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TEACHING IN HIGHER EDUCATION
https://doi.org/10.1080/13562517.2020.1863354

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ABSTRACT

The application of Challenge-Based Learning (CBL) has increased in higher education institutions, fostering student transversal competencies, knowledge of sociotechnical problems, and collaboration with industry and community actors. However, a broad range of different frameworks, hybrid approaches, and educational interventions are using this term to define their approach. This lack of standardization creates definitional and conceptual challenges for the domain. A review of CBL literature was conducted to examine key characteristics, challenges and benefits, and educational factors. A total of 100 articles were reviewed using a qualitative thematic matrix. Results describe CBL benefits despite many institutional, practical and academic challenges. Although there was much variability in CBL approaches, eight common characteristics emerged from the literature. This research can support future research and implementation of CBL by providing a guiding conceptual framework and a preliminary classification of CBL approaches.

ARTICLE HISTORY
Received 27 July 2020
Accepted 19 November 2020

KEYWORDS
Challenge-based learning; higher education; educational theories; educational methods

Introduction

Challenge-based learning (CBL) is a growing approach in higher education and has been promoted as a means for students to align the acquisition of disciplinary knowledge with the development of transversal competencies while working on authentic and sociotechnical societal problems (Nichols and Cator 2008; Nichols, Cator, and Torres 2016). This flexible approach frames learning with challenges using multidisciplinary actors, technology enhanced learning, multi-stakeholder collaboration and an authentic, real-world focus.

While the term CBL has appeared in academic literature since 2001 (Giorgio and Brophy 2001), publications range from standardized CBL frameworks, hybrid approaches, and general educational interventions using challenges in their design. This mass of different approaches using the same term in different ways creates challenges in its definition and in conceptualizing its research landscape.

This lack of definitional clarity coupled with the varied range of approaches and frameworks presents problems for practitioners and researchers in higher education. Educational practitioners who are keen to try challenge-based learning (either from their own

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intrinsic motivation or due to promotion from extrinsic actors and institutions) will encounter a confusing array of what CBL is and how to implement it. Educational researchers will face methodological difficulties in establishing the efficacy of CBL due to a lack of consistency of reported results from a range of implementations that are fundamentally different.

The risk, therefore, is that the meaningful and considered implementation of CBL for the benefits of students in higher education is compromised due to a lack of a shared understanding of what CBL is, widely varied implementations that arise from that confusion, and contradictory or debatable results on its efficacy from the research community.

By analysing the existing literature in the area, this paper seeks to identify the commonly agreed characteristics of CBL in order to provide clarity to practitioners and researchers on what CBL implementations consist of and contribute to the development of definitional clarity. This will also support the educational practitioners who are seeking to understand and implement CBL and the educational researchers who are investigating its efficacy.

This research broadly explores the corpus of existing literature related to CBL in higher education to establish the nature of what is meant by CBL. It will do this by examining the varying definitions of CBL within the literature in order to provide a common understanding of what CBL is and is not. The key characteristics, challenges and benefits of CBL interventions will be synthesized. Furthermore, this research will provide an overview of the current CBL research landscape in order to identify the dominant strands and potential areas for future research. A key contribution, therefore, is a preliminary classification of CBL research to guide future action in this space.

Origins of CBL

> A challenge-based learning experience is a learning experience where the learning takes places [*sic*] through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable. (Malmqvist, Rådberg, and Lundqvist 2015, 87)

The earliest mention of CBL within academic literature described the STAR Legacy Cycle; used primarily at Vanderbilt University. This approach contained six phases; challenge, generate ideas, multiple perspectives, research and revise, test your mettle, and go public (Birol et al. 2002) in a project focussed enquiry cycle. Derived from the How People Learn pedagogical framework, it was used for module development to enhance student learning experiences (Birol et al. 2002). Several case studies were published based on this approach within the disciplines of engineering and biotechnology (Barry et al. 2008; Lovell and Brophy 2014).

In 2008, Apple published a report as part of their 'Apple Classrooms of Tomorrow – Today' project, describing how they developed a CBL approach by working with American educators. CBL within this context describes a three phased approach to teaching; engage, act and investigate. Through this process, students collaborate with academia, industry and extra-academic actors to solve real-world challenges through creative and authentic experiences. From this publication, a wide variety of case studies, hybrid approaches and research literature emerged describing how many higher level institutions used CBL to increase student collaboration and engagement (Chanin et al. 2018), develop twenty-first century skills (Cheng 2016) and face real-world problems in their learning (Cheung et al. 2011). In addition, a variety of other studies using the CBL term were published using more bespoke approaches.

While many suggest that CBL was not a completely new approach and emerged via aligned pedagogies (Kohn Rådberg et al. 2018), it is striking how many of the early manifestations of CBL fail to discuss or attempt to identify its pedagogical heritage.

Aligned pedagogies

At this stage in the development of CBL as a distinct pedagogy, there is no agreement as to its predecessors or even with underlying overarching approach it falls under.

At a conceptual level, active learning is noted as being an overarching approach used by CBL (Hernández-de-Menéndez et al. 2019; Kalinga et al. 2018; Membrillo-Hernández et al. 2019b; Suwono, Saefi, and Susilo 2019); however, the term experiential learning (Chanin et al. 2018; Detoni et al. 2019; Gama 2019) and inquiry learning (Martin, Rivale, and Diller 2007) are also cited. For some authors it is a combination of experiential learning and active learning (Gibson, Irving, and Scott 2019) while others draw upon the influences of Vygotsky's sociocultural theory due to the focus on social interaction and knowledge artefacts (Baloian et al. 2006).

