A Review of Competency-Based Learning: Tools, Assessments, and Recommendations

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Abstract

Background Over the past decade, there has been a shift in science, technology, engineering and math education, especially in engineering, towards a competency-based pedagogy. Competency-based learning (CBL) is an outcome-based, student-centered form of instruction where students progress to more advanced work upon mastering the necessary prerequisite content and skills. Many articles have been published on the implementation of CBL in engineering higher education; however, the literature lacks a systematic review that summarizes prior work to inform both future research and practice.

Purpose The purpose of this review is to integrate previous literature as well as identify gaps in competency-based engineering higher education research. It summarizes the different approaches for implementing CBL, the effects of the pedagogy on student outcomes, tools to enhance its effectiveness, and assessment strategies. In addition, suggestions and recommendations for future research are provided.

Method Engineering education articles were obtained from several EBSCO educational databases. The search was limited to articles published from 2005-2015, and inclusion criteria consisted of peer-reviewed journal articles that address the use of CBL in engineering higher education. Articles were then classified into several categories, summarized, and evaluated.

Conclusions Theoretical and applied perspectives are provided that address both the theoretical basis for the effectiveness of CBL and practical aspects of implementing successful CBL instruction in engineering education. There are gaps in the literature regarding how CBL programs should be structured and assessed. Future research directions include empirical quantitative evaluation of CBL's pedagogical effectiveness and the use of CBL for teaching professional skills.

Keywords competency; literature review; pedagogy

Introduction

Engineering education currently faces many challenges in meeting the diverse needs of its students and the growing demands of a global industrial environment. The diversity of the student population in higher education institutions in the United States is increasing, with up to 85% of the student body being nontraditional students (Roe, 2015). These students include those who are working full-time, enrolled in higher education courses part-time, or those who require distance education courses. Although engineering programs have not experienced

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the same surge in diversity as other higher education fields, many initiatives across the United States are currently focused on increasing the diversity of the engineering student body (Einaudi, 2011), in particular many targeting the recruitment of nontraditional students (Bushey-McNeil et al., 2014). As a result, higher education institutions have the responsibility of being prepared to meet the needs of the students they are actively recruiting. As for industry's demands, there is an increasing need to produce competent engineers to meet the employment gap, as a large proportion of workers in engineering careers are retiring. Higher education institutions face the challenge of producing engineers prepared to fill many of these positions as well as ensuring that their graduates possess the necessary competencies to succeed in the workplace.

Recently, in response to student and industry demands, competency-based learning (CBL) has received increasing attention in engineering education, with evidence suggesting that CBL plays a key role in meeting the needs of a diverse student population. Many CBL programs offer distance education options and allow students to work at their own pace. The flexibility of CBL is especially useful for nontraditional students, many of whom juggle family and work responsibilities. Furthermore, CBL can help meet the growing demands of industry for competent engineers by ensuring that graduates have mastered the necessary skills to be successful in industry. This literature review examines and analyzes the current literature on the use of CBL in engineering higher education along with providing recommendations for future research. In addition, the potential impact of CBL on student recruitment, retention and achievement are discussed.

Definition and Description of Competency-Based Learning

CBL can be broadly defined as a pedagogical approach that focuses on the mastery of measurable student outcomes. The evaluation of student progress is based solely on whether students demonstrate mastery of predetermined competencies (Albanese et al., 2008), that is explicit and measurable objectives clearly communicated to them. Under the CBL framework, mastery of competencies includes the ability to apply knowledge in practical real-life situations. In this system of instruction, students cannot advance or be evaluated for a new competency until they have mastered the prerequisite materials. Thus, students receive differentiated support based on their pace of learning.

The term CBL (or competency-based education), which became widely used in the 1970's, refers to a type of outcome-based pedagogy (Burke, 1989; Spady, 1977). However, the term dates to the early 1920's and was rooted in the education and training of teachers (Carraccio, Wolfsthal, Englander, Ferentz, & Martin, 2002; Spady, 1977). What sets CBL apart from other instructional structures is the shift in focus to behavioral outcomes. This approach moved away from setting time limits during which a certain amount of knowledge should be learned, allowing students to progress at their own pace. The CBL movement changed the objective from increasing the amount of information that can be taught in a semester or quarter to ensuring that students master outcomes before moving on to the next level. In the CBL framework, instructional materials are linked to specific predefined outcomes that are clearly communicated to students at the beginning of any course (Burke, 1989; Spady, 1977).

CBL can be considered a subset of mastery learning, a pedagogy introduced into the American educational system during the 1920's (Washburne, 1922). Mastery learning focuses on achieving a certain level of competency before learning subsequent information (Tyler, 2013) and as such has been widely investigated as a strategy for improving student outcomes (Bloom, 1984). Because it is an outcome-based pedagogy, it does not place traditional time constraints on the mastery of the content. Rather mastery learning emphasizes student-centered strategies that highlight the need for individualized attention. In addition, this approach requires a level of performance that all students must attain prior to advancing to the next level (Spady, 1977). What distinguishes CBL from other mastery learning approaches is that it has very stringent criteria for what constitutes mastery. It emphasizes assessing students on measurable competencies, meaning that mastery of competencies in CBL is based not only on theoretical or conceptual understanding of the subject matter but also on the ability to apply the knowledge gained in practical settings.

Other terms that have been used to describe CBL in the past include self-paced, student-centered, student- or self-directed, individualized or personalized instruction, outcome-based, performance-based, standard-based, and proficiency-based education (Roe, 2015). These labels are not consistently applied in the literature. Sometimes they are used to refer to CBL while other times they describe similar pedagogies that lack some of the key elements of CBL. Currently, the United States Department of Education (DOE) (Department of Education, 2016) defines CBL as "a structure that creates flexibility, allows students to progress as they demonstrate mastery of academic content, regardless of time, place, or pace of learning." Furthermore, according to the DOE, CBL leads to higher student engagement and can help institutions save both time and money; however, its primary purpose, regardless of the field, is to improve student outcomes. To improve student achievement, desirable skill sets are broken into discrete competencies that build on each other (Brumm, Hanneman, & Mickelson, 2006). In this context competencies are defined as discrete units of behavior or patterns of behaviors suggestive of mastery of certain knowledge or skills (Brumm, Mickelson, Steward, & Kaleita, 2006). An equally important goal of CBL is to accommodate individual differences in pace or style of learning (Evans et al., 2015). CBL achieves both goals by individualizing learning, promoting autonomy, encouraging continuous or life-long learning, and encouraging students to take charge of their own education.

CBL has influenced education in many fields in the United States and abroad. However, the extent to which it is adopted in various programs differs widely. For instance, some programs implement CBL in all their courses, while others fully or partially implement CBL in some courses. An infographic (Infographic: What Competency-Based Education Looks Like, 2014) describes the variation in CBL implementation, which is partially due to the different needs of each institution, by categorizing CBL education as three types: a model viewed as either more conventional, middle of the road, or less conventional. The more conventional model is structured very similarly to the traditional model of higher education, but with some CBL elements implemented. For instance, the course may be time-bound and attract more traditional students; however, well-defined competencies are embedded in the course, and assessments directly evaluate student mastery of them. Middle of the road programs, which tend to be mostly or completely delivered online, have a higher level of mentoring and coaching, and some content may be unbundled from courses. On the other end of the spectrum, less conventional models have no formal courses, a structure known as open entry or open exit. Supplemented by adaptive learning and assessment tools, these programs attract a larger number of nontraditional students than the other two models (Infographic: What Competency-Based Education Looks Like, 2014). Despite the variation in CBL implementation, what distinguishes these programs from other pedagogical structures is that the competencies students are expected to master are clearly communicated and defined (Infographic: What Competency-Based Education Looks Like, 2014) and all instruction and assessments are targeted toward ensuring students master those predetermined competencies.

