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A sampled literature review of design-based learning approaches: a search for key characteristics

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Abstract Design-based learning (DBL) is an educational approach grounded in the processes of inquiry and reasoning towards generating innovative artifacts, systems and solutions. The approach is well characterized in the context of learning natural sciences in secondary education. Less is known, however, of its characteristics in the context of higher engineering education. The purpose of this review study is to identify key characteristics of DBL in higher engineering education. From the tenets of engineering design practices and higher engineering education contexts we identified four relevant dimensions for organizing these characteristics: the project characteristics, the role of the teacher, the assessment methods, and the social context. Drawing on these four dimensions, we systematically reviewed the state-of-the-art empirical literature on DBL or DBL-like educational projects in higher engineering education. Based on this review we conclude that DBL projects consist of open-ended, hands-on, authentic and multidisciplinary design tasks resembling the community of engineering professionals. Teachers facilitate both the process of gaining domain-specific knowledge and the thinking activities relevant to propose innovative solutions. Teachers scaffold students in the development from novice to expert engineers. Assessment is characterized by formative and summative of both individual and team products and processes and by the use of a variety of assessment instruments. Finally, the social context of DBL projects includes peer-to-peer collaboration in which students work in teams. The implications of these findings for further research on DBL in higher engineering education are discussed.

Keywords Design-based learning · Engineering education · Authentic projects · Scaffolding

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Introduction

Design-based learning (DBL) is an educational approach grounded in the processes of inquiry and reasoning towards generating innovative artifacts, systems and solutions. It employs the pedagogical insights of problem-based learning (PBL) (Barrows 1985; Kolmos et al. 2009), although the scenario problems at hand take the form of design assignments. Some evidence has been provided to consider DBL a promising instructional method to enhance the learning of the natural sciences in secondary education. In higher engineering education, however, the characteristics of DBL have been hardly explored systematically. The aim of this review study is to identify characteristics of DBL in higher engineering education.

In our review study, we focused on the tenets of engineering design practices and higher engineering education contexts. That is, engineering educational tasks are undertaken in open-ended projects in which the teacher scaffolds the reasoning and inquiry process from novice to expert development working in a social and collaborative setting with multidisciplinary teams. Starting from these underpinnings, we identified four relevant dimensions for organizing the characteristics of DBL in higher engineering education: the project characteristics, the role of the teacher, the assessment methods, and the social context. These four dimensions are essential elements in the DBL learning environment. Drawing on these four dimensions, we systematically reviewed the state-of-the-art empirical literature on DBL or DBL-like educational projects in higher engineering education.

In this manuscript, we communicate the setup and the findings of the review. In the coming section, we discuss the background and the underlying theoretical principles of design-based learning. Next, we explain the rationale of the method followed to analyze the context of design-based learning environments. Subsequently, we outline the results of the literature review and describe the specific elements and the features of the four dimensions (e.g. projects' features, teachers' role, the assessment process, and the social context) relevant in design-based learning environments. Our findings in the next section reveal that: projects consist of open-ended, hands-on, authentic and multidisciplinary design tasks resembling the community of engineering professionals; teachers facilitate both the process of gaining domain-specific knowledge and the thinking activities relevant to propose innovative solutions, and scaffold students in the development from novice to expert engineers; assessment is characterized by both formative and summative individual and team assessment and by the use of an amalgam of assessment instruments; and the social context of DBL projects includes peer collaboration in which students work in teams. Finally, we discuss further research on DBL in higher engineering education.

Background

Broadly speaking, DBL can be taken as an instructional method which engages students in solving real-life design problems while reflecting on the learning process (Mehalik and Schunn 2006). DBL emphasizes planning and design of activities resembling authentic engineering settings in which students make decisions in the design cognitive thinking processes as they go through iterations in generating specifications, making predictions, experiencing and creating solutions, testing and communicating (Dym et al. 2005; Doppelt et al. 2008). As an educational approach DBL is akin to and in part stems from pedagogical principles of problem-alike reasoning and project-oriented practices (De Graaff and Kolmos 2003; Mooney and Laubach 2002; Prince 2004). Although it becomes complex to strictly set the boundaries between DBL and problem-based project-based learning, in DBL the accent lies in integrating knowledge from sciences, mathematics and from the engineering discipline itself in design assignments to construct artifacts, systems and solutions (Wijnen 2000). In DBL engineering cognitive processes scoping, generating, evaluating and creating are essential activities in the design of artifacts and in the realization of ideas (Dym et al. 2005). While PBL processes are more general, more importantly within the DBL approach is to have students to plan and reflect upon the construction process (Doppelt 2009).

Design-based learning has been introduced in secondary education with the purpose of learning science and to learn design skills (Apedoe et al. 2008; Doppelt et al. 2008). The theoretical underpinning of design-based learning applied in high school curriculum has been built upon successful experiences of using design as a framework to foster science learning (Apedoe et al. 2008), but also to engage students in authentic engineering design methods (Mehalik et al. 2008). Research studies have demonstrated the effectiveness of approaches such as learning by design (LBD) (Kolodner et al. 2003) and design-based science (DBS) (Fortus et al. 2004) in elementary and upper secondary science classes. Although all these methods hold similar science pedagogy theories they also encounter differences in the rationale behind the application. LBD is crafted from models, e.g. case-based reasoning (Kolodner et al. 2003), and problem-based learning (Barrows 1985), which expose students to sequence real-world and hands-on experiences to learn science concepts and develop inquiry reasoning skills (Kolodner 2002; Kolodner et al. 2003; Scaffa and Wooster 2004; Zimmerman 2000). The focus in LBD is on design as a medium for constructing new science knowledge by using iterations around the same science concepts but increasing the levels of complexity (Kolodner 2002; Kolodner et al. 2003). At the heart of design-based science (DBS) curriculum lie design experiences. Experiences in designing artifacts are to support students construct scientific understanding and problem-solving skills (Fortus et al. 2004). In DBS, however, design takes place first and iteration focuses on different science concepts (Fortus et al. 2004).