It is outside the scope of this work to posit the exact heritage of CBL; however the identification of the commonly agreed upon characteristics and definitional clarity will, it is hoped, assist in any future analysis of the developmental roots of CBL as a distinct pedagogy.

When CBL is discussed as a teaching method or strategy, then it is often used interchangeably, or in the same definition, with other similar pedagogies such as project based learning (PjBL) and problem based learning (PBL) (May-Newman and Cornwall 2012). However, CBL has its own frameworks, definitions, and approaches. Binder et al. (2017) describe how CBL differs from PBL and PjBL with its absence of predefined study, content or challenge. Stakeholders from multiple settings are used in CBL to support students, as opposed to being supported solely by professors or project managers (Garay-Rondero, Rodríguez Calvo, and Salinas-Navarro 2019), and act as co-researchers and designers, rather than facilitators (Membrillo-Hernández et al. 2018). Unlike PBL and PjBL, CBL has a focus on sustainability issues and demands a verifiable and urgent solution (Garay-Rondero, Rodríguez Calvo, and Salinas-Navarro 2019). In addition, the focus is not on the final product, such as in PjBL, but the process is viewed as being as important. However, there are some commonalities between CBL, PBL and PjBL; their use of a problem or challenge such as PBL, and their use of a project such as PjBL. Nonetheless, in the same way that PBL and PjBL differ (Dobber et al. 2017), CBL should be understood as an approach of its own.

CBL in higher level institutions

The broad defining features of CBL strongly align with the strategic goals and policies of many higher level institutions. Transversal skills and competencies, such as collaboration and innovation, are commonly integrated into institutional policy and curricula to improve student employability and post-university life. The acquisition of such skills requires a different means of teaching students whereby they actively develop these skills rather than focusing on strict disciplinary learning objectives. Student-led approaches, such as CBL, can support this type of skill development and have been identified in higher level policy and strategy as key to institutional reform, student progression, and mobility (Gaebel et al. 2018).

Industry and community collaboration are also identified by institutions in strategic goals and research funding applications. Improving the link between academia and industry is crucial for the advancement of knowledge, innovation in design and development, and providing solutions to transdisciplinary societal problems (Trinity College Dublin 2020). Similarly, strengthening the links between higher level institutions and their local community not only provides a means for delivering on their goals of education as a public good but also allows access to authentic situations and contexts in collaboration with local extra-academic actors (Hall 2009). Sustainability and the SDGs are also mentioned in many institutional policies and align with all university disciplines (Franco et al. 2019; Lozano et al. 2015).

CBL, at its most broad understanding, ties into all these factors, however, it is a very different approach compared to traditional pedagogical approaches common to many institutions. Understanding how CBL is being employed in higher level institutions, at what curriculum level, and how it is assessed, is crucial to the long-term applicability and adoption of this approach.

To date, no review has been conducted on the use of challenge-based learning in higher level institutions within the peer-reviewed literature. The definition and research landscape of CBL is therefore vaguely defined despite the rapid increase of its use and interest among higher level institutions. There is a real and pressing need to review the existing knowledge in order to clarify its definition, outline the key characteristics of the pedagogy in action, and identify the emerging research themes and areas for future research.

Materials and methods

The term 'challenge based learning' was searched for in the article title, abstract and keywords on Scopus and Web of Science between 1900 and December 2019, and an initial 168 articles were returned. The inclusion criteria for literature were:

- Inclusion of 'challenge based learning' within the text;
- Higher education focussed (e.g. universities, higher level institutes);
- English language journal articles or conference proceedings;
- Full peer-reviewed papers only (i.e. grey literature and literature where abstracts were only available were not included).

The initial set of 168 articles were reviewed in terms of the inclusion criteria, and 73 were removed having been out of scope. A content analysis of the remaining 95 pieces of literature was conducted. The analysis was structured using a thematic matrix which first consisted of a priori themes (such as CBL definition, research methodology), and subsequently other themes emerging through the process of analysis. These emergent themes were identified as being of importance to the aim of understanding the CBL research landscape (such as instructors, and assessment) (see Appendix for full list of themes).

Each paper was read by the researchers, and text or personal notes related to each theme for each paper was entered in the matrix. This allowed for a structured review of each theme across all the reviewed literature. The matrix was created in Microsoft Excel and EndNote was used to maintain a literature repository, and as a means for searching through full text versions of the literature. After the first review, an additional 5 peer-reviewed articles emerged via the initial articles that were omitted by the two primary catalogues but were deemed within scope as peer-reviewed literature. The same process of analysis using the thematic matrix was used for these 5 papers. Data from the final set of 100 papers, organized and structured using the thematic matrix, were then reviewed and analysed (see Figure 1).