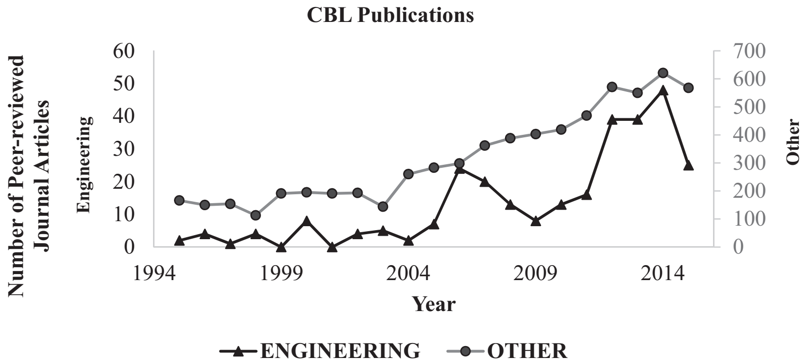

Figure 1 Number of publications on CBL. "Engineering" is plotted on the left Y-axis, and "Other Fields" is plotted on the right Y-axis. Publication count was obtained from EBSCO educational databases. Publications included in the figure were published from 1995-2015, and the keywords that were used to identify relevant publications were [competency-based] AND [engineering].

History of Competency-Based Learning in Engineering Education

Specifically, in engineering education over the past three decades, there has been a shift towards a competency-based approach (Froyd, Wankat, & Smith, 2012), not only in the United States but also in many universities in Europe, Asia, Australia, and South America (Felder, Brent, & Prince, 2011). The focus of engineering higher education has shifted from input to output, where students master predetermined outcomes before moving on to more advanced content (Brumm, Mickelson, et al., 2006). This shift is evident in the number of publications that contain the term *competency-based* in relation to education in engineering and other fields, as indicated in Figure 1. Overall, there has been an increase in the number of peer-reviewed journal articles addressing CBL in many applied fields, including health, medicine, social work, business, and science, technology, engineering and math (STEM) education.

Rationale for Competency-Based Learning Research

Because CBL is an old concept that has been gaining increasing attention in engineering education, the question becomes what caused this shift. It is our view, as informed by the literature, the increased recent interest in CBL is tied to

1. The need to improve recruitment and retention rates while also appealing to a diverse population
2. The pressure to improve student achievement and meet industry's need for more competent engineers
3. The ease of implementation of CBL strategies given technological advances

There is a growing need for skilled technical personnel across multiple industries. In the oil and gas industry, for example, PricewaterhouseCoopers (2009) reports a strong demand for a skilled workforce as the employment opportunities continue to grow. More specifically the American Petroleum Institute reports a shortage of approximately one million skilled workers in the field (Modine & Welsh, 2013). In the nuclear power industry, 35% of the current workers are eligible to retire within the next five years, and an additional 11% of that workforce may be lost through attrition (Speich, McLeskey Jr, & Gad-El-Hak, 2010). The challenge becomes recruiting and retaining enough students to graduate engineers who are prepared to fill these positions and who will value and pursue continuous or life-long learning (Paton, 2002). Based on findings from the literature, CBL has the potential to improve both recruitment, especially the recruitment of nontraditional students, and retention rates. Evidence for the effectiveness of CBL is discussed in the Results Section.

Regarding student needs, higher education institutions in the United States are increasingly enrolling a more diverse population of students. In fact, in the fall of 2008 more than 1 million students enrolled in American Association of State Colleges and Universities were over age 25 (Pelletier, 2010). Many of these nontraditional students enrolled in colleges in the United States deal with the challenges of balancing school obligations with such life obligations as family and job responsibilities (Pelletier, 2010).

Reviewing and recommending good practices for engineering education are essential to address the growing need for competent engineers in such areas as information technology (Sutcliffe, Chan, & Nakayama, 2005) and manufacturing (Roe, 2015). Belkin (2015) reported that many college graduates lack proficiency in the skills needed for many of these jobs, including critical thinking and written communication, a conclusion he based on the Collegiate Learning Assessment Plus (CLA+), which was administered to approximately 32,000 students from 169 institutions. This qualification gap is also applicable to engineering graduates; Jang (2016) identifies opportunities for improving necessary engineering competencies as compared to engineering education frameworks (e.g., ABET), and Daly, Mosyjowski, and Seifert (2014) emphasize the need for creativity, while others (e.g., (Johnson & Wang, 2015; Litchfield, Javernick-Will, & Maul, 2016)) cite the need for improved professional skills. Roe (2015) reported that 82% of employers hiring engineers see a lack of qualified applicants. Harris and Cullen (2009) cite Vest (2007), former president of the Massachusetts Institute of Technology, stating that it is essential for "engineering graduates to write and communicate well, think about ethics and social responsibility, and conceive and operate systems of great complexity within a framework of sustainable development and be prepared to live and work as global citizens" (p. 52). These best practices in engineering education need to be identified and applied to bridge the gap between student education and industry needs and to produce engineers who actively take charge of their continuing education. CBL may offer an effective and efficient way of ensuring that qualification gaps are closed and that students have the necessary qualifications.

Increased internet access and online technological capabilities allow for new ways to address and meet the needs of diverse and nontraditional students. More online courses are being offered and are in more demand, and CBL provides a framework in which online education can be used as the primary instructional method. The CBL structure allows students to learn the material on their own time and at their own pace, a strategy that works well in an online format where students do not have be synchronized with others. Students can complete work they are more competent with quickly or review material they find difficult at a slower pace. Modern learning management systems allow for interactive instruction that can provide instant feedback, direct students to relevant additional content based on responses, and allow them to advance to more difficult content only after competence has been shown. These technological advances allow for a more efficient implementation of CBL.

Theoretical Basis for Competency-Based Learning

There are numerous reasons why CBL is an effective pedagogy. According to Spelt, Luning, van Boekel, and Mulder (2015), CBL is effective, especially in interdisciplinary fields, because it is a student-centered approach that likely leads students to be more autonomous. Autonomy is a major factor in student achievement (Fazey & Fazey, 2001), with research indicating that when students have a higher sense of perceived control of their own education, they tend to perform better (O'Reilly, 2014). In addition, more autonomous students are likely to be better equipped to achieve the necessary competencies in their fields or disciplines and are better at information and knowledge integration. Furthermore, within a CBL context, student motivation increases as a result of increased autonomy, impacting performance (O'Reilly, 2014) and an increased sense of autonomy has been found to be connected to overall satisfaction with the course (Radovan & Makovec, 2015). Based on their results, Radovan and Makovec (2015) recommend using instructional methods that promote student-centered teaching and learning. Similarly, Fazey and Fazey (2001) emphasize that educators are responsible for structuring the learning environment in a manner that promotes autonomous behaviors, asserting that autonomous learning should be one of the outcomes of higher education. Overall, as its primary strategy, CBL seems to rely on the promotion of autonomous learning, which impacts performance directly and indirectly through motivation and positive attitudes towards learning.

By increasing student autonomy and motivation and generating a positive attitude toward learning, CBL is especially useful in STEM education as these three factors play an important role in improving student achievement. Research on STEM students has shown that increased perceived autonomy (Black & Deci, 2000; Hall & Webb, 2014), motivation (Aeschlimann, Herzog, & Makarova, 2016), and positive emotions and attitudes (Pekrun, Hall, Goetz, & Perry, 2014; Pekrun & Stephens, 2010) significantly predict improved performance. The mediation between motivation and positive emotions or attitudes and between perceived autonomy and learning outcomes found for CBL has also been observed in STEM higher education.

Need for a Systematic Review

Generally, in engineering education, there is a lack of systematic literature reviews that integrate the advantages and challenges, assessment strategies, and interaction among pedagogies. Despite the increase in publications in engineering education outlining innovative instructional methods, the number the literature reviews published each year has not followed the same trend over the past decade (Borrego, Foster, & Froyd, 2014). Borrego et al. (2014) illustrated the discrepancy between the numbers of literature reviews in engineering education compared to other fields, finding that compared to psychology, education, and engineering, the linear growth in the number of literature reviews over the past two decades in engineering education has remained almost flat (Borrego et al., 2014). More specifically, while many articles on CBL have been published, most of them in engineering education do not build on what other researchers have reported. There is a lack of integration of evidence, especially when it comes to which methods can be used to enhance CBL's effectiveness in preparing engineering students for the workforce or higher degrees. For new areas of research, ignoring past literature, even if it is limited, may lead researchers to "reinventing the wheel" rather than building on what is already known (Borrego et al., 2015).