The examination of design-based approaches in secondary education revealed substantial empirical evidence to suggest that this approach supports the enhancement of reasoning, self-direction and team work skills in teaching sciences. In contrast, less empirical evidence exists about the working—let alone its effectiveness—of DBL in higher engineering education. In this regard, little is known of the characteristics of DBL in higher engineering education and the way these characteristics are integrated in design-based learning environments. Some researchers may argue that in the application of DBL in higher education there are experiences from which to learn in DBL in secondary education. Although these approaches could be similar the rationale is different as the context in higher education focuses on engineering design. Hence the aim of this review study is to systematically identify the characteristics of design-based learning in higher education engineering contexts. As a first step in doing so, we lay a theoretical foundation rooted in the tenets of engineering design practices and higher engineering educations. Specifically, we identity four dimensions relevant for organizing the characteristics of DBL in higher engineering education: the project characteristics, the role of the teacher, the assessment methods, and the social context. In what follows in this section, we discuss each of these dimensions and their relevance for this study. Finally, drawing on this theoretical grounding, we formulate the research questions central to the review study.

Project features

The features of design-based learning projects are based on the inquiring nature inherent to engineering design practices to solve ill-structured problems. In doing so, students experiment and deal with constraints and are engaged in cognitive conflicts and intuitions, to generate answers and respond to society and user's needs (Dym et al. 2005; Dym and Little 2009). One of our premises is that 'design'

> can be seen as learning; as a designer, you gradually gather knowledge about the nature of the design problem and the best routes to take towards design solution. You do this by trying out different ways of looking at the problem, and experimenting with various solution directions. You propose, experiment, and learn from the results, until you arrive at a satisfactory result. […] design can be described as a process of going through many of these 'learning cycles' (propose-experiment-learn) until you have created a solution to the design problem. In this way, you explore different possibilities and learn your way towards a design solution (Lawson and Dorst 2009, p. 34)

In higher engineering education contexts, design assignments are to learn students to acquire and apply knowledge in designing innovative solutions and systems (Wijnen 2000). Furthermore, design projects occur in authentic settings simulating engineering practices in which students work and communicate in multidisciplinary design team projects in an engineering community of practice (Brown et al. 1989; Miller and Olds 1994; Roth 1995; Roth et al. 2008). Design-based projects embed students in design thinking activities and processes used by experts analogically to engineering design (Schunn 2008), to investigate the unknown and understand the scope and context of the problem, explore multiple solution methods, select the criteria, redefine constraints and anticipate problems, develop new products and systems and test their validity (Cross 1990; De Grave et al 1996; Dym et al. 2005; Jonassen et al. 2006; Lawson and Dorst 2009). Each step of this iterative learning process opens up a new experiential and discovery situation which promotes reasoning and development of higher-order skills towards proposing solutions to unstructured and open-ended design challenges (Ramaekers 2011). Each iteration becomes more concrete as the designer gains more knowledge from each experiencing cycle (Lawson and Dorst 2009). Given this nature of higher engineering contexts, we are interested in the project features of DBL constituting learning therein.

Furthermore, numerous empirical studies refer to positive experiences in learning in association with theoretical models such as cognitive apprenticeship, (Collins et al. 1989; Collins 2006); situated cognition (Lave and Wenger 1991) and constructivist learning environments (Jonassen and Rohrer-Murphy 1999), which advocate authentic learning tasks to stimulate meaningful and complex learning (van Merriënboer and Kirschner 2007). Supporting students to learn to manage the complexity of real-life professional practice in authentic situated tasks (Kolodner et al. 2003; Collins et al. 1989; Lave and Wenger 1991; Ramaekers 2011) requires a development in the level of expertise on the one hand. On the other, learning the culture of professional engineers demands students' collaboration in multidisciplinary teams of community of practices (Kolodner et al. 2003, Collins et al. 1989; Lave and Wegner 1991). Thus, we are interested in project features of authenticity that guide students into the professional practice in particular.

Role of the teacher

The teacher has a role as a facilitator of learning in the literature on problem-based (Hmelo-Silver et al. 2007; Moust and Schmidt 1994; Moust et al. 2005; Schmidt et al. 1995). Research on students' coaching in problem-solving and inquiry learning provides evidences on scaffolding strategies to reduce cognitive load in complex tasks (Hmelo-

Silver et al. 2007; Ramaekers 2011; Schmidt et al. 2007). Likewise, the literature on engineering education indicates the important role of the teacher in the development of students from a novice to an expert engineering level. To learn building domain specific knowledge in the subject matter, the teacher guides the apprentice by modeling the reasoning thinking as expert engineers perform the problem analysis in a task (Atman et al. 2007). In doing so, teacher may provoke students with questions, model the inquiry thinking, encourage the reflection process and have students explore their reasoning modes while articulating engineering terminology. Furthermore, in supporting students to build knowledge in a discipline and develop gradually self-directness, process-oriented instruction (Boekaerts 1997; Bolhuis 2003; Loyens et al. 2008; Vermunt and Verloop 1999) is central to design-based learning environments. The process to utilize prior knowledge, to experiment with approaches and methodologies to produce new 'knowledge-in-action' and 'reflecting-in-action' (Schön 1987) on preliminary questions are suitable strategies in design-based learning. Grounded on that given on teachers' actions, our interest in the review study is to understand which teacher's strategies are considered a common practice in the literature.