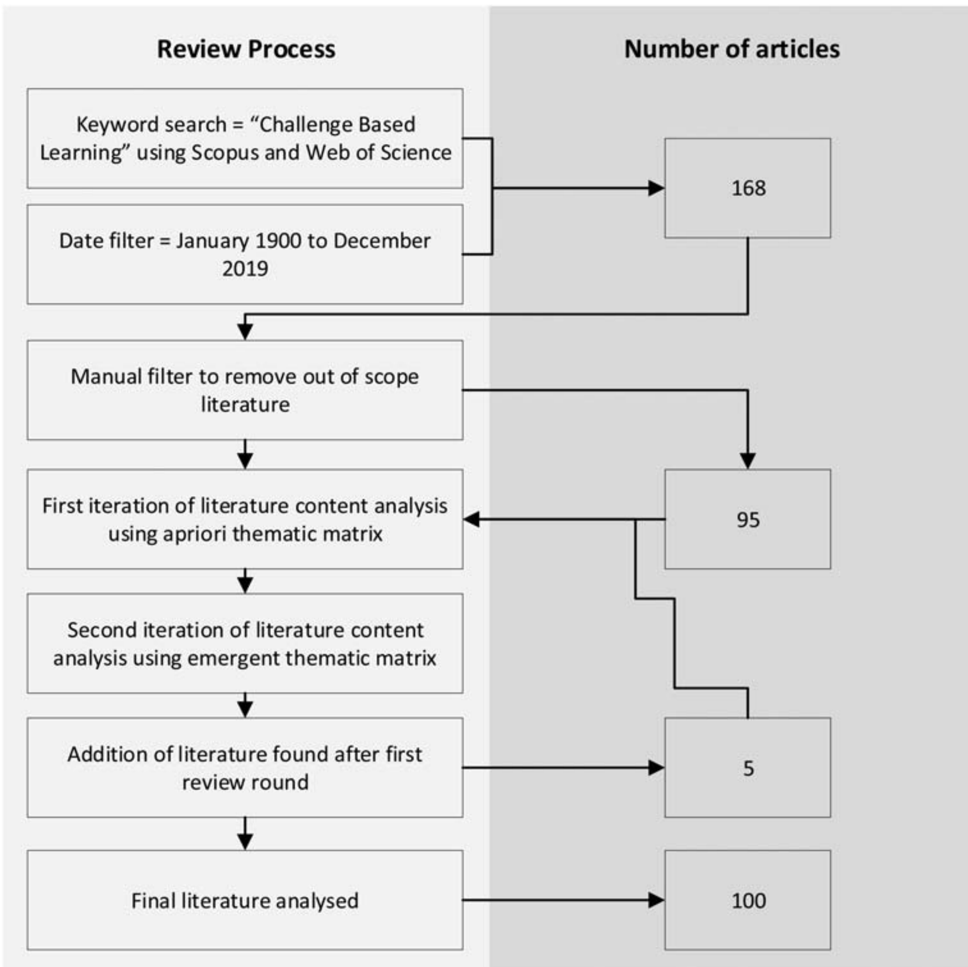

Figure 1. Description of literature selection.

Results

Review scope and publication type

A total of 100 publications were reviewed for this research and most publications identified were conference papers or proceedings ($n = 65$), with lesser numbers of peer-reviewed journal articles ($n = 33$) or peer-reviewed book chapters ($n = 2$). The first instance of CBL was recorded in 2001, and publication outputs remained low until 2017 where a large growth in publications appeared (Scopus 2019). Literature published was located within a relatively narrow range of disciplines with engineering, computing (including software engineering), and educational specific publications within those disciplines, being most common. Non-Science, Technology, Engineering and Mathematics (STEM) publications were relatively absent from the analysis (see Figure 2).

Keywords used

Exploring the keywords used within the literature can give a sense of what key topics are being investigated, and what disciplines are using CBL. The keywords used for each paper were analysed using Vosviewer (van Eck and Waltman 2010) to visualize the networks between common keywords used. The relatedness of keywords was analysed using co-occurrence analysis which visualized the number of documents in which the keywords were used together (see Figure 3).

The most prominent keywords that emerged included, students ($n = 48$), teaching ($n = 28$), engineering education ($n = 25$), education ($n = 22$), education computing ($n = 13$), curricula ($n = 12$), learning systems ($n = 12$) and educational innovations ($n = 10$). It is apparent from the visualization that CBL research has had a focus in the engineering and computing disciplines. Five areas of co-occurrence were visualized which grouped literature into disciplinary areas linked with different pedagogical approaches. Engineering and computing education tended to be linked with project based learning, whereas software design was linked with student centred learning. Design thinking was linked to sustainability, whereas biomedical sciences were linked with learning systems. Experiential learning was linked to professional competencies and nursing education.

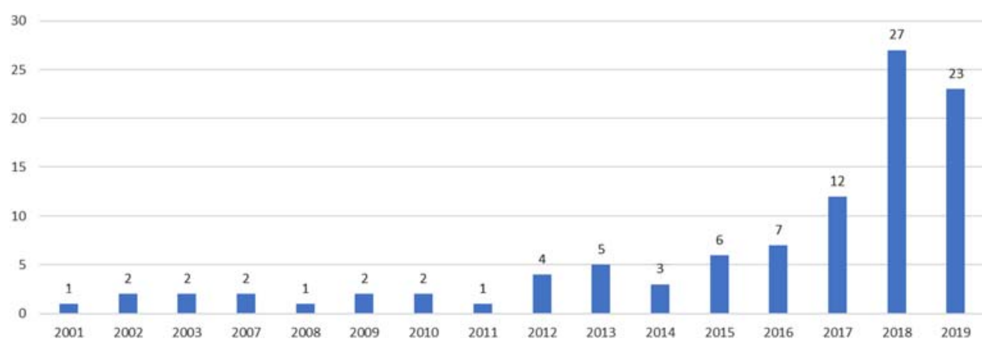

Figure 2. Description of CBL publications by year.