Purpose and Research Questions

To address these needs, this review will summarize the research on how CBL has been implemented in engineering higher education programs and assess its effects on student outcomes as well as list current assessment strategies and supplementary tools for improving these outcomes. Additionally, this work will provide recommendations based on those findings for future research and practice. Specifically, this work addresses the following research questions:

1. What are the advantages or disadvantages of CBL in engineering higher education?
2. What methods are used for assessing competencies?
3. How can learning outcomes be enhanced using a CBL approach?
4. What are the challenges and limitations of a CBL approach and how can they be addressed?
5. What are the next steps for researchers to meet the gap in the literature?

Method

Key recommendations from Borrego, Foster, and Froyd (2015) for the appropriate methodology and type of information that should be reported in a literature review were followed in this work. These include:

1. Stating the main objectives of the literature review
2. Specifying and justifying inclusion and exclusion criteria
3. Describing the search and selection process
4. Addressing the limitations of the review

For a more comprehensive list, refer to Borrego et al. (2015, p. 224).

The EBSCO database was used to search for relevant articles, with the Educational Administration Abstract, ERIC, Education source, Education full text (H.W. Wilson), and the British Education Index being selected. The keywords used to identify relevant publications were [competency-based] AND [engineering]. To remain as consistent as possible in the definition of CBL used, only articles that used the term *CBL* were included, meaning those that may have referred to CBL using a different term were excluded because of the lack of certainty that they are referring to the same pedagogy being examined in this review.

The search of publications was limited to peer-reviewed journal articles. This criterion was imposed to ensure the availability and consistency of the quality of publications being reviewed. These articles were published in a variety of journals, including the *European Journal of Engineering Education, International Journal of Engineering Education*, *Journal of Engineering Education*, and *Journal of Professional Issues in Engineering Education and Practice*. These journals represent various national and international perspectives as well as have a relatively high impact factor in engineering education. Further, the articles included were limited to those published between the years 2005-2015. Around 2005 the number of publications on CBL sharply increased compared to previous years (see Figure 1), an increase that may have been caused by technological advances that facilitated CBL or as a response addressing unmet educational needs. The initial search in this time period yielded 105 articles, of which

Table 1 The Classification of CBL Articles Included in This Literature Review

	CBL programs	CBL assessment	Engineering competencies	Total
Quantitative	11	7	5	**23**
Qualitative	0	1	2	**3**
Mixed methods	1	1	0	**2**
Descriptive or commentary	19	10	3	**32**
Total	**31**	**19**	**10**	**60**

37 addressed only K-12 education or doctoral student education; these were excluded. The additional 8 articles that addressed administrative policies or were not relevant to engineering education were also excluded. After this process, 60 articles remained for detailed review.

To examine the distribution of methodological approaches, the articles were first classified as quantitative, qualitative, mixed methods, or descriptive (Table 1). Articles were classified as quantitative if they contained any type of statistical analyses or provided descriptive statistics such as standard deviations, variances or covariances, means and correlations for the constructs under investigation, while articles were classified as qualitative if they included qualitative analyses such as content analysis, grounded theory, or narrative analyses, and mixed methods were articles that used methodologies involving the integration of quantitative and qualitative analyses to address the research questions. Lastly, descriptive or commentary refers to publications that either described a program or assessment protocol, or offered recommendations for practice or research but did not contain any form of statistical or qualitative analyses.

The articles were also classified by their main themes using a content analysis approach. First, the main goal or purpose of each article was examined. Then a coding scheme was applied to qualitatively describe the goals of each. Once all the articles were coded, themes were extracted based on commonalities among the codes assigned to each article. This process was repeated to reduce the number of themes until a coherent and limited set emerged. These themes included CBL programs, CBL assessments, and Engineering Competencies. CBL Program articles outline, describe, or analyze the conversion of traditional programs to CBL programs, or the addition of supplementary pedagogical strategies to existing CBL programs. These articles generally focus on the practical aspects of implementing CBL strategies in engineering programs. CBL Assessment articles describe, outline or analyze competency-based assessment strategies, emphasizing how to define and assess mastery of competencies within a CBL framework. Lastly, articles in Engineering Competencies list general competencies that higher education engineering programs should target as part of CBL outcomes, discussing the types of skills outside of content area knowledge, such as teamwork and communication skills, that CBL programs should include.

Results and Discussion

A content analysis approach was again used to assess the literature reviewed, with the following categories emerging: assessments, programs, supplementary pedagogies, and professional competencies. The following two sections present a survey of the advantages and disadvantages or challenges of CBL in engineering education based on the programs summarized in Table 2. Assessment strategies of CBL are discussed followed by a summary of additional

Table 2 CBL Assessments

Author (year)	Topic	Competencies	Assessment strategy	Findings/conclusions
Al-Thani, Abdelmoneim, Daoud, Cherif, & Moukarzel (2014)	Engineering	Professional Content-based	Online assessment	Online assessment management systems create a sustainable system for continuous assessment.
Anwar (2012)	Civil engineering	Professional	Online survey system	Incorporation of peer feedback led to higher student satisfaction and improvements in learning outcomes in civil engineering courses.
Badilla Quintana, Carrasco Saez, & Prats Fernandez (2014)	Technical engineering	Professional Content-based	Personal learning environment portfolios	PLE portfolios promote higher competency development, increase motivation and collaborative learning.
Baughman, Brumm, & Mickelson (2012)	Industrial Technology	Professional	360 assessments	Overall, peer evaluations were lower than self-evaluations. 360 assessments helped students improve their outcomes.
Blicblau (2008)	Engineering & industrial sciences	Professional Content-based	Electronic portfolios	Electronic portfolios incorporate continuous self-evaluation and are effective in motivating students to oversee their own learning.
Brumm, Hanneman, et al. (2006)	Engineering	Professional	Online assessment	Workplace competencies are difficult to acquire in the traditional classroom setting.
Brumm, Mickelson, et al. (2006)	Agricultural engineering	Professional Content-based	Electronic portfolios	Targeting workplace competencies in an experiential learning environment improved the quality of education for engineers.
Carbonell, Lanzo, Ion & Cano (2012)	Engineering	Content-based	360 assessments	Instructor's feedback and self-evaluation were essential in improving learning attitudes and outcomes.
Chong & Ng (2013)	Chemical engineering	Professional Content-based	Group writing assignments & presentations	Most instructors agree that through these assessment methods, students achieved the basic competencies targeted. The time constrains presented a challenge.
El Falaki, El Faddouli, Idrissi, & Bennani (2013)	Computer science	Content-based	Adaptive formative assessment	An adaptive assessment approach identifies the learners' competency levels and guides them to reach their educationally drawn output profile.