Assessment

In the context of problem-alike approaches there is empirical evidence referring to feedback as a central component of formative assessment to increase motivation and ultimately, to support achievement in individual learning (Gijbels et al. 2005; Shute 2008). Whereas in DBL projects students are also coached and assessed based on teamwork processes and products, formative feedback becomes a meaningful instrument in the design learning process, in the process of building domain knowledge. Formative feedback can be effective for the student in self-directing the learning as they learn to adjust the strategies towards the expected outcome of their inquiry process (Black and Wiliam 1998; Hattie and Timperley 2007; Yorke 2003). Although we believe formative and summative assessment are relevant, we consider formative feedback and assessment crucial in the learning process. In this vein, we are keen on learning more about the assessment methods suitable for design-based learning projects.

Social context

Design tasks are generally conducted collaboratively in a community of practice in contextualized situations (Lave and Wenger 1991). So is the context of student teams in learning to design innovative solutions. In DBL students work as peers, communicate ideas and use the engineering terminology as part of a community of practice. Thus, we envision that the social context of the learning environment is one major dimension of DBL. In learning environments, the social context takes form in different ways, each with varying effectiveness for the learning taking place. For instance, empirical results on collaborative learning advocate activities such as competitions or presentations with industry as motivating strategies for team work (Okudan and Mohammed 2006). Peer-to-peer activities such as providing feedback are also encountered in the literature as effective methods in collaborative learning (Tien et al. 2002; Topping 1996). Given the importance of the social context in DBL, we want to further investigate what characteristics are considered relevant in this respect.

Research questions

Following the aforementioned theoretical dimensions of DBL we consider relevant in higher engineering design education, we aim at answering the following questions with our review study:

1. What project features are characteristic in design-based learning projects?
2. What are the methods teachers use to support students in design-based learning?
3. What assessment methods stimulate learning in design-based learning?
4. What are the salient features of the social context of design-based learning?

Review approach

In this section, we present the research method we have followed to conduct the literature review. First we illustrate how we selected the articles on which we based the literature review. Next, we describe how we analyzed the articles by drawing on the four theoretical dimensions discussed previously.

Selection of articles

For our review we have selected fifty empirical studies in the context of higher engineering education. This selection has been made previously to serve the purpose of another review study which aimed at the analysis of design elements in DBL in higher engineering education (Gómez Puente et al. 2011). For the selection of these publications we have taken into consideration four criteria. The first criterion concerned the sources of the literature. All 50 articles have been published in international peer reviewed journals indexed in either the Thomson Reuters' (Social) Science Citation Index or accepted as scientific research journals by the Dutch Interuniversity Centre for Educational Research (ICO). The second selection criterion was based on a series of key terms referring to higher engineering educational approaches akin to DBL practices, such as Problem-Based Learning, Project-Based Learning, Design Education, Scenario Assignments or Case-Based Studies. These key terms were used to identity relevant articles in the selected lists of journals. The third criterion concerned representativeness of the database. We made sure the database of selected publications represents a balanced variety of engineering disciplines. Finally, the fourth criterion concerned the time span of the publications, which was limited to 2000–2010. The result of the selection of articles based on the four selection criteria yielded a database of 50 articles representing the literature on DBL.

Analysis of articles

The analysis of articles consisted of two steps: preliminary classification and in-depth analysis. The first step, preliminary classification, allowed us to systematically record the key content of many articles in a standardized format. This structured way of classifying the articles' contents is akin to Biggs (2003) alignment model of teaching and learning in higher education. Biggs (2003) model builds upon components which interact to each other in the teaching and learning curriculum process such as the student, the learning environment and context (e.g. curriculum, objectives, teacher, and assessment), and the learning process and activities, which are aligned to the learning outcomes. In our case, we

Table 1 Overview of four dimensions and frequency in articles

Dimensions	Number of articles
Projects' features	34
Teacher's role	16
Assessment	18
Social and learning context	13

started classifying the data according to the students' activities, the curriculum, the teacher's role, the pedagogical theory, the assessment, the project features, and the social context.

In the second step, the in-depth analysis, we drew on our theoretical framework to focus on the four dimensions relevant to DBL (the project features, the role of the teacher, the assessment methods, and the social context). In Table 1 we present the number of articles in which we have found characteristics of design-based learning in relation to the projects' features, the role of the teacher, the assessment and the social context.

Findings

In the following sections, we provide an overview of the findings of the four dimensions we have researched in the fifty empirical studies, namely, the features of design projects, the role of the teacher, the assessment process, and the social and learning context.

Project features

Table 2 provides an overview of the characteristics of DBL pertaining to project features. The 34 articles dealing with the features of design-based projects referred to assignments conducted in open-ended (Behrens et al. 2010; Chinowsky et al. 2006; Roberts 2001; Hirsch et al. 2001; Denayer et al. 2003; Wood et al. 2005; Mese 2006; Maase 2008; Nonclercq et al. 2010), authentic (Linge and Parsons 2006; Mckenna et al. 2006; Massey et al. 2006), hands-on (Wood et al. 2005; Kalkani et al. 2005; Lee et al. 2010), real-life (Macías-Guarasa et al. 2006; Mckenna et al. 2006; van Til et al. 2009), and multidisciplinary (Macías-Guarasa et al. 2006; Nonclercq et al. 2010; Selfridge et al. 2007; Kundu and Fowler 2009; Shyr 2010) design projects.