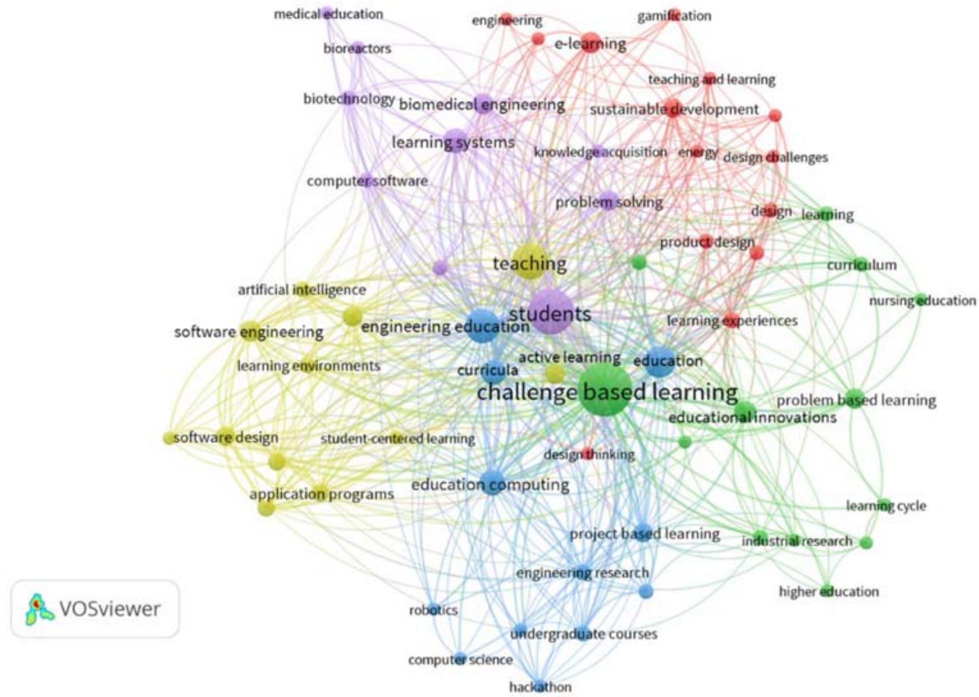

Figure 3. Vosviewer visualization of keywords within reviewed literature.

In conclusion, this analysis demonstrates the variety of pedagogical approaches used in conjunction with CBL and conversely, the lack of breadth of disciplinary applications of CBL learning experiences within the literature.

Research methodologies

The most common methodology employed in the surveyed literature was a descriptive case study, followed by quantitative, mixed method, qualitative and literature review. Descriptive case studies ($n = 40$) generally described how a CBL project was implemented or designed (Siqueira da Silva 2018). Quantitative methodologies ($n = 28$) included surveys (Williams et al. 2012), analysis of student performance scores (Giorgio et al. 2002), student learning gain scores (Membrillo-Hernández et al. 2019b), student transaction data (Ifenthaler, Gibson, and Zheng 2018), and social network analysis (Dornfeld Tissenbaum and Jona 2018). Mixed methodologies ($n = 26$) were most commonly a quantitative survey augmented with qualitative analysis of observations (Gama 2019), open ended questions (Guo et al. 2014) or more specific methods such as video analysis (Eraña-Rojas et al. 2019). Qualitative methods ($n = 4$) including interviewing students or teachers and employing thematic analysis on the data (Cruger 2018). Two studies used a literature review for their research; these were reviews of pedagogical approaches of which CBL was included (Table 1).

This finding describes how CBL research is in a nascent state and could benefit by more rigorous methodological approaches.

Table 1. Methodologies used in CBL research reviewed.

Methodology	Number of studies
Descriptive case study	40
Quantitative	28
Mixed method	26
Qualitative	4
Literature review	2

The focus within the methodological spread is understandable for a field of research that is in its infancy. The dominant use of case studies, with their focus on description of the experience within the specific context of the implementation and their lack of generalizability, reflects experimentation within authentic learning contexts. However, explanatory or predictive knowledge from these predominant methodologies is lacking and could fail to provide conceptual or theoretical perspectives of CBL.

Common CBL approaches

Two common CBL approaches emerged within the literature reviewed; Apple CBL and STAR Legacy Cycle/HPL. These were identified through the text and references section of the literature where authors referenced these approaches as being a guiding structure for their research. Although, in many cases hybrid approaches were used (see section 'Flexibility' below), the basis of many of the papers was founded on these two frameworks. In addition, some literature referred to CBL, but did not explicitly reference CBL frameworks or literature (Gray and Schwartz 2017). It is worth noting that some higher level institutions created a hybrid model mentioning both Apple and STAR approaches (Table 2).

Having explored the scope, methodology and frameworks used, clarity in the definition of CBL was identified as a key output for this literature review.

Key features and definitions of CBL

At the onset, it is important to note the trichotomy between research using CBL original approaches, CBL approaches derived from previous approaches (hybrid) and literature using the term CBL to describe an educational project that uses challenges within its design. Although CBL is designed to be a flexible approach, many projects do not explicitly refer to CBL as an approach but use the term CBL in describing their research.

At the highest level of definition, CBL has been described in a multitude of ways; as a learning framework (Chanin et al. 2018; Santos et al. 2015), an instructional (Marin, Hargis, and Cavanaugh 2013), philosophical (Moresi et al. 2018) or multidisciplinary approach (Kalinga et al. 2018; Kohn Rådberg et al. 2018; Nichols and Cator 2008), a

Table 2. Literature that used defined frameworks in some form.

Framework	Number of articles
Apple CBL and hybrid versions	64
STAR Legacy Cycle and hybrid versions	24
Undefined or no framework	13
Other (e.g. DCBL, Challenge Based Learning Cycle)	9

model (Membrillo-Hernández et al. 2019a), a learning experience (Olivares et al. 2018) and, amongst many others, a methodology (Quweider and Khan 2016). This variation can create difficulties in understanding what exactly CBL is at a conceptual level. For the purposes of this article, the term 'approach' has been used, given that it is a broad and often used term within the literature. However, the authors note that given the relative novelty of this research space, a variety of terms can be used depending on the application and conceptualization of CBL.