Table 2 (continued)

Author (year)	Topic	Competencies	Assessment strategy	Findings/conclusions
Grodzicki & Madigan (2011)	Engineering	Content-based	Lab tasks practicals	Practicals and hands-on assessments lead to more student enthusiasm and resulted in significantly better attendance.
Gron, Bradley, McKenzie, Shinn, & Warfield Teague (2013)	Chemical engineering	Content-based	Formative and summative assessments	The use of multiple assessments was time-consuming but allowed for an accurate evaluation of the students' competencies and the program's strengths.
Montfort, Brown, & Pegg (2012)	Engineering	Professional	Team Citizenship Assessment Instrument	The qualitative analysis revealed that students believed the TCAI measured competencies that are aligned with their \ institutions' goals
Petrova, Tibrewal, & Sobh (2006)	Engineering	Content-based	Tests, quizzes, assignments and projects	The assessment tools used prove to be good indicators of mastery for the competencies of interest.
Ro, Merson, Lattuca, & Terenzini (2015)	Engineering	Professional	Contextual Competence Scale	The 4-item scale was psychometrically sound as indicated by factor analyses and validity calculations.
Sabri et al. (2013)	Mechanical engineering	Professional Content-based	Big Picture Assessments	Big Picture Assessment is a comprehensive monitoring tool that applies to psychomotor, cognitive, and affective components.
Seniuk Cicek, Ingram, & Sepehri (2014)	Engineering	Professional Content-based	Formative assessments	Faculty members tend to assess content-based competencies a lot more frequently compared to professional competencies.
Sluijsmans, Prins, & Martens (2006)	Engineering	Content-based	Realistic whole tasks	This type of assessment enables the construction of realistic whole tasks rather than advocating for an education that breaks skills into discrete parts.
Tsugihashi et al. (2013)	Process dynamics	Content-based	Competency scale	The test was psychometrically assessed and validated. This approach allows for appropriate measurement of students' competencies in higher education.

pedagogical strategies that have been reported to be used in the CBL framework to enhance instruction. Next, based on the literature review, professional competencies are identified and summarized, and finally, gaps in the literature, recommendations for research and practice, as well as directions for future research are discussed.

Survey of Advantages of Competency-Based Learning

Retention and Recruitment The advantages of CBL in engineering education are numerous. In an engineering curriculum, later topics build heavily on previous content, meaning that students struggling in prerequisite materials will ultimately struggle to master later content (Nelson, 2013). Falling behind not only affects the student learning outcomes but can also impact retention rates. The structure of CBL requires students to continuously review fundamental content not only for the course they are currently enrolled in but also for future courses. When students are in the habit of reviewing prerequisite material, performance is improved, and so is retention as the chance of falling behind is reduced (Nelson, 2013). A competency-based structure ensures that students master prerequisite materials before moving on to more complex content, thereby improving not only learning outcomes but the learning experience of each student. Ensuring that students have a positive learning experience and don't fall behind in courses is likely to reduce the probability that those students will drop out. The effects of CBL on retention are highlighted in the literature, with several CBL programs noting or anticipating lower dropout rates and higher attendance (Silva, Almeida, Martins, Baptista, & Campos Neves, 2013; Witt et al., 2006)

Diverse Needs The CBL framework is especially useful in the United States where higher education institutions are increasingly serving a more diverse student body (Roe, 2015). One way of addressing the needs of this nontraditional student population is to integrate remote, mobile or online learning. Integrating these approaches in the CBL structure is not only feasible but recommended as it facilitates student-centered, individualized learning paths (Hsu & Ho, 2012). Many CBL programs have been transitioned to completely web-based (De Los Rios-Carmenado et al., 2015; Mohtar et al., 2007; Sommaruga et al., 2007) or hybrid structures integrating a combination of face-to-face and online components (Quarless & Nieto, 2012; Rikakis et al., 2013). Some of these online programs utilize modules as the primary form of content delivery and assessment (Hsu & Li, 2015; Mohtar et al., 2007; Roe, 2015; Sutcliffe et al., 2005). Many nontraditional students must balance major life responsibilities in addition to academic work. Having a program that offers distance education options and allows them to progress at their own pace, ensuring that they do not fall behind, is ideal for these students. The flexibility of CBL has the potential to increase nontraditional student enrollment in engineering programs. Based on the literature reviewed, CBL is an appropriate strategy for today's diverse student body.

Student Outcomes and Attitudes The CBL structure results in more positive student attitudes regarding the courses and curriculum (Khoumsi & Gonzalez-Rubio, 2006; Sutcliffe et al., 2005). Overall, both students and educators seem to respond positively to the implementation of CBL in engineering courses. Evidence also suggests that student outcomes are improved, with Nelson (2013) finding that students in CBL courses performed significantly better than students in traditional courses. In addition, research has found that in a CBL structure, student knowledge is increased (Dinsmore et al., 2008) and performance on achievement assessments is improved (Canaleta et al., 2014; Cheng, 2006). Research also suggests that student attitudes towards the learning experience are very positive in CBL courses (Canaleta et al., 2014) and they tend to be more enthusiastic about learning than their counterparts in traditional courses (Sutcliffe et al., 2005).

Industry Needs As for industry demands for more qualified engineers, research suggests that implementing CBL in engineering programs is an appropriate way of meeting those needs. The number and types of competencies required of applicants to be competitive in the job market is changing, and the structure of CBL can adapt easily to that change (Sutcliffe et al., 2005). Additional competencies can be implemented in the curriculum by breaking them into discrete units that can be assessed individually. An added benefit of CBL in preparing students for the workforce is its effectiveness in promoting continuous learning. CBL places a strong emphasis on self-directed continuous learning beyond the classroom, and this life-long learning has been identified as one of the key characteristics needed for success in industry. Sutcliffe et al. (2005) found that students in CBL contexts had more positive attitudes about continuous learning. Furthermore, some researchers suggest that CBL can be effective in improving not only the knowledge-based competencies needed for the workforce but also the professional competencies that are equally important for engineers in the current global economy (Bensah et al., 2011; Dinsmore et al., 2008; Hernandez et al., 2009; Spelt et al., 2015; Woodrow et al., 2013). Overall CBL's appropriateness for today's engineering education is evident in research that has found that students who graduate from CBL programs are successful in finding internships (Witt et al., 2006) and employment upon graduation (Silva et al., 2013; Witt et al., 2006).

Assessments and Structure As for advantages in the classroom, CBL informs and guides assessments, leads to a mutual understanding between faculty and students, and helps direct the design of learning materials (Baughman et al., 2012). In CBL, instructors clearly communicate to the students the competencies to be taught and assessed. Consequently, students have a clear roadmap for successfully completing courses. When students are aware of the learning objectives and goals from the beginning, and instructors are directly assessing pre-established competencies, there is less student confusion or dissatisfaction with the courses. The clear communication of objectives makes engineering instruction more time- and cost-efficient for instructors, students, and higher education institutions (Di Trapani & Clarke, 2012). Furthermore, the flexible structure of CBL allows for the implementation of additional pedagogical strategies that enhance student learning and student outcomes, including project-based learning (Abdulaal et al., 2011; Dinsmore et al., 2008; Sommaruga et al., 2007), problem-based learning (Veldman et al., 2008; Woodrow et al., 2013), experiential learning (Bensah et al., 2011; Di Trapani & Clarke, 2012; May et al., 2015), simulations/virtual reality (Lin et al., 2013; Tang, 2014), team-based learning (Oladiran et al., 2011), and scaffolding (Evans et al., 2015).

Survey of Disadvantages and Challenges of Competency-Based Learning

Assessing Professional Competencies Although CBL has many benefits, there are also documented disadvantages and challenges. There is disagreement in the literature as to whether CBL is effective in teaching students professional skills such as communication, prioritizing, working under pressure, and teamwork (Felder et al., 2011; Gharaibeh et al., 2013; Walther, Kellam, Sochacka, & Radcliffe, 2011). Research suggests that engineering students often graduate academically prepared but lack the professional skills necessary for quality professional performance and career growth (Evans et al., 2015). As Roe (2015) reported, technical engineering courses seldom help engineering students develop noncontent-based skills, which are then learned only incidentally or "accidently" (Walther et al., 2011). These professional skills and contextual competencies are essential in the workforce but are difficult to define and break into units that can be taught and assessed. This inability to discretize professional skills along with their integration into other curricular aspects makes it challenging to teach them using CBL. Research also suggests that engineering students lack key aspects of contextual competence and feel less confident in their contextual competence than in other competencies (Ro et al., 2015). However, technical engineering competencies alone are not sufficient in the current work environment (De Los Rios-Carmenado et al., 2015), meaning the importance of developing the appropriate skills and attitudes needed for the workplace should be equally emphasized (Woodrow et al., 2013). Engineering graduates are now required to be proficient not only in their content areas but also to be effective communicators who can utilize their context to inform decisions (Blicblau, 2008). However, it can be argued that deficiency in professional competencies is a result of poorly designed curricula rather than a shortcoming of the CBL pedagogy.