Some examples of activities including open-ended and ill-structured assignments are those in which students handle incomplete information (Mese 2006); devise their own design work plan (McMartin et al. 2000), seek alternatives and consider design solutions (Roberts 2001). Other examples of authentic and real-life methods in design projects are represented by community of practices in which students work on multidisciplinary problems similar to, linked to or in co-operation with the industry (Massey et al. 2006; van Til et al. 2009). In this authentic settings, faculty staff performs different roles as users, costumers, or consultants (Denayer et al. 2003; Martínez Monés et al. 2005).

Role of the teacher

We have found sixteen articles reporting about successful experiences associated with the coaching role of the teacher. We illustrate in Table 3 the characteristics of the teachers' role in engineering design-based education.

Table 2 Characteristics of DBL pertaining to project features

Project feature	Examples	Source
Open-ended	No unique solution is given Search alternatives and solutions Students define the problem, the goals and the specifications No specification is given. Students are requested to determine own procedures and testing plan Incomplete information is provided at the start. Process of consultation and questioning help to arrive to a fully developed specification Freedom in task implementation to encourage diversity in design approaches Project proposal based on project planning and implementation Case reasoning approach to solve problems Design methodology involved in set up of project activities	Behrens et al. (2010), Chang et al. (2008), Cheville et al. (2005), Chinowsky et al. (2006), Hirsch et al. (2001), Jacobson et al. (2006), Kimmel and Deek (2005), Kimmel et al. (2003), Linge and Parsons (2006), Macías-Guarasa et al. (2006), Martínez Monés et al. (2005), Maase (2008), Massey et al. (2006), McMartin et al. (2000), Mese (2006), Nonclercq et al. (2010), Ringwood et al. (2005), Roberts (2001), Shyr (2010), Wood et al. (2005), Zhan and Porter (2010)
Hands-on experiences/ experiential	Students apply theory in practical schemes Students conduct experiments and learn from iterations Design methodology embedded in projects Encouraging reflection based on experiencing	Clyde and Crane (2003), Etkina et al. (2006), Etkina et al. (2010), Geber (2010), Jacobson et al. (2006), Kalkani et al. (2005), Lee et al. (2010), Mistikoglu and Özyalçin (2010), Nooshabadi and Garside (2006), Selfridge et al. (2007)
Authentic/real-life scenarios	Realistic scenarios: assignments represent real-life engineering problems; teacher/ tutor represent customer's role Students are put in scenarios as company workers in design projects Linking project activities to industry: company is issuer of assignment; provides feedback	Denayer et al. (2003), Macías-Guarasa et al. (2006), Massey et al. (2006), Mckenna et al. (2006), Nonclercq et al. (2010), van Til et al. (2009)
Multidisciplinary	Integration of content from different disciplines Teachers/expertise form different disciplines involve in project	Kundu and Fowler (2009), Macías-Guarasa et al. (2006), Nonclercq et al. (2010), Selfridge et al. (2007)

A number of studies make use of scaffolding strategies as stepping stones for the students in solution generation. Supervision of students entails as well providing pieces of information in a just-in-time form and tailor-made to the needs of students. Moments devoted for mini lectures, lecture-by-demand strategy or the so-called "benchmark lessons" (Maase 2008), provide complementary mentoring moments to enhance students understanding. Commonly, asking questions during different project implementation phases are employed to model and apprentice learners through the more complex parts of the design such as the process of scoping the problem, inquiring and troubleshooting (Chang et al. 2008; Etkina et al. 2006; Roberts 2001; van Til et al. 2009). In addition, problem-solving heuristics such as formulating problem, planning and designing the solution, and testing and delivering the solution, have yield positive results in assisting

Table 3 Characteristics of DBL pertaining to the teacher's role

Teacher's role	Examples	Source
Coaching on task, process and self	Challenge students by asking questions Process of consultation and questioning to help arrive to fully develop specifications: students realize whether they need more information and improve own design Focus on heuristics to implement major tasks Scaffolding: use of rubrics, hands-outs, worksheets Teacher gives just-in-time teaching or lecture-by-demand strategy Stimulation of evaluation of process and self-reflection Discussions to reflect on process and explicate rationale for their technical design and business case Faculty (teachers) act as consultants Contact with company for product design Formative feedback upon mid-term deliverables: project plans, proj. proposal, Gantt chart, prototype On-line questionnaires before class to clarify concepts	Chang, et al. (2008), Cheville et al. (2005), Clyde and Crane (2003), Denayer et al. (2003), Etkina et al. (2006), Etkina et al. (2010), Geber (2010), Hirsch et al. (2001), Kimmel and (2003), Mckenna et al. (2006), Martínez Monés et al. (2005), Maase (2008), Massey et al. (2006), Lyons and Brader (2004), Roberts (2001), van Til et al. (2009)

learners in learning to design. Other examples of scaffolding students' gaining content knowledge include on-line quizzes, discussions (Cheville et al. 2005; Maase 2008), worksheets with questions or the use of a solution plan (Etkina et al. 2010; Kimmel and Deek 2005; Lyons and Brader 2004).

We also find examples of guided instructional approaches focusing on meta-cognitive activities to help students to analyze learning processes. Geber (2010), Clyde and Crane (2003), Massey et al. (2006) identify that inserting meta-cognitive activities such as questions and rubrics pave the way to reflect upon knowledge and strategies in developing scientific abilities.

Situated learning scenarios in which students perform as practitioners of a community that is represented by having the teacher acting as a customer, user, or expert (Denayer et al. 2003; Martínez Monés 2005; Massey et al. 2006) argue in favor of such a depiction of the teacher's role. Guidance and feedback on technical designs is rather provided in settings in which the use of the terminology of the engineering professionals of an authentic community is articulated (Hirsch et al. 2001; Mckenna et al. 2006).