The following key defining features of CBL emerged from the literature; global themes, real-world challenges, collaboration, technology, flexibility, multi-disciplinarity and discipline specificity, creativity and innovation, and challenge definition.

Global themes

The first defining feature of CBL emerging from the literature is that the thematic content areas predominantly addressed in a CBL approach are rooted in themes of global importance, such as sustainability, or war (de la O Campos 2019; Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo 2016; Gama et al. 2019a; Johnson et al. 2009; Marin, Hargis, and Cavanaugh 2013; Ossiannilsson and Ioannides 2017). Themes of global importance respond to the need for students to have skills in a global environment, a global mindset (Sternad 2015), knowledge of global problems, and the ability to face global issues themselves (Suwono, Saefi, and Susilo 2019). Solutions to global issues should have a local focus (Binder et al. 2017) and applicability (Gama et al. 2019a).

However, challenges of this type can be removed from the specificities of academic subjects (Conde et al. 2017) and are, in some cases, gently guided to course themes (Gaskins et al. 2015). The terms sustainability, and Sustainable Development Goals (SDGs) are also commonly used in many CBL studies, both as a competency (Bordonau, Olivella, and Velo 2017) and as a theme used in the design of the challenges (Gibson, Scott, and Irving 2019; Martinez and Crusat 2017).

Real-world challenges

A second defining feature of CBL is using and validating real-world challenges; for example 'Increase the knowledge of adolescents towards type 2 diabetes mellitus'(Cheng 2016, 131). While the range of challenges posed to and experienced by students undertaking CBL can vary significantly, they commonly demonstrate elements of being situated within an authentic real-world context or scenario. Whiley et al. (2018) utilized an overarching scenario of a natural disaster (through a Zombie apocalypse) to pose challenges to the students around obtaining safe drinking water, dealing with toilet waste, and obtaining safe food to eat from an analysis of contaminated ground. These challenges were designed to require skills of scientific knowledge, soft skills (such as teamwork and communication), basic knowledge (in microbiology and toxicology), and applied knowledge (in a practical context). For Valenzuela et al. (2018), the challenges for their Marketing students arose through interactions with local businesses. Medium and large enterprises were invited in to present marketing challenges to students who in turn selected the businesses who they wished to work with. The students then formed themselves as consultant teams to address the challenges of the enterprises. Membrillo-Hernández et al. (2018) combined lecturer-generated and externally sourced approaches to challenge generation in their i-week at the Tecnologico de Monterrey by inviting organizations to pose challenges alongside challenges offered by academic staff. Students selected their challenge and worked in groups of at least 15 students on their challenges. The organizational challenge examples included the challenge of how to preserve the Chinampas agriculture system of the World Heritage City of Xochimilco from the risks posed to it from population and urban growth due to its location within Mexico City.

These real-world challenges aim to bring students 'closer to the real world' (Conde et al. 2017, 252) and increase motivation and engagement (Gaskins et al. 2015) by having an impact on their own lives (Johnson et al. 2009). Real-world challenges can be discipline specific (e.g. engineering) (Rowe and Klein 2007) and many projects are assessed and validated in the 'real world' by presenting their results to the wider community (Díaz Martínez 2019). In addition to the challenges being 'real world', associated competencies such as communication are deemed to be important for 'real world' industry participation (Hernández-de-Menéndez et al. 2019). However, difficulties mimicking real-world scenarios in a classroom were noted by some studies (Detoni et al. 2019).

Collaboration between students, academic and extra-academic actors

Collaboration was identified as a key competency in many of the studies and was at the forefront of both the design of the educational intervention and as a means for solutions to be developed. Students, educators and extra-academic actors (e.g. industry partners, community members) collaborate in most CBL case studies (Santos et al. 2015). This collaboration can be students working with other students in groups or teams (Da Costa et al. 2018); students, academics and industry partners collaborating to find solutions to a challenge (Bordonau, Olivella, and Velo 2017 Díaz Martínez 2019; Membrillo-Hernández et al. 2019b) and provide student feedback (Félix-Herrán, Rendon-Nava, and Nieto Jalil 2019); and students collaborating with community members to define challenges, and identify, develop and present solutions (Cruger 2018; Gibson, Scott, and Irving 2019; Malmqvist, Rådberg, and Lundqvist 2015; Maya et al. 2017).

The literature reported that student collaboration with academic and extra-academic actors deepened student knowledge, (Barth and Luft 2012; Serrano et al. 2018), motivated and engaged students (Morales-Menendez et al. 2019), and supported industry-specific training (Mora-Salinas et al. 2019). Although there were many examples of literature in which extra-academic actors were used in CBL projects, there was little detail as to what their input was, their perceptions of the CBL approach, and whether their participation was evaluated.

Technology

Technology is 'infused' within the lifecycles of CBL projects (Gaskins et al. 2015, 35; Quweider and Khan 2016), and is a recurring theme within the literature. For CBL students, technology supported communication with project stakeholders, engagement with the public, accessing and researching information, publishing outcomes, collaborative workspaces, computational applications and tools, and accessing module content through a VLE (Conde et al. 2017; Cruger 2018; Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo 2016; Gibson, Irving, and Scott 2019; Lam 2016). For educators, technology tracked student interactions, evaluated student performance, provided a collaborative space for sharing course materials, and helped identify issues with student engagement and instructional design (Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo 2016; Gibson, Irving, and Scott 2019; Nelson and Chesler 2009).

