Design-based learning : exploring an educational approach for engineering education

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Design-based learning: exploring an educational approach for engineering education

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Where innovation starts

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Design-based learning: exploring an educational approach for engineering education

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Technische
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door

Sonia María Gómez Puente

geboren te Madrid, Spanje

Dit proefschrift is goedgekeurd door de promotoren en de samenstelling van de promotiecommissie is als volgt:

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	Prof.dr.ir. A.B. Smolders
	Prof.dr. T.C.M. Bergen

To Bart, my husband and father of our two children.
Thanks Bart for supporting me always and consistently
throughout this time. Despite of ‘my absence’, as I devoted much
of our family time to my research in the last years, you have barely complained
and have encouraged me to go on during the difficult moments.

To Ivan and Laura, our children, thanks for growing up happy.
It has been a very demanding period for you two!

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Chapter 1

… In our view, learning is not merely situated in practice as if it were some independently reifiable process that just happened to be located somewhere; learning is an integral part of generative social practice in the lived-in world…

Lave & Wenger, 1991 (p. 35)[1]

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

Chapter 1

Introduction

1.1 Background

Design-based Learning (DBL) is a promising educational concept for engineering education, as design is a core element in engineering. DBL, like both problem-based learning and project-organised learning, receives increased interest in technical universities as a result of a worldwide trend advocating for the transition towards more learner-centred curricula in higher education, enhancing the skills and knowledge required for complex activities learned by doing in group work. These considerations played a part in introducing DBL at Eindhoven University of Technology (TU/e) in 1997 as an educational concept that provides a common view and platform for innovation in the educational system. The rationale behind this approach was to provide the study programs at the TU/e with a more competence-oriented perspectieve (e.g., group work, communication, etc) and to educate students to meet the requirements posed by realistic engineering settings. In this chapter we will briefly introduce the concept of DBL as an educational approach for engineering education, and present the focus and context of our research. The chapter concludes with an overview of our studies.

1.1.1 The historical context

Some technical universities in Europe, such as the universities of Roskilde and Aalborg (Denmark), already had, in 1972 and 1974 respectively, made a change in their teaching paradigm towards problem-based (PBL) and project-organized learning. These two universities, together with Linköping University (Sweden) in 1972, became the PBL pioneers in Europe. These first steps towards founding new educational models followed the PBL concept coined by Don Woods while teaching a chemistry class. The PBL concept later was adopted as the pedagogical method for the development of a new medical curriculum at McMaster's university (Canada) in 1969. Other universities followed soon after, such as Maastricht (the Netherlands) in 1972 and Newcastle (Australia) in 1976. Mainstream education began to embrace the principle that real-life problems constitute the stimulus for learning, and that problem-solving skill development could be achieved in self-directed groups guided by facilitators.

1.1.2 Design-based learning at Eindhoven University of Technology (TU/e)

The Danish project work served as inspiration for the TU/e. Their focus centered on the application of acquired knowledge and skills development. As an active learning method, DBL was inserted into the curricula to have students work in groups collaboratively on multidisciplinary design assignments. Although DBL was introduced with a vision to stimulate innovation, it has been molded in each engineering department with a particular local flavor, generating different versions of the concept in each departmental study program (Perrenet, Bouhuijs, & Smits, 2000; Perrenet & Pleijers, 2000; Perrenet, 2001; Perrenet & Mulders, 2002). To initiate DBL implementation, departments outlined one project to be carried out over a two-year period. However, DBL was not implemented following a uniform curriculum model. Rather, it was adapted according to the needs of every specific department at the TU/e (Wijnen, 2000). Some departments adopted DBL as an educational concept that served as a foundation for curriculum renewal; for others, however, it was interpreted as an educational form to be integrated into courses.

For most programs, implementation eventually meant the incorporation of a series of projects into the curriculum. An example of how the TU/e introduced DBL into the curricula is the redesign of Computer Sciences courses to make more room for project work and the related skills training. In the Mechanical Engineering department, DBL was adapted to provide form to the curriculum by dividing the time into 60 percent coursework/instruction and integrating DBL-projects performed in student groups for the other 40 percent of the time. In the Industrial Design department, the competency-based model builds upon context-related, experiential and reflective learning (Kolb, 1984; Schön, 1983). Through project-based assignments, students perform professional experts' roles and tasks, and are prepared to create, apply, and disseminate