Compartmentalization Another limitation of CBL is that the content and skills are divided into discrete competencies, suggesting that this approach can limit the ability of the student to see the "big picture." Thus, students end up having a strong grasp of each unit of information but lack the ability to synthesize content. In other words, CBL may compartmentalize knowledge, making it difficult for students to learn how to integrate that knowledge (Walther et al., 2011). According to Burke (1989), one of the main criticisms of CBL as it gained more popularity in teacher education in the early 1970's was that it treats each skill as no more than the sum of its parts. This compartmentalization can be addressed by assessments that involve integration of competencies, including comprehensive exams and end of the year projects/assignments that require an understanding and mastery of not only each competency but also the relationships among those discrete units. Another way to address this limitation is to explicitly link competencies to a larger framework. For instance, ABET (2016) requires that programs link student educational outcomes to predetermined objectives. Doing so can help the students link each competency or skill to a larger framework.

Implementation Based on previous research, there are several challenges that educators encounter when transforming an engineering program from a traditional instructional format to a competency-based framework. Any time an instructional method changes, more time and effort must be invested into making the transition, and the transition to CBL can be difficult for instructors and students who are used to traditional classrooms and instructional settings (Rikakis et al., 2013). For instructors, it is time intensive to break materials and skills into discrete competencies that build upon each other and construct objective assessments for those competencies (Brumm, Mickelson, et al., 2006). Instructors must structure the course in a way that allows students who fall behind to catch up rather than move forward without mastering previous course materials (Roe, 2015). Doing so can be difficult when teachers have to follow a certain pace to cover all course materials within a semester. Instructors also must dedicate more of their time outside the classroom to provide opportunities for students to make up work they did not master. As Roe (2015) pointed out, especially with open entry/open exit programs, faculty members must be engaged in monitoring, mentoring and managing students who are taking different courses on different schedules during the same semester. Thus, faculty members need to shift their expectations and their allocation of time to different activities.

As for students, many are used to moving on to new material after exams or evaluations even if they haven't mastered the previous information. The idea that they must go back and relearn the material first before moving on can be frustrating at the beginning. In addition, the student-centered focus of CBL gives students more autonomy and responsibility, which may be a difficult transition at first (Evans et al., 2015). As with any change, there are initial demands and challenges. However, based on the literature, once instructors and students have successfully managed the learning curves, the benefits to the learning experience are worth the time and effort. Once instructors have restructured the way they spend their time, the structure of CBL results in a more efficient use of it (Di Trapani & Clarke, 2012).

Assessments Strategies

The literature suggests that CBL assessments vary widely. Currently, there are no uniform or agreed upon assessments for engineering competency-based courses; practices differ widely among universities, and little work has focused on identifying best practices. This review provides an overview of assessment strategies that have been reported in the literature, including their strengths and weaknesses, in Table 3, which contains summaries of articles discussing different assessment strategies and lists the competencies they are meant to evaluate as well as major findings. Competencies are divided into professional and content-based. Content-based competencies are related to specific information that pertains to a subject area, while professional competencies, on the other hand, are general knowledge and skills necessary for success in the workplace.

The most commonly mentioned assessments in the literature were paper and pencil exams, such as unit, take-home, comprehensive, or lab exams (Bensah et al., 2011; Gharaibeh et al., 2013; Nelson, 2013; Witt et al., 2006). Group work, such as projects and presentations, has also been widely used (Quarless & Nieto, 2012). In addition to exams and group work, portfolios, online assessments, 360 degrees assessments, and surveys/questionnaires have also been discussed in the literature.

Portfolios Portfolios are a purposeful collection of students' work exhibiting their mastery of several competencies. Their purpose is to allow employers/educators to use them as an assessment or evaluation tool as well as tool for providing feedback and to make students aware of their achievements. Competency-driven portfolios in engineering programs have been successfully implemented at a variety of institutions, including the Rose-Hulman Institute of Technology, the University of Texas at Austin, the University of Wisconsin–Superior, and Alverno College, Wisconsin (Brumm, Mickelson, et al., 2006). The way portfolios are graded lends itself very well to the CBL approach. All competencies are mapped to outcomes, and each aspect of the portfolio can be supplemented by the student's own self-reflection and ratings of the competencies each artifact represents (Brumm, Mickelson, et al., 2006). Electronic portfolios as an assessment method, especially in capstone courses, are also common in the literature. These portfolios, which include visual, digital/electronic, oral, and paper content, are a way to evaluate not only knowledge-based competencies but professional competencies as well such as effective communication, organization, and team work (Blicblau, 2008).

Of the articles reviewed for this paper, five list portfolios as a method of assessment. Some use them to increase motivation and autonomy in learning while giving students the opportunity to demonstrate such professional competencies as writing and communication skills (Badilla Quintana et al., 2014). One of the benefits of portfolios is that they are self-directed and must involve self-reflection. Further, they encourage students to be responsible for their own learning (Blicblau, 2008) and engage them in the learning process by allowing them to choose which works to select and present (Brumm, Mickelson, et al., 2006). In addition, revisiting past work often helps improve earlier work as well as the quality of later work (Brumm, Mickelson, et al., 2006). Electronic portfolios have been used as a way of

Table 3 CBL Programs

Author (year)	Subject	Instruction	Assessment	Findings/conclusions
Abdulaal, Al-Bahi, Soliman, & Iskanderani (2011)	Engineering design	FTF lecture	Assignments & reports	Addition of PBL in CBL courses results in improvement in students' learning outcomes.
Bensah, Ahiekpor, & Boateng (2011)	Chemical engineering	FTF lecture Online modules	Exams, quizzes, reports & presentations	CBL is essential in improving technical and professional competencies necessary for the workplace.
Canaleta et al. (2014)	Communication technology	Online modules	Module evaluation	Program improved students' academic performance, professional competencies and improved attitudes towards the learning experience.
Chang & Chi-Cheng (2006)	Microprocessor laboratory	Online modules	Exams	Implementing CBL web learning significantly improved students' scores on achievement assessments.
Dallosta (2011)	Defense engineering	Digital simulations	Exams and gaming/ simulation results	CBL is the best method to enable students to learn and demonstrate the behaviors and knowledge necessary to succeed in engineering.
De Los Rios-Carmenado, Rodriguez Lopez, & Perez Garcia (2015)	Engineering	Cooperative learning Online teaching	360 assessments, exams and portfolios	Technical engineering competencies alone are not sufficient for today's global economy.
Di Trapani & Clarke (2012)	Biological engineering	FTF lab Online workshops	Lab performance assessment	CBL courses equip students with skills and knowledge needed for employment and are cost efficient for the institution.
Dinsmore, Alexander, & Loughlin (2008)	Engineering design	NA	Open-ended items	CBL course contributed to a rise in students' declarative knowledge, but not their procedural or principled knowledge of engineering design.
Evans et al. (2015)	Professional competencies	Online modules	Open badge system	The new system was a learning curve for students and instructors.
Gharaibeh et al. (2013)	Wireless communication	Online modules, workshops & simulations, FTF labs.	Exams, assignments, projects.	Recommendations to improve engineering education include considering the technical contents as well as professional skills.
Hernandez, Palmero, Labrador, Alvarez-Vellisco, & Bonache (2009)	Electrical engineering	Student-centered lecture labs	Formative assessments Lab performance	CBL significantly improved students' performance on formative assessments and laboratory assessments of all competencies.