Case studies describe various bespoke online platforms for communication, process implementation, self-direction, time management, scalability, and student engagement (Gibson, Scott, and Irving 2019). Virtual learning environments such as Moodle or Blackboard are used to host module resources (Díaz Martínez 2019; Lovell and Brophy 2014; Nelson and Chesler 2009), assignments (May-Newman and Cornwall 2012), online communication (Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo 2016), and to track student activity data (Conde et al. 2017).

In many cases, technology used in the daily life of students is employed for the CBL approach (Conde et al. 2017; Johnson et al. 2009). Online communication applications used to facilitate communication and project management such as Facebook, WhatsApp, Skype and Google Drive (Cheng 2016; Díaz Martínez 2019; Hernández-de-Menéndez et al. 2019) were commonly used. Social media was mentioned as being important for student societal contributions and for organizing and disseminating information (Cruger 2018; Kuswadi and Nuh 2017). Gibson, Irving, and Scott (2019) also note that technology options are open and flexible, and not confined to a particular process. Technology provides options for students who can be creative in developing solutions.

Flexibility

Although structured approaches (e.g. Nichols, Cator, and Torres 2016 and Giorgio and Brophy 2001) were often described within the literature, flexible adaptation of CBL approaches were also very common. Examples include experiential learning, competency based learning and CBL (Garay-Rondero, Rodríguez Calvo, and Salinas-Navarro 2019), research based learning and CBL (Morales-Menendez et al. 2019), CBL and design thinking (Gama et al. 2019a, 2019b), CBL and competency-based education (Félix-Herrán, Rendon-Nava, and Nieto Jalil 2019), CBL and challenge-based instruction (Fidalgo-Blanco, Sein-Echaluce, and García-Peñalvo 2016), design challenge-based learning (DCBL) (Blevis 2010), CBL and feedback (CFL) (Sternad 2015), CBL, flipped classroom, and case based learning (Hartono et al. 2018), CBL and agile practices (Santos et al. 2018), CBL and problem based learning (Barry et al. 2008) and CBL and game design thinking (Siqueira da Silva 2018). This suggests that CBL is used as a flexible methodological approach open to interpretation, augmentation and innovation. However, it could also suggest that the lack of a clear CBL definition is the precursor to this wide range of CBL approaches. Potentially, definitional muddying rather than a conceptual basis in flexibility is emerging in CBL literature.

Multidisciplinarity and discipline specificity

While CBL often proposes a multidisciplinary approach in its execution, most of the literature explored case studies within Science, Technology, Engineering and Mathematics (STEM). These case studies commonly researched teachers from a single discipline, or students from a single discipline. Multidisciplinarity is conceived in many cases as using professional competencies that support general academic curricula, rather than a stricter multidisciplinary approach where teachers from different disciplines work with students on a challenge. The STEM field was seen as particularly suitable for CBL, as STEM curricula can be ‘complex, real-world and multi-disciplinary’ (Quweider and

Khan 2016). As technology itself is a key part of CBL, technology rich learning environments lend themselves well to this discipline (Johnson and Brown 2011).

Within STEM, common disciplines that utilized CBL included mobile application education (Chanin et al. 2018), civil, biotechnology, software, mechanical and introductory engineering (Chanin et al. 2018; Membrillo-Hernández et al. 2019a; Rowe and Klein 2007), and computer science (Barth and Luft 2012). Within non-STEM disciplines there were far fewer examples of CBL case studies or analyses; for example communication studies (Cruger 2018), English language (Marin, Hargis, and Cavanaugh 2013), international business (Sternad 2015), and marketing (Valenzuela et al. 2018). Multidisciplinary approaches within the literature, though few, included students from medicine, law and marketing (Eraña-Rojas et al. 2019)

Innovation and creativity

Many CBL case studies used innovation and creativity either as module descriptors (Díaz Martínez 2019; Yang et al. 2018), as key competencies assessed (e.g. Bordonau, Olivella, and Velo 2017), or as general values within the CBL intervention. Students are encouraged by teachers to use these values to provide challenge solutions. Studies reported increases in student ability to innovate and create through a CBL approach (Johnson and Brown 2011; Yang et al. 2018).

Challenge definition

A key similarity within all CBL literature is the use of a challenge: a broad statement or task as a means of encouraging students to address educational criteria, fulfil competencies and complete learning objectives (Gibson, Irving, and Scott 2019). However, within the curriculum design, differences in the definition of challenges emerged in the analysis. In many cases the initial challenge was defined by the educators (Giorgio and Brophy 2001; Jansen et al. 2003) whereas in some cases it was defined by the student (Gabriel 2014). A key demarcation between two of the main approaches (Apple and STAR) is in this definition of challenges; for educators using the Apple approach students would generally determine their challenge, but for the STAR approach the challenge was determined for the students by educators.

Many studies reviewed and evaluated student success in achieving the educational criteria however there was very little reporting on whether the challenges themselves had been successfully met to the satisfaction of the stakeholders engaged.

CBL educational factors

Curriculum structure

Few studies had CBL as embedded curriculum practice (Malmqvist, Rådberg, and Lundqvist 2015), rather CBL was included as a novel pedagogical approach to supplement existing structures. This reinforces the 'flexibility' theme above whereby CBL was commonly used with a broad range of pedagogical approaches. Many studies described how their case study was developed as a pilot (Guo et al. 2014), as a forthcoming educational intervention (Kerber et al. 2013), or was at an initial implementation phase to be included in future strategy (Maya et al. 2017). However, other studies noted how positive results from their initial project caused CBL to be expanded to other courses within the university (Quweider and Khan 2016), how CBL is now integrated into core curricula (Valenzuela et al. 2018) or has been used for multiple cohorts of students (Morales-Menendez et al. 2019). CBL was used in both short term (i.e. in a single day or week) (Gama 2019) and long-term curricula (i.e. over full semesters or across an entire programme) (Chanin et al. 2018).

