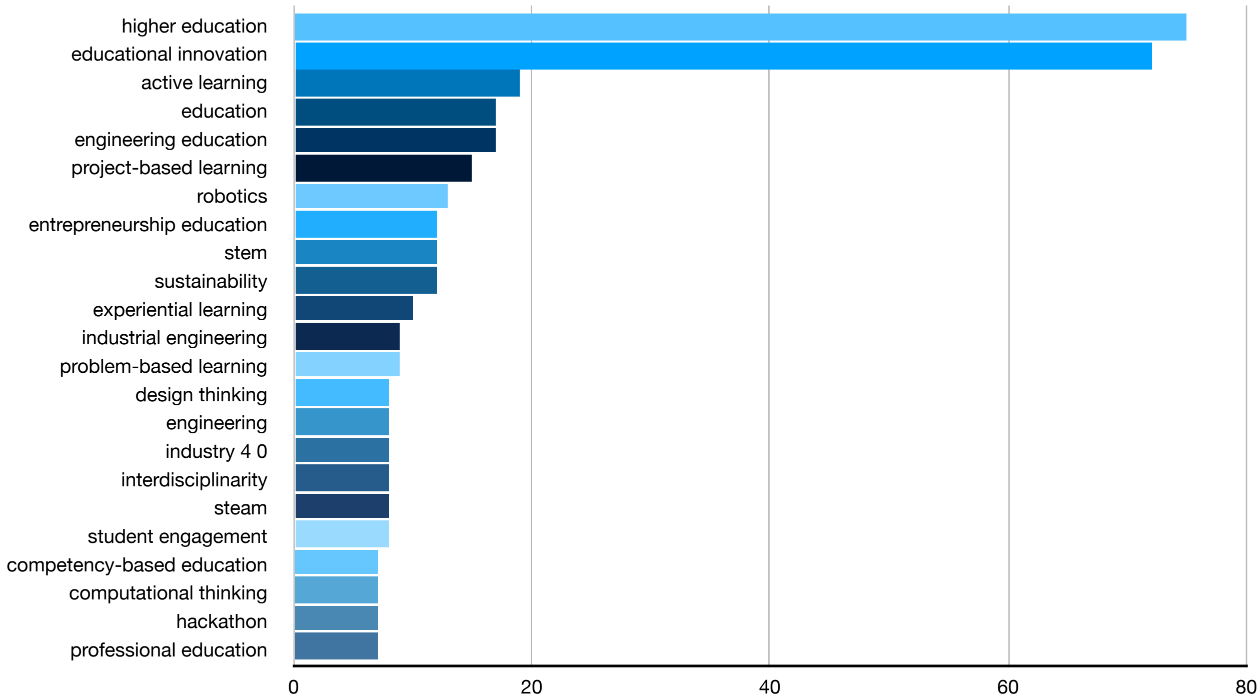
Keywords Count and Co-occurence Network

The most used keywords beyond "Challenge-Based Learning" are represented in Figure 7. The analyzed keywords are the "author's keywords" as reported in the specific fields in Scopus and WoS.

Beyond the simple frequency count of keywords, additional insights emerge from the network analysis of keyword co-occurrence. Keyword co-occurrence analysis has been widely utilized across numerous scientific disciplines to understand the associations among keywords in a given corpus.

The technique identifies the most pertinent and common keywords associated with a particular theme or subject. Co-occurrence happens when two keywords appear in the same document (in this case, in the author-provided keywords in the dataset). The frequency of these co-occurrences is measured and displayed using a network graph.