Table 3 (continued)

Author (year)	Subject	Instruction	Assessment	Findings/conclusions
Hsu & Ho (2012)	Electrical engineering	FTF lecture Online modules	Module, pretest & exit tests & comprehensive exam	Students receiving automated feedback based on module assessment performance performed significantly better on comprehensive exam.
Hsu & Li (2015)	Information engineering	Mobile learning (ant genetic algorithm)	Formative assessments	CBL mobile learning can provide each learners with individualized learning paths depending on their pace and their baseline.
Khoumsi & Gonzalez-Rubio (2006)	Electrical & computer engineering	Online tutorials & FTF lab	Formative & summative written assignment	Student feedback has been very positive, and the implementation of PBL within a CBL context encouraged autonomous learning.
Lin, Duh, Li, Wang, & Tsai (2013)	Construction	Mobile collaborative augmented reality	Multiple choice exam	The augmented reality system in CBL context serves as a supportive tool to aid student learning and lead to more positive outcomes.
May, Wold, & Moore (2015)	Engineering	Online synchronized course and role playing/simulations	Observations Role playing assessment	Involving students from diverse cultures in online role playing enhances students' cultural competencies.
Mohtar, Tong, Jin-Yong, Engel, & Fast (2007)	Environmental systems	Web-based models	Pre- and post- surveys that match learning outcomes	Web-based modeling in CBL enhances undergraduates' understanding of subject matter.
Nelson (2013)	Thermodynamics	FTF lecture	Homework, quizzes, exams	Students in CBL courses performed significantly better on final examination compared to traditional course.
Oladiran, Uziak, Eisenberg, & Scheffer (2011)	Engineering manufacturing	Virtual teams	Questionnaire-based survey	Using virtual teams in a CBL context facilitates multidisciplinary teamwork at an international level.
Quarless & Nieto (2012)	Chemical engineering	Hybrid structure	Quizzes, exams & discussion boards	Converting a CBL course to be a more interdisciplinary and web-facilitated pedagogy plays a role in improving learning outcomes.
Rikakis, Tinapple, & Olson (2013)	Art engineering	Hybrid lectures	360 assessments	Transitioning to CBL instruction and assessment from traditionally structured courses was difficult; however, retention was improved.
Roe (2015)	Manufacturing engineering	Online modules open lab	Module quizzes, lab and comprehensive exams	CBL meets the needs of nontraditional students, is expected to increase enrollment and retention, but conversion to CBL was a learning curve.

Table 3 (continued)

Author (year)	Subject	Instruction	Assessment	Findings/conclusions
Silva et al. (2013)	Robotics	FTF lecture and lab	Homework & exams	CBL has achieved high retention, and students who graduated from the program have been successful in securing jobs.
Sommaruga, De Angelis, Sommaruga, & Angelis (2007)	Building automation	Hybrid	Dialogue & discussions	Resistance in accepting the e-learning approaches by both instructors and students is partly due to lack of confidence in technical abilities.
Spelt et al. (2015)	Food quality management	FTF lecture	360 assessments	Compared to traditionally structured courses, students perceived CBL courses as contributing more to their achievement of intended outcomes.
Sutcliffe et al. (2005)	Science and information systems	Online modules	Skill portfolios	Students are more enthusiastic about learning and have a more positive attitude about continuous/life-long learning in this CBL program.
Tang (2014)	Electrical engineering	Interactive simulator-based pedagogy	Multiple choice quizzes	Interactive simulator approaches in CBL programs overcome some of the limitations of traditional engineering programs.
Veldman et al. (2008)	Engineering	NA	Behavioral assessments	Integrating problem-based learning is effective in promoting the development of knowledge-based and professional competencies.
Witt et al. (2006)	Chemical engineering	Expert & student led teams	Final reports, presentations and projects.	CBL led to higher attendance, lower dropout, and higher internship and employment placements.
Woodrow, Bisby, & Torero (2013)	Safety engineering	Lecture, videos, and lab	Design problems Peer, self and expert critique	Technical knowledge should not overshadow the importance professional skills and attitudes.
Zou & Ko (2012)	Chemical engineering	FTF lab	Quantitative and qualitative assessments.	Implementing team-based work resulted in social loafing and student conflict. Educators should focus on team work and conflict resolution strategies.

Note. FTF refers to face-to-face.

encouraging self-evaluation, increasing motivation, and mimicking the type of assignments common in the workplace (Blicblau, 2008; Brumm, Mickelson, et al., 2006). In addition, e-portfolios can be easily shared, at the discretion of the student, with different instructors, peers, and current and potential employers, or as part of an application for graduate work. They are an efficient method of demonstrating competency to various individuals, and the material can be easily published on databases or checked for plagiarism.

360 Degree Assessment Another common approach to assessment involves utilizing feedback from multiple sources, such as self, peer, and expert or instructor feedback, a strategy known as 360-degree assessment. This flexible, low-cost assessment tool that can be applied in any educational setting involves the systematic integration of feedback about a student's performance from various sources. In classroom settings, feedback may be obtained from the individuals whose work is being assessed, their peers, instructors and other faculty members, or external experts in the field. Its primary purpose is to improve learning by providing the students with various perspectives of the strengths and weaknesses of their work. The benefits of 360 degree assessments are present regardless whether the feedback from different sources is repetitive or unique. If feedback is repetitive, it serves to reinforce the credibility of it; if it is unique, it adds additional information about a student's performance.

According to the literature, 360-degree assessment strategies have been used either exclusively or in conjunction with other methods to enhance the acquisition of content-based skills and professional skills such as communication, critical thinking, and time and task management. In some cases, 360 degree assessment was a way of evaluating students' portfolios or was used combined with traditional methods of evaluation such as quizzes, tests, projects and presentations (De Los Rios-Carmenado et al., 2015; Zou & Ko, 2012). Varying the sources of feedback aided in improving learning outcomes (Baughman et al., 2012; Carbonell et al., 2012; Spelt et al., 2015; Woodrow et al., 2013). Specifically, regarding professional competencies, Woodrow et al. (2013) and De Los Rios-Carmenado et al. (2015) suggested that 360 degree assessments may be one way of promoting professional skills and attitudes. Of the articles reviewed, six utilized or advocated the use of 360 degree assessments (Baughman et al., 2012; Carbonell et al., 2012; De Los Rios-Carmenado et al., 2015; Rikakis et al., 2013; Spelt et al., 2015; Woodrow et al., 2013).

Online Assessments The use of electronic or online assessment tools is also common in the programs surveyed in the literature (Anwar, 2012; Brumm, Hanneman, et al., 2006; Sutcliffe et al., 2005). Online assessments can be built into online modules as a way of evaluating pre-existing knowledge before beginning a new unit and determining the extent of learning at the end of the module in the form of a post-test (Mohtar et al., 2007). They can also be in the form of electronic quizzes and exams that students take as soon as they finish a module or a section of a module, with their performance on these evaluations determining whether they have sufficient mastery of the content to move to the next section or module (Gharaibeh et al., 2013; Roe, 2015). Some programs utilize simulation, virtual reality, or online role playing as both an instructional method and an assessment tool. For instance, the score of an online educational game can be interpreted as a student's ability to complete the tasks needed to score points in the game. These tasks can require specific area knowledge and/or professional competencies such as teamwork and communication skills (Dallosta, 2011; May et al., 2015). Furthermore, online testing can accommodate computer adaptive evaluation of student knowledge and can provide students with automated feedback based on the module assessment (Hsu & Ho, 2012). Online assessments can be a time-efficient and sustainable system of continuous monitoring of student progress (Al-Thani et al., 2014).

Table 4 Number of CBL Programs That Employ Additional Pedagogy in CBL Framework

Pedagogy	#Programs
Experiential learning	14
Field/Service learning	1
Collaborative learning	3
Problem-based learning	6
Project-based learning	9
Scaffolding	1
Team-based learning	7

Note. $N = 60$.

Surveys/Questionnaires Most of the strategies listed above focus on technical competencies rather than professional competencies. To address this need, surveys and questionnaires have been developed to capture students' levels and improvement in these competencies. Although they are much less frequently mentioned in the literature, they can still play an important role in CBL assessment. For example, Montfort et al. (2012) utilized the Team Citizenship Assessment Instrument (TCAI) to assess the professional competencies aligned with their institution's goals, while Taskinen, Steimel, Gräfe, Engell, and Frey (2015) used a competency scale that was psychometrically assessed and validated to capture content-based competencies in a Process Dynamics course. Scales, surveys, and questionnaires can be used either as written feedback or, more efficiently, as an online tool to capture an array of indicators of student or program success.