Assessment

Both formative and summative assessment were used within CBL approaches, including workshop attendance and participation (Malmqvist, Rådberg, and Lundqvist 2015), oral presentations (Díaz Martínez 2019), peer evaluations (Gabriel 2014), conference paper reports (Hernández-de-Menéndez et al. 2019), exams (Gaskins et al. 2015), laboratory reports (Mora-Salinas et al. 2019), open book exams (Da Costa et al. 2018), quizzes (Martin, Rivale, and Diller 2007), and progress reports (Membrillo-Hernández et al. 2019b). CBL research that follows a framework or hybrid framework approach generally use both summative and formative assessments. However, CBL hackathons or competitions generally use only summative assessment (i.e. was the project effective). Both individual and team involvement was often assessed, and summative assessment also took into account communication with extra-academic actors; Conde et al. (2017) describe difficulties in measuring communication and developed an ad hoc tool to measure online activity.

Assessment rubrics were often used to assess student performance (Díaz Martínez 2019; Vargis and Mahadevan-Jansen 2010), and were usually linked to overall learning objectives, competencies of the module (e.g. innovation – Flores, Montoya, and Mena 2016), or assessing a CBL output (e.g. oral presentation – Gabriel 2014). These rubrics were, in most cases, developed by the academic team rather than collaboratively with students (Félix-Herrán, Rendon-Nava, and Nieto Jalil 2019; Valenzuela et al. 2018). In some cases, existing rubrics such as the Research Skills Development Framework (RSD) were used for assessment (Hernández-de-Menéndez et al. 2019).

Challenge-based competitions and hackathons

Within the literature there were some examples of competitions or hackathons described with the term CBL as a keyword or an article headline. These examples did not always follow a strict CBL approach, and tended to describe how challenges were used within a competitive environment for learning (Gama 2019; Gama et al. 2019a; Gama, Gonçalves, and Alessio 2018; Hitchcock 2017; Rakos et al. 2017). One example did follow the Apple framework, and as part of student learning application, was entered into a competition following CBL derived education (Cheung et al. 2011). These competitions were assessed in terms of project presentation, technical applicability, potential impact, innovation, and likelihood of impact, among others (Malmqvist, Rådberg, and Lundqvist 2015).

Challenges with implementing CBL

Challenges faced with implementing CBL included a high level of uncertainty emerging from the challenges (Membrillo-Hernández et al. 2019b), the need for flexibility when working with industry partners (Mora-Salinas et al. 2019), educator resistance to technology or non-traditional ways of teaching (Félix-Herrán, Rendon-Nava, and Nieto Jalil

2019; Lam 2016; Lin and Chen 2018), additional time needed by academics for evaluation (Díaz Martínez 2019) and students for working on the challenge (Detoni et al. 2019), difficulties related to the generalizability of the curriculum design (Yang et al. 2018), the need for student support during the transition to CBL teaching (Dornfeld Tissenbaum and Jona 2018), a lack of student technical skills (Binder et al. 2017), a need for additional technical resources, a lack of hierarchy causing student demotivation (Cheung et al. 2011), higher level students being accustomed to traditional forms of learning (Johnson and Brown 2011), accommodating multidisciplinary student groups, and decreased ability to offer subject specific feedback (Malmqvist, Rådberg, and Lundqvist 2015). Some literature noted the importance of discussing CBL at a policy level within universities such as setting up a steering group (Lin and Chen 2018) to mitigate for some of these challenges.

Benefits of CBL

The benefits of CBL were commonly reported in the literature by analysing student or academic feedback, or through a descriptive approach. Benefits for students included industry networking, improving technical skills, application of skills in a real-world environment, training in multidisciplinary teamwork, improving problem solving skills, and achieving a deeper understanding of knowledge (Cheung et al. 2011; Conde et al. 2017; Gama et al. 2019a; Kohn Rådberg et al. 2018). In addition, students improving their innovative thinking ability and skills were also commonly cited (Lin and Chen 2018). For academics and industry, benefits included improving research and innovation partnerships, teaching ability, and commercial products (Membrillo-Hernández et al. 2019b). There was a much greater focus and research rigor on student benefits than academic and industry benefits.

Conceptual framework of CBL characteristics

Having explored the key characteristics of CBL within the literature, a preliminary conceptual framework summarizing these characteristics was developed. This can be used by practitioners, instructional designers and researchers as a reflective, design or analysis tool for CBL methods. Given the wide variability of CBL approaches, this conceptual framework could be used to support CBL implementation and ensure that if CBL is being used, each of these characteristics are embedded, in some way, within the design. Ultimately, this framework may help standardization of the CBL term, currently lacking within teaching and academia and could be augmented in the future as CBL evolves (Figure 4).

Discussion

This literature review has explored the landscape of CBL research, its definition, and its application in higher level learning environments. Three key areas for discussion have clearly emerged from this review: an understanding of common CBL definitional themes, the wide variety of CBL approaches, and the nascent state of CBL research.

Figure 4. Conceptual framework of CBL characteristics.