Assessment

We summarize in Table 4 assessment characteristics we found in the literature. There are examples of both formative and summative feedback. Although engineering design is a cognitive activity conducted in collaborative teams, individual formative assessment has been identified as a common practice. The methods to assess students individually, however, varies. Several studies report on the successful application of individual assessment as a formative tool to monitor progress (Baley 2006; Behrens et al. 2010; Chang et al.

Table 4 Characteristics of DBL pertaining to assessment

Assessment	Examples	Source
Formative	Individual and group tasks Weekly online quizzes; laboratory work Weekly presentations; reports; prototype; concept design Intermediate checkpoints based on intermediate deliverables: improvements in reports; prototypes; quality of experiments	Baley (2006), Behrens et al. (2010), Chang et al. (2008), Kimmel et al. (2003), Lee et al. (2010), Macías-Guarasa et al. (2006), Maase (2008), Massey et al. (2006), Martínez Monés (2005), Mese (2006), Nooshabadi and Garside (2006), Roberts (2001), Stiver (2010)
Summative	Individual contribution to project group; oral exams; final exam Presentations; reports Portfolio assessment; peer- and self-assessment Use of rubrics Involvement of industry representatives in assessment	Chang et al. (2008), Cheville et al. (2005), Denayer et al. (2003), Masse (2008), Massey et al. (2006), Mckenna et al. (2006), Roberts (2001), Shyr (2010), Stiver (2010), Zhan and Porter (2010)

2008; Cheville et al. 2005; Lee et al. 2010; Maase 2008; Mese 2006; Stiver 2010). Some of these methods include oral questioning, weekly presentations of individual reports and home work. In the same line, a number of studies emphasize that weekly questionnaires of on-line quizzes become a flexible assessment method by which the material presented in lectures and lab during the week can be easily tested (Macías-Guarasa et al. 2006; Martínez Monés et al. 2005; Massey et al. 2006; Nooshabadi and Garside 2006; Chang et al. 2008; Cheville et al. 2005). The added value of the formative quizzes is that, as scaffolding method, it helps students understand concepts and theories involved in the problem to be solved (Kimmel and Deek 2005).

In the reviewed studies self- but also peer-to-peer assessment are oftentimes used assessment methods to enhance both individual and group progress (Cheville et al. 2005; Chang et al. 2008; Shyr 2010). Cheville et al. (2005), Baley (2006), and Shyr (2010); underline that self-assessment supports personal reflection on own progress. Formative assessment on task-related assignments is conducted therefore based on writing individual parts on correct use of design methods, reports, logbooks or portfolios in which students register own work and reasoning (Denayer et al. 2003; Cheville et al. 2005; Chang et al. 2008; Macías-Guarasa et al. 2006; Shyr 2010; Roberts 2001).

Examples of summative assessment of application and integration of knowledge to generate innovative solutions, artifacts and products is not the only goal in project work reports (Stiver 2010; Zhan and Porter 2010). In design scenarios (Mckenna et al. 2006) students develop process competencies such as communication, presentation and written skills, cooperation, creativity, project management. In doing so, students provide feedback to each other (Shyr 2010). Denayer et al. (2003) consider that the development of these competences therefore require a continuous assessment, particularly when individual learning becomes the focus to monitor progress and personal development.

Social context

In Table 5 we provide an overview of the characteristics pertaining to the social context. The social context in design education centers around collaborative learning examples which resembles professional practices of the engineering community. These different

Table 5 Characteristics of DBL pertaining to the social context

Social context	Examples	Source
Collaborative learning	Communication with real-life stakeholders: presentations of prototypes with company Students manage processes as experts Team work	Denayer et al. (2003), Linge and Parsons (2006), Martínez Monés et al. (2005), Massey et al. (2006), Mckenna et al. (2006), Nonclercq et al. (2010), Shyr (2010)
	Peer-to-peer communication: peer-to-peer feedback in presentations in groups Peer learning processes within and across teams when students shared laboratory resources and engaged in debates	Behrens et al. 2010, Mckenna et al. (2006)
	Motivation through competitions; variation in design techniques and approaches: learning principles are the same by prototype is different	Cheville et al. (2005), Kundu and Fowler (2009), Massey et al. (2006), Roberts (2001), Wood et al. (2005), Zhan and Porter (2010)

examples are to be found in at least thirteen articles we have searched. In design-based projects students work in teams. A number of studies emphasize the link of student's presentations within industry stakeholders to develop technical and engineering domain terminology (Denayer et al. 2003; Linge and Parsons 2006; Massey et al. 2006; Mckenna et al. 2006; Shyr 2010). Other examples of students resembling expert communication is by having students play roles as, for instance, engineers and customers (Martínez Monés et al. 2005; Nonclercq et al. 2010). We find also examples of active participation of students with their peers in the social environment by holding presentations of prototypes (Behrens et al. 2010; Mckenna et al. 2006; Cheville et al. 2005; and Wood et al. 2005; Zhan and Porter 2010). Another feature related to the social context of the projects is motivation. Motivation is encouraged by holding competitions (Kundu and Fowler 2009; Massey et al. 2006; Wood et al. 2005) or by giving students the ownership of both products and processes (Roberts 2001; Nonclercq et al. 2010).

Conclusions

Our literature review allowed for each of the dimensions a number of conclusions on the characteristics of DBL. Accordingly, the findings reveal ways to prepare students for professional practices by bridging the gap between education and engineering preparation for industry settings. Regarding the features of DBL projects, design tasks are embedded in open-ended, hands-on experiential, and authentic learning environments. These are common characteristics of design projects in higher technical education which have been consistently found in the researched articles. Resembling the nature of the engineering community of professionals lies in creating design scenarios in which students as novice engineers learn to work in complex and multidisciplinary exploratory tasks. Delivering innovative technological solutions request from students to analyze ambiguous situations, seek alternatives and review design concepts in iterative loops. The inquiry character of these design-alike methods fosters, therefore, self-direction in making choices in the planning, in the implementation and in the testing of the design schemes.