Additional Pedagogical Strategies

Most of the literature reviewed also addressed other pedagogical approaches and strategies in the context of CBL in engineering education. The summary of these strategies below focuses on the benefits and drawbacks of using them in addition to CBL. The most common pedagogical strategies include experiential learning, project-based learning, problem-based learning, and team-based learning. Table 4 lists different pedagogical strategies in alphabetical order including the number of programs of those reviewed ($N = 60$) that employed each. If programs utilized more than one of the strategies listed, they were cross-listed.

Experiential education can be broadly defined as a philosophy and methodology in which educators purposefully engage with the learner in direct experience and focused reflection to increase knowledge, develop skills, and clarify values (Brumm, Hanneman, et al., 2006). Experiential learning activities, key to successfully preparing students for the workplace, have become more wide-spread in the last decade for improving student learning and fostering deeper understanding (Grodzicki & Madigan, 2011). According to Bogue, Shanahan, Marra, and Cady (2013), a successful engineering program must involve hands-on activities, interdisciplinary activities, problem solving, teamwork, business skills, real-world engineering experience, and contact with experienced students and faculty. One widely used experiential learning activity is laboratory work, which was common in the literature reviewed. Di Trapani and Clarke (2012) maintained that students who are in CBL courses supplemented with experiential learning activities such as lab work are more equipped with the research project development skills and higher order skills and knowledge needed for employment or graduate education. Experiential learning can come in the form of virtual reality or simulation activities

(Tang, 2014). Augmented reality systems serve as supportive tools to aid student learning and lead to more positive outcomes (Lin et al., 2013). Virtual reality can include online or web-based laboratories (Chang, 2006) and web-based modeling (Mohtar et al., 2007). According to Bensah et al. (2011) experiential learning in the context of CBL education not only improves the skill-based outcomes but can also be used to enhance the acquisition of professional skills.

Project-based and problem-based learning are other widely used and well-known pedagogies. Abdulaal et al. (2011) asserted that project-based courses are effective in exposing students to engineering design and promoting higher levels of learning. Their results indicated that hands on project-based learning results in improved student learning outcomes. Gharaibeh et al. (2013) used project reports as an assessment and lab work as part of projects for a master's program in telecommunication engineering. Problem-based learning promotes thinking strategies and domain knowledge by leading students through the experience of solving an open-ended problem. It has the potential to improve students' professional competencies and their probability of success in the workplace (Canaleta et al., 2014; Veldman et al., 2008) by encouraging students to think "outside the box" (Woodrow et al., 2013).

Another popular approach that has been frequently cited is team-based learning (TBL), an instructional strategy that focuses on utilizing student collaboration to apply and integrate information. It allows the instructor to divide students into small groups and give them each a task requiring the utilization of relevant knowledge and competencies. The instructor in this case acts as an expert advisor, providing feedback to the teams throughout the task. TBL can be combined with project-based learning by assigning teams of students different projects with the aim of improving overall learning outcomes (Abdulaal et al., 2011). Team-based learning has also been used in online settings. For example, Oladiran et al. (2011) proposed the use of global engineering teams including students located in different countries and across multiple time zones working on solving practical engineering problems. Their approach has the added benefit of promoting multicultural awareness and internationalism in higher education. One of the challenges involved in implementing team-based education is social loafing, the practice of team members relying on the work of others rather than contributing a reasonable effort to the endeavor. The results from Zou and Ko (2012) revealed that in teams, social loafing widely existed but students tended not to report it or hold the loafers accountable. Another issue that they encountered was conflict resolution within teams. Instructors should have a strategy for both addressing social loafing and equipping students with the tools to address conflicts within teams if TBL is used. However, collaborative learning (CL), which is a similar approach, seems to mitigate some of the limitations of TBL (Canaleta et al., 2014; Dinsmore et al., 2008; Lin et al., 2013).

Other strategies worth noting that have been used in conjunction with CBL include scaffolding and fieldwork. Scaffolding, which provides directions to the student that reduce the complexity of a task and highlight its important features, is meant to reduce student frustration and guide students in the learning process (Belland, Walker, Olsen, & Leary, 2015). In the context of engineering education, scaffolding can be implemented in an online module format (Evans et al., 2015). As for field work, including service learning activities that expand the learning experience by meeting certain needs of a community (Tapp & Macke, 2011) can also be implemented in the context of CBL in engineering education. Bensah et al. (2011) advocated field work to enhance the quality of engineering education. The literature suggests that these strategies help give students a well-rounded learning experience.

Professional Competencies in Engineering

A bulk of the literature on CBL application in engineering education addresses the noncontent-based competencies that all engineering students should possess by the time they graduate in all areas of engineering across the globe (see Table 5). The articles included in this literature review are only a subset of a much larger body of literature that discusses how to determine which professional or contextual competencies engineering students should have and how to improve the achievement and assessment of those competencies. In this review, common professional competencies are briefly summarized and discussed.

First, any engineering education pedagogy, including CBL, should not only be effective in producing engineers proficient in technical knowledge and skills but also those ready to compete in a global economy by possessing the ability to successfully work with diverse groups of people in diverse contexts. The right pedagogy is ineffective if it is not teaching the necessary skills. Although knowledge-based competencies vary across different disciplines, there is a general set of professional competencies that all engineers should have upon receiving their undergraduate degrees. These professional competencies are essential for students to be competitive and competent engineers in the workplace. The National Academy of Engineering (2004) outlined the following set of outcomes that prepare engineering graduates for work in a dynamic, interdisciplinary, and global workplace:

1. Leadership skills
2. Teamwork skills
3. Communication skills
4. Reflective behavior practice
5. Interdisciplinary skills
6. Recognizing disciplinary perspective
7. Contextual awareness
8. Design skills

Similarly, Ball et al. (2012) extracted a set of 23 general professional competencies based on research, literature reviews, and expert opinion. These competencies can be divided into:

1. Disciplinary, including the ability to interact with engineering students from diverse cultures and understanding and respecting engineering practices that are foreign

2. Organizational, most importantly the ability to collaborate with others towards a common goal as a team member

3. General, such as appreciating cultural difference and practicing tolerance and flexibility

The most strongly emphasized competencies have been effective communication (Baughman et al., 2012; Grodzicki & Madigan, 2011) and contextual competencies (Ro et al., 2015) such as:

1. Knowledge of social, cultural, political, economic and environmental contexts that may affect a solution to an engineering problem

Table 5 Examples of Professional Competencies in the Literature

Author (year)	Competencies	Conclusions
Ahn, Annie, & Kwon (2012)	Ethical issues, problem-solving skills, interpersonal skills, leadership, adaptability, collaborative skills, safety issues, interdisciplinary application, practical awareness, technical skills, computer skills, estimating/scheduling skills, communication, and environmental awareness.	These competencies were identified as important in the literature for Construction Graduate from an industry perspective.
Ball et al. (2012)	Cross-cultural communication, cross-cultural dispositions, world knowledge, cross-cultural teams and engineering specific cross-cultural competencies	The categories contained 23 competencies, which were validated by professionals, industry experts and academics.
Bish, Newton, Browning, O'Connor, & Anibaldi (2014)	Self-management/personal effectiveness, achievement and action, problem solving, influence and persuasion, teamwork, leadership, communication, corporate and social responsibility, emotional awareness, and coping with pressure.	The nine clusters of competencies identified provide the skills engineers need to work efficiently in the global industry.
Downey, Lucena, & Moskal (2006)	Knowledge of cultural difference between engineers and nonengineers, ability to analyze how experience shapes priorities and respect for diverse cultural perspectives on problem solving.	These learning outcomes all contribute to teaching students how to effectively work with individuals from different culture, which is essential in supporting the global learning of engineering students.
Jesiek et al. (2014)	Foreign language proficiency, self-evaluation, cross-cultural adaptability, intercultural development, personal autonomy, perceptual acuity, flexibility and openness, and emotional resilience	The article discusses orientation strategies designed to improve student readiness for global practice and suggests assessment tools for necessary global competencies.
Knight (2014)	Professional values, professional skills, broad perspective, teamwork, leadership skills, communication skills, reflective behaviors, interdisciplinary skills, recognizing disciplinary perspectives, and contextual awareness.	The E2020 outcome survey consisted of 51 items that rated the respondent's abilities on engineering-related knowledge and skills. The purpose of the article was to examine the characteristics of students who scored high on the survey.
Lantada, Bayo, & De Juanes Marquez Sevillano (2014)	The ability to work in multidisciplinary teams, the capability of efficient oral and written communication, the pursuit of life-long learning, creative thinking, the acquisition of ethical principles and the capability of applying them.	Strategies to promote the development of professional skills are discussed. Challenges and problems that typically arise when implementing those strategies are also discussed and several solutions are proposed.
Lohmann, Rollins, & Hoey (2006)	Ability to communicate in a second language, demonstrate comparative global knowledge, intercultural assimilation, and effective communication	This article outlines a model that conceptualized global competence for engineering students and ways to assess those competencies.