Global themes, real-world challenges, collaboration, technology, flexibility, multidisciplinarity and discipline specificity, challenge definition, and creativity and innovation were the most common emerging themes from exploring CBL research definitions. Although there was variance between CBL practical approaches, these key themes were present in most research reviewed. However, what is notable is the lack of practical implementation of some themes described by the studies, such as multidisciplinary teaching. For example, the majority of CBL projects within higher level institutions were delivered to STEM students, even though CBL at its core is a multidisciplinary pedagogy. Using challenge-based teaching in non-STEM higher level courses appears to be a significant gap in the research and future should consider exploring multiple disciplines in the design, analysis and evaluation of CBL.

Technology was another emerging theme within the literature; however, few research studies explored the impact of technology, or identified technology-enabled institutional structures in this space. Developing best practice instructional design models for implementing technology within CBL initiatives is an important area for future research. Given that technology-enabled learning is embedded in most higher level institutions, exploring how CBL and TEL can be integrated is key to successful institutional adoption of this approach.

Sustainability and addressing real-world challenges themes were also present in all studies but identifying crossover between CBL curriculum design and institutional adoption of education for sustainability development was absent. Determining whether CBL is integrated with institutional strategies on sustainability, or are seen as novel and bespoke approaches outside of these strategies could be an indicator of the long-term viability of CBL.

Although there was much variability in CBL approaches and similarities with other approaches such as Project Based Learning and Problem Based Learning, the use of the term 'challenge' differentiated itself from other approaches. Definitions of CBL within the literature tended to describe key characteristics, but an actual definition of a challenge was absent. In order to fully demark CBL from other approaches, defining the term 'challenge' is crucial. It is suggested that practitioners consider what a challenge is at the onset of curriculum design and how it differs from a problem or a project proposal.

In relation to the challenges, it was also notable how little reporting there was on whether the challenge was successfully met or not. Most of the studies reviewed focussed on evaluating the student experience and the acquisition of the desired competencies and skills. Objective success criteria for the challenges themselves were absent.

Most tellingly, the review identified the wide flexibility and variability of CBL approaches. This is a significant contribution as it shows how CBL is not a static approach and can be moulded to fit different disciplines, curricula, institutional strategies, and assessment types. This flexibility paves the way for more innovative hybrid approaches to student-led learning, vital for many higher level institutions. However, conversely a major difficulty in defining CBL is this wide variety of different approaches using the term CBL. There is a clear dichotomy between the theory driven CBL research and research that uses the term CBL to describe general challenge statements within their design. Should the CBL term only be used for studies that use a CBL approach derived from existing frameworks, or should it be more widely used for any educational intervention using challenge statements? To clarify CBL within the literature three literature classifications within the scope of higher level CBL research are proposed; strict, hybrid and general (Table 3).

Classifying CBL in this way can help researchers and practitioners make better sense of CBL, and perhaps inform improved development of CBL approaches. For example, an academic using basic challenges in a classroom could be guided to use a more formalized and validated approach. This classification and clarification may go some way towards addressing the risk of CBL becoming a portmanteau pedagogy, blending aspects of problem based learning, project based learning, and situated learning, as opposed to its development as an effective pedagogy in its own right.

The results of this research also have implications for higher education institutions. Strategic goals and national level policies often include transversal skill development, engagement with industry, transdisciplinarity, and responding to the SDGs as key principles. CBL definitions within the literature strongly align with these themes, and its use in higher level institutions can be a means for addressing and practically implementing these goals and policies. However, challenges identified, such as academic resistance, additional time needed for development, curriculum design and student support need to be considered before implementation. Drawing on this research, future research should develop best practice strategies to support institutional adaptation of CBL.

The review also identified how CBL is at an early stage of research development, visible by the large number of descriptive case studies. In the same sense that CBL is seen as an evolution of PBL, there is space for a new phase of CBL to emerge. Presently,

Table 3. Proposed classification of CBL approaches.

Approach	Definition	Example
Strict CBL	An educational approach using strict application of a CBL framework.	Cheng (2016)
Hybrid CBL	An educational approach using a hybrid version of an existing CBL framework.	Hartono et al. (2018)
General CBL	An educational approach using general challenge statements in its design.	Hitchcock (2017)

most CBL research is small scale, focusing on case studies in universities, and student perceptions. Comparative research, detailed qualitative methodologies, instructor perceptions, challenge success criteria, industry collaboration, longitudinal studies, university level implementation and policy, and alignment with education of sustainable development strategies are all potential avenues for research. One of the key goals of these avenues of research is the identification and description of best practice guidelines which are lacking due to the nascent state of CBL as a pedagogy and an area for research.

At this stage, CBL remains a novel approach in higher level institutions and it remains to be seen whether CBL will become more integrated into university structures or if it will continue to be used in bespoke projects within a traditional framework.

Limitations

This research omitted other keywords using the term challenge in their title, for example, challenge driven learning. In some cases, these keywords were used in conjunction with CBL but there may have been instances where these terms were used in isolation. The authors decided not to include these terms in order to standardize this analysis and provide a linear narrative to CBL. Future studies could augment this research with these keywords and ascertain whether there are commonalities.

Conclusion

Reviewing CBL literature has contributed to research in this space by identifying emergent themes, clarifying its definition, and gaps in knowledge for future research. This research can be applied by CBL practitioners to guide their approaches to teaching and learning, future research, and supporting higher level institutional adoption of CBL.

Acknowledgements

Figure 4 was based on a Creative Commons diagram from Showeet.com.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix. A priori and emergent themes in the thematic matrix

A priori themes	Emergent themes
Keywords	Challenges faced with implementation
Defining CBL	Instructor training
Research question	STEM or Non-STEM course
Methodology	Mention of project based learning
Results	Mention of problem based learning
Course type and discipline	Policy
Assessment	
Challenge examples	
Future research	
Framework used	