Building knowledge in the discipline is not a stand-alone process in the context of DBL projects. Teachers facilitate the process of gaining domain-specific knowledge scaffolding the development from novice to expert by for instance modelling the inquiry and cognitive process and performing engineering roles, encouraging reflection and supporting articulation of domain terminology. These are key examples of 'reflection-in-action' through which iterations of reasoning in planning, experimenting and making decisions for further testing is stimulated to proposed innovative solutions. In so doing, the teacher coaches students by providing formative feedback on design tasks but also on processes to undertake those design activities.

Concerning the assessment instruments, examples from empirical articles show different methods of informative and summative assessment that enhance learning in DBL. Furthermore, formative feedback has been identified as an instrument to foster deep learning and as a mechanism to optimize the processes inherent to engineering design thinking, e.g. acquiring information, planning and using different approaches and methodologies, analyzing iteratively knowledge generated against preliminary questions, and testing new solutions. Among the strategies to assess students both group and individual contribution to project work are design assignments, portfolios, quizzes, reflections or oral presentations. Project work is also assessed by prototypes, team reports and demonstrations with industry involvement but also by peer assessment.

Finally, collaborative learning methods pertaining to the social context embed students in critical thinking peer-to-peer activities. Optimal implementation of DBL to promote collaborative learning is to provide feedback to each other's plan or results of experiments. This supports communication.

Further research

The findings reported in this paper open up several venues for further investigation. One venue runs along the open-ended and authentic design tasks that offer a suitable mechanism for students to develop their reasoning and domain-specific knowledge. Research is required to understand how students can learn the inquiry process by which complex design tasks are tackled. Another venue has to do with the broad scope of educational strategies and methods applied in design-based learning environments. Little empirical research has been done to understand which educational strategies and methods are actually effective in the practice of higher engineering education. Furthermore, this broad scope of educational strategies reflects the versatile nature of design-based learning, which in turn, requires a versatile role of the teacher as well. Understanding this versatile role can opens up another venue for further research. For instance, the assumption that engineering students learn to develop design thinking and reasoning as experts requires a transformation of the teachers' role. One challenge in this transformation process is how control can be transferred from teachers to students to develop self-directness. Another challenge concerns finding the right balance of complex inquiry and authentic tasks supported by scaffolding. Understanding how to overcome such challenges requires an iterative process of design-based research together with teachers and educational practitioners.

References

Apedoe, X. A., Reynolds, B., Ellefson, M. R., & Schunn, C. D. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education and Technology, 17*(5), 454–465.

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education, 96*(4), 359–379.

Baley, R. (2006). Assessing engineering design process knowledge. *International Journal Engineering Education, 22*(3), 508–518.

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years*. New York: Springer.

Behrens, A., Atorf, L., Schwann, R., Neumann, B., Schnitzler, R., Ballé, J., et al. (2010). MATLAB meets LEGO Mindstorms—A freshman introduction course into practical engineering. *IEEE Transactions on Education, 53*(2), 306–317.

Biggs, J. (2003). *Teaching for quality learning at university*. Buckingham, UK: Open University Press.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7–74.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5–31.

Boekaerts, M. (1997). Self-regulated learning: A new concept embraced by researchers, policy makers, educators, teachers and students. *Learning and Instruction, 7*(2), 161–186.

Bolhuis, S. (2003). Towards process-oriented teaching for self-directed lifelong learning: A multidimensional perspective. *Learning and Instruction, 13*(3), 327–347.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Chang, G.-W., Yeh, Z.-M., Pan, S.-Y., Liao, C.-C., & Chang, H.-M. (2008). A progressive design approach to enhance project-based learning in applied electronics through an optoelectornic sensing project. *IEEE Transaction on Education, 51*(2), 220–233.

Cheville, R. A., McGovern, A., & Bull, K. S. (2005). The light applications in science and engineering research collaborative undergraduate laboratory for teaching (LASE CULT)—Relevant experiential learning in photonics. *IEEE Transactions on Education, 48*(2), 254–263.

Chinowsky, P. S., Brown, H., Szjnman, A., & Realph, A. (2006). Developing knowledge landscapes through project-based learning. *Journal of Professional Issues in Engineering Education and Practice, 132*(2), 118–124.

Clyde, S. W., & Crane, A. E. (2003). Design-n-code fests. *Computer Science Education, 13*(4), 289–303.

Collins, A. (2006). Cognitive apprenticeship. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 47–60). New York, NY: Cambridge University Press.

Collins, A., Brown, J., & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453–494). Hillsdale, NJ: Erlbaum Associates.

Cross, N. (1990). The nature and nurture of design ability: Author's inaugural lecture as professor of design studies. *Design Studies, 11*(3), 127–140.

De Graaff, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International Journal of Engineering Education, 19*(5), 657–662.

De Grave, W. S., Boshuizen, H. P. A., & Schmidt, H. D. (1996). Problem based learning: Cognitive and metacognitive processes during problem analysis. *Instructional Science, 24*(5), 321–341.

Denayer, I., Thaels, K., Vander Sloten, J., & Gobin, R. (2003). Teaching a structured approach to the design process for undergraduate engineering student by problem-based education. *European Journal of Engineering Education, 28*(2), 203–214.