Table 5 (continued)

Author (year)	Competencies	Conclusions
Lunev, Petrova, & Zaripova (2013)	Include ability for abstract thinking, work in teams, manage time, resolve conflict, work autonomously, appreciate multiculturalism, and capacity to generate innovative ideas	The goal was to develop a list of professional competencies for all engineering programs in Russia.
Walther et al. (2011)	Integrate knowledge of ethical behavior, working under pressure, & prioritizing tasks	These competencies are acquired mainly as an artifact of the structure of the courses and interactions with faculty. Rather than being targeted by instructors, they tend to be taught incidentally.

Note. This table summarizes some of the literature on professional competencies, including global and contextual competencies

2. Knowledge between technological solutions and the context in which they are operating
3. Ability to use knowledge from different cultures, social values, political systems, economic conditions, and environmental issues to guide engineering solutions

Despite the emphasis on the importance of these competencies, there is a gap in the literature on clear purposeful strategies for helping students acquire them and appropriate ways for assessing them. In fact, in many programs, those competencies are acquired accidently or incidentally as a result of the college experience. As instruction and assessments change, there is a need to outline in detailed specificity what activities promote those global, contextual, and professional competencies. However, this limitation seems to be a shortcoming of the CBL literature in engineering higher education. It is a result of the lack of integration of previous findings in engineering education and the lack of adaptation of validated professional competency assessments in a CBL context. Several efforts have been suggested in engineering education research in general for how to construct reliable and valid assessments of professional competencies. For example, Ohland et al. (2012) outlined the development of a web-based instrument for measuring the contributions of team members as a way of measuring teamwork skills.

Gaps in the Literature

One of the gaps in CBL research is a method for improving the teaching of professional skills, as mentioned in previous sections. Recently, more effort has focused on determining sets of competencies for specific fields that should be adopted by all programs in that field. Additionally, many researchers have offered recommendations for a set of common professional competencies that all engineering students should have by the time they enter the workforce (Baughman et al., 2012; Grodzicki & Madigan, 2011; Jesiek, Haller, & Thompson, 2014; Ro et al., 2015). Yet, fewer such efforts have been put forth to recommend practices for promoting and developing students' professional competencies, especially in the CBL context. In an effort to address this gap, Evans et al. (2015) outlined an initiative for incorporating professional skills as part of the curriculum in a competency-based setting at Purdue, its primary goal being to improve communication skills and social and cultural awareness. However, research on enhancing the teaching of professional skills currently remains limited.

Despite the increase in CBL publications, there is little consensus on how CBL engineering programs ought to be structured or how competencies should be assessed. Researchers and educators differ in their definitions of CBL, what constitutes mastery, what is considered appropriate assessment, and how much flexibility should be given to students to work at their own pace. For example, in terms of assessment, many programs that claim to be completely CBL still assess students based on factors such as attendance and class participation (e.g., Witt et al., 2006). Other programs give students limited time to master certain competencies before being evaluated for the next ones (e.g., Spelt et al., 2015). Having a consensus on what the structure of a CBL engineering program ought to be is beneficial for two main reasons. First, it ensures that institutions that wish to convert a traditional program to a CBL one have clear guidelines for how to do so. Second, it is beneficial for researchers and consumers of research; if CBL is compared to another method and found to be more effective, then consistent definitions of CBL make it possible to generalize those results to other CBL programs. If the structure is different, then any differences found in research may not be as generalizable.

Recommendations and Future Research

Although the current literature suggests CBL is an effective pedagogy, more empirical research is needed to validate this conclusion. There is lack of empirical investigation in the current literature quantifying the effects of CBL and other pedagogical approaches, instructional methods, and assessment tools on student outcomes and program success in a reliable and valid manner. Therefore, many of the conclusions made in the extant literature are based on author experiences. In order to have confidence in causal claims about the effectiveness of CBL, its definition and implementation need to be consistent across programs. Currently, the definition and extent to which CBL is implemented across programs varies widely. This lack of consistency and control may reduce the confidence in the causal claims that CBL leads to an improvement in student outcomes. Therefore, we recommend that researchers operationally define what they mean by CBL and use quantitative methods to assess the effects of CBL on the outcomes of interest.

Regarding the reporting of quantitative information, even if simple preliminary analyses are conducted, all relevant statistical information should be provided, including descriptive statistics such as means, standard deviations and sample sizes. If hypothesis testing is conducted, in addition to reporting the significance testing results, the effect sizes should also be reported. Including all relevant statistical information is especially useful to researchers who aim to synthesize the results of multiple studies such as in a meta-analysis. In the cases where surveys are used, it would be beneficial and more parsimonious to conduct a reliability analysis to ensure these measures meet at least the minimum requirement of good reliability and then compare total scores on surveys rather than question by question. It would make it easier to interpret for both the authors and the readers.

Additionally, it is important for all future research to consider past findings. Integration of previous research is necessary for the advancement of the science of learning. However, based on the review of recent publications, integration seems to be limited in CBL literature. Lastly, more effort should be dedicated to comparing the benefit of using CBL over other pedagogical strategies in engineering higher education

Limitations of the Literature Review

There are limitations to this literature review. First, it was limited to peer-reviewed journal articles published between 2005-2015. This ten-year limitation may have resulted in the omission of significant works outside of this time frame. The exclusion of conference proceedings and theses may also have led to significant work being excluded. Second, only articles addressing CBL in engineering education are included; however, much can be learned about CBL from other fields such as medicine, nursing, and social work. Additionally, quantitative information on the effect of CBL on student outcomes was not discussed due to the lack of sufficient rigorous empirical investigation into the effectiveness of CBL in improving engineering student competencies. Most quantitative articles provided simple descriptive statistics. Lastly, the generalizability of many of the claims made is limited due to the variance in the definitions of CBL and the extent to which CBL is applied across programs.

Conclusion

Despite the limitations, to our knowledge, this literature review is the first attempt to systematically review the use of CBL in engineering education. This review summarizes prior work and offers recommendations for future research. The majority of prior work in CBL is related to descriptions of or commentaries on CBL programs. There is an opportunity to quantitatively and qualitatively examine CBL programs and their impact on student performance. In the case of quantitative analyses, relevant statistics should be provided to allow for comparisons and meta-analyses. There are also significant research opportunities for examining the efficacy of the CBL framework on engineering competencies, especially the case of the teaching and assessment of professional skills. Research should work towards a clearer and more consistent definition of CBL, one including both the structure of the CBL program and the assessment methods used. Consistency would allow for increased confidence in the results and casual claims. Based on the theoretical and applied evaluation of the literature, it can be concluded that CBL is becoming much more widely used in engineering education, and there is evidence to support its effectiveness in improving learning outcomes, meeting the needs of diverse student populations, and responding to industry's demands for competent engineers. This research needs to be ongoing to ensure continued effectiveness and improvement in CBL programs.

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