Figure 7
Keyword Count

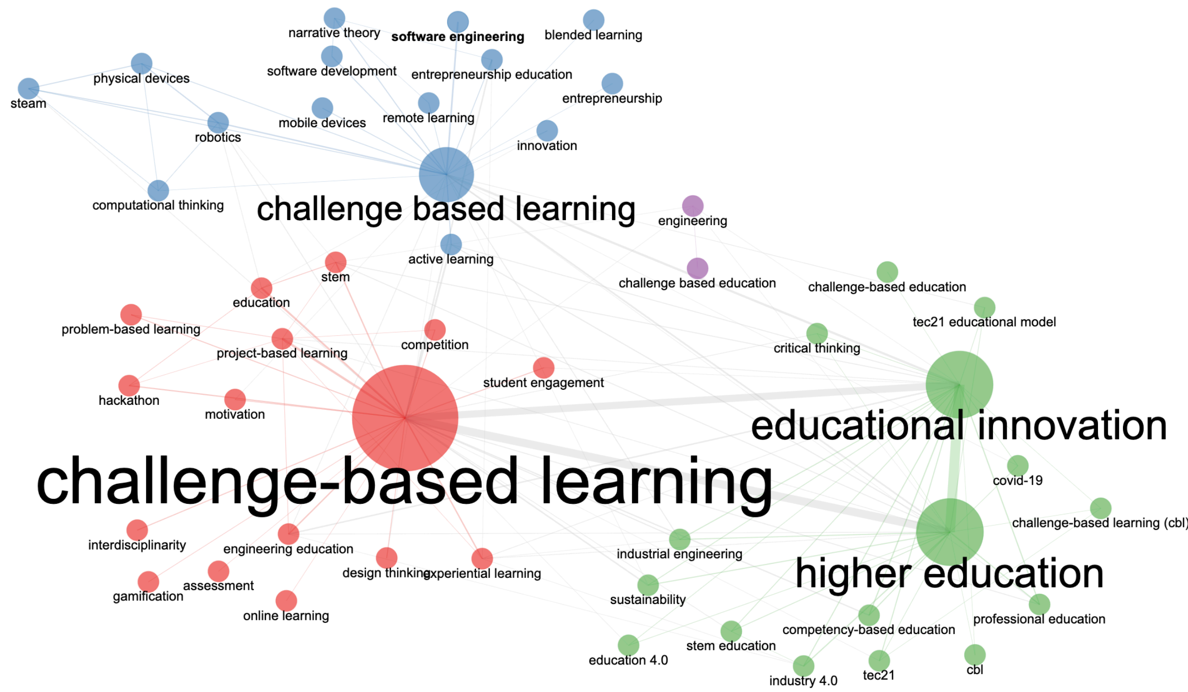


The nodes signify keywords in a keyword co-occurrence network, and the edges denote their co-occurrences. The size of each node reflects the frequency of the keyword occurrence, while the thickness of the edges indicates the intensity of the co-occurrence relationship between the keywords. Researchers can detect groups of strongly interconnected keywords related to a certain theme or subject by analyzing the structure of the keyword co-occurrence network. These clusters provide insights into the main conceptual components of the field and its interrelationships.

The technique identifies the most pertinent and common keywords associated with a particular theme or subject. Co-occurrence happens when two keywords appear in the same document (in this case, in the author-provided keywords in the dataset). The frequency of these co-occurrences is measured and displayed using a network graph. The nodes signify keywords in a keyword co-occurrence network, and the edges denote their co-occurrences. The size of each node reflects the frequency of the keyword occurrence, while the thickness of the edges indicates the intensity of the co-occurrence relationship between the keywords. Researchers can detect groups of strongly interconnected keywords related to a certain theme or subject by analyzing the structure of the keyword co-occurrence network. These clusters provide insights into the main conceptual components of the field and its interrelationships.

Figure 8

Keyword Co-occurrence



In conclusion, the network analysis presented could be useful for researchers and educators to identify groups of relevant authors and sources in the field and how scholars are interconnected to form communities of researchers and practitioners around a common topic of interest, as well as relevant thematic areas through clusters of interconnected keywords.

Appendix B: Comprehensive Bibliography

The literature survey uncovered published works that extended beyond the scope of this document. Nevertheless, these documents contribute to the overall understanding of CBL. The following is a comprehensive, at least at this moment, collection of publications, including the references above and all other identified publications addressing CBL found through the survey. The intent is to continue to build the bibliography and make it available online to support future research. If a document is missing, send the citation (APA) to admin@challengebasedlearning.org.

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