Doppelt, Y. (2009). Assessing creative thinking in design-based learning. *International Journal of Technology and Design Education, 19*(1), 55–65.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education, 19*(2), 22–39.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120.

Dym, C. L., & Little, P. (2009). *Engineering design: A project-based introduction*. New York: Wiley.

Etkina, E., Karelina, A., Ruibal-Villasenor, M., Rosengrant, D., Jordan, R., & Hmelo-Silver, C. E. (2010). Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories. *Journal of the Learning Sciences, 19*(1), 54–98.

Etkina, E., Murthy, S., & Zou, X. (2006). Using introductory labs to engage students in experimental design. *American Journal of Physics, 74*(11), 979–986.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Rachel Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110.

Geber, E. (2010). Learning to waste and wasting to learn? How to use cradle to cradle principles to improve the teaching of design. *International Journal of Engineering Education, 26*(2), 314–323.

Gijbels, D., van de Watering, G., & Dochy, F. (2005). Integrating assessment tasks in a problem-based learning environment. *Assessment and Evaluation in Higher Education, 30*(1), 73–86.

Gómez Puente, S. M., van Eijck, M., & Jochems, W. (2011). Towards characterizing design-based learning in engineering education: A review of the literature. *European Journal of Engineering Education, 36*(2), 137–149.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research, 77*(1), 81–112.

Hirsch, P. L., Shwom, B. L., Yarnoff, C., Anderson, J. C., Kelso, D. M., Olson, G. B., et al. (2001). Engineering design and communication: The case for interdisciplinary collaboration. *International Journal of Engineering Education, 17*(4 and 5), 342–348.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.

Jacobson, M. L., Said, R. A., & Rehman, H. (2006). Introducing design skills at the freshman level: Structured design experience. *IEEE Transactions on Education, 49*(2), 247–253.

Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research and Development, 47*(1), 61–79.

Jonassen, D., Strobel, J., & Lee, B. C. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139–151.

Kalkani, E. C., Boussiakou, I. K., & Boussiakou, L. G. (2005). The paper beam: Hands-on design for team work experience of freshman in engineering. *European Journal of Engineering Education, 30*(3), 393–402.

Kimmel, S. J., & Deek, F. P. (2005). Using a problem-solving heuristic to teach engineering graphics. *International Journal of Mechanical Engineering, 32*(2), 135–146.

Kimmel, S. J., Kimmel, H. S., & Deek, F. P. (2003). The common skills of problem solving: From program development to engineering design. *International Journal of Engineering Education, 19*(6), 810–817.

Kolmos, A., De Graaff, E., & Du, X. (2009). Diversity of PBL—PBL learning principles and models. In D. Xiangyun, E. de Graaff, & A. Kolmos (Eds.), *Research on PBL practice in engineering education* (pp. 9–21). Rotterdam: Sense Publishers.

Kolodner, J. (2002). Learning by design™: Iterations of design challenges for better learning of science skills. *Cognitive Studies, 9*(3), 338–350.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., et al. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting leaning by design™ into practice. *Journal of the Learning Sciences, 12*(4), 495–547.

Kundu, S., & Fowler, M. W. (2009). Use of engineering design competitions for undergraduate and capstone projects. *Chemical Engineering Education, 43*(2), 131–136.

Lave, J., & Wenger, E. (1991). *Situated learning. Legitimate peripheral participation*. Cambridge: University of Cambridge Press.

Lawson, B., & Dorst, K. (2009). *Design expertise*. Oxford, UK: Architectural Press.

Lee, C.-S., Su, J.-H., Lin, K.-E., Chang, J.-H., & Lin, G.-H. (2010). A project-based laboratory for learning embedded system design with Industry support. *IEEE Transactions on Education, 53*(2), 173–181.

Linge, N., & Parsons, D. (2006). Problem-based learning as an effective tool for teaching computer network design. *IEEE Transactions on Education, 49*(1), 5–10.

Loyens, S. M. M., Magda, J., & Rikers, R. M. J. P. (2008). Self-directed learning in problem-based learning and its relationships with self-regulated learning. *Educational Psychology Review, 20*(4), 411–427.

Lyons, J. S., & Brader, J. S. (2004). Using the learning cycle to develop freshmen's abilities to design and conduct experiments. *International Journal of Mechanical Engineering Education, 32*(2), 126–134.

Maase, E. L. (2008). Activity problem solving and applied research methods in a graduate course on numerical methods. *Chemical Engineering Education, 42*(1), 23–32.

Macías-Guarasa, J., Montero, J. M., San-Segundo, R., Araujo, A., & Nieto-Taladriz O. (2006). A project-based learning approach to design electronic systems Curricula. *IEEE Transactions on Education, 49*(3), 389–397.

Martínez Monés, A., Gómez Sánchez, E., Dimitriadis, Y. A., Jorrín Abellán, I. M., & Rubia Avi, B. (2005). Multiple case studies to enhance project-based learning in a computer architecture course. *IEEE Transactions on Education, 48*(3), 482–488.

Massey, A. P., Ramesh, V., & Khatri, V. (2006). Design, development and assessment of mobile applications: The case for problem-based learning. *IEEE Transactions on Education, 49*(2), 183–192.
McKenna, A., Colgate, J. E., Carr, S. H., & Olson, G. B. (2006). IDEA: Formalizing the foundation for an engineering design education. *International Journal of Engineering Education, 22*(3), 671–678.
McMartin, F., McKenna, A., & Youssefi, K. (2000). Scenario assignments as assessment tools for undergraduate engineering education. *IEEE Transactions on Education, 43*(2), 111–119.
Mehalik, M. M., Doppelt, Y., & Schunn, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71–85.
Mehalik, M. M., & Schunn, C. (2006). What constitutes good design? A review of empirical studies of design processes. *International Journal of Engineering Education, 22*(3), 519–532.
Mese, E. (2006). Project-oriented adjustable speed motor drive course for undergraduate curricula. *IEEE Transactions on Education, 49*(2), 236–246.
Miller, R. L., & Olds, B. M. (1994). A model curriculum for a capstone course in multidisciplinary engineering design. *Journal of Engineering Education, 83*(4), 1–6.
Mistikoglu, S., & Özyalçin, I. (2010). Design and development of a cartesian robot for multi-disciplinary engineering education. *International Journal of Engineering Education, 26*(1), 30–39.
Mooney, M. M., & Laubach, T. A. (2002). Adventure engineering: A design centered, inquiry based approach to middle grade science and mathematics education. *Journal of Engineering Education, 91*(3), 309–318.
Moust, J. C., & Schmidt, H. G. (1994). Effects of staff and student tutors on student achievement. *Higher Education, 28*(4), 471–482.
Moust, J. H. C., van Berkel, H. J. M., & Schmidt, H. G. (2005). Signs of erosion: Reflections on three decades of problem-based learning at Maastricht University. *Higher Education, 50*(4), 665–683.
Nonclercq, A., Vander Biest, A., De Cuyper, K., Leroy, E., López, M. D., & Robert, F. (2010). Problem-based learning in instrumentation: Synergism of real and virtual modular acquisition chains. *IEEE Transactions on Education, 53*(2), 234–242.
Nooshabadi, S., & Garside, J. (2006). Modernization of teaching in embedded systems design—An international collaborative project. *IEEE Transactions on Education, 49*(2), 254–262.
Okudan, G. E., & Mohammed, S. (2006). Facilitating design learning in a cooperative environment: Findings n team functioning. *International Journal of Engineering Education, 22*(3), 496–502.
Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223–231.
Ramaekers, S. (2011). *On the development of competence in solving clinical problems: Can it be taught? Or can it only be learned*? Doctoral dissertation. Utrecht: University of Utrecht.
Ringwood, J. V., Monaghan, K., & Malaco, J. (2005). Teaching engineering design through Lego Mindstorms. *European Journal of Engineering Education, 30*(1), 91–104.
Roberts, L. (2001). Developing experimental design and troubleshooting skills in an advanced biochemistry lab. *Biochemistry and Molecular Biology Education, 29*, 10–15.
Roth, W.-M. (1995). *Authentic school science. Knowing and learning in open-inquiry science laboratories*. Dordrecht: Kluwer.
Roth, W.-M., van Eijck, M., Reis, G., & Hsu, P.-L. (2008). *Authentic science revisited. In praise of diversity, heterogeneity, hybridity*. Dordrecht: Sense Publishers.
Scaffa, M. E., & Wooster, D. M. (2004). Effects of problem-based learning in clinical reasoning in occupational therapy. *The Journal of Occupational Therapy, 58*(3), 333–336.
Schmidt, H. G., Loyens, S. M. M., van Gog, T., & Paas, F. (2007). Problem-based learning is compatible with human cognitive architecture: commentary on Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 91–97.
Schmidt, H., van der Arend, A., Kokx, I., & Boon, L. (1995). Peer versus staff tutoring in problem-based learning. *Instructional Science, 22*(4), 279–285.
Schön, D. A. (1987). *The reflective practitioner: How professionals think in action*. San Francisco: Jossey-Bass.
Schunn, C. (2008). Engineering educational design. *Educational Designer, 1*(1), 1–21.
Selfridge, R. H., Schultz, S. M., & Hawkins, A. R. (2007). Free space optical link as a model undergraduate design project. *IEEE Transactions on Education, 50*(3).
Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153–189.
Shyr, W.-J. (2010). Teaching mechatronics: An innovative group project-based approach. *Computer Applications in Engineering Education*. doi:10.1002/cae.20377.
Stiver, W. (2010). Sustainable design in a second year engineering design course. *International Journal of Engineering Education, 26*(2), 378–383.

Tien, L. T., Roth, V., & Kampmeier, J. A. (2002). Implementation of a peer-led team learning instructional approach in an undergraduate organic chemistry course. *Journal of Research in Science Teaching, 39*(7), 606–632.

Topping, K. J. (1996). The effectiveness of peer tutoring in further and higher education: A typology and review of the literature. *Higher Education, 32*(3), 321–345.

van Merriënboer, J. G., & Kirschner, P. A. (2007). *Ten steps to complex task: A systematic approach to four-component instructional design*. New York, NY: Routledge.

Van Til, R. P., Tracey, M. W., Sengupta, S., & Fliedner, G. (2009). Teaching lean with an interdisciplinary problem solving learning approach. *International Journal Engineering Education, 25*(1), 173–180.

Vermunt, J. D., & Verloop, N. (1999). Congruence and friction between learning and teaching. *Learning and Instruction, 9*(3), 257–280.

Wijnen, W. H. F. W. (2000). *Towards design-based learning*. Eindhoven: Eindhoven University of Technology.

Wood, J., Campbell, M., Wood, K., & Jensen, D. (2005). Enhancing the teaching of machine design by creating a basic hands-on environment with mechanical 'breadboards'. *International Journal of Mechanical Engineering Education, 33*(1), 1–25.

Yorke, M. (2003). Formative assessment in higher education: Moves towards theory and the enhancement of pedagogic practice. *Higher Education, 45*, 477–501.

Zhan, W., & Porter, J. R. (2010). Using project-based learning to teach six sigma principles. *International Journal of Engineering Education, 26*(3), 655–666.

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review, 20*(1), 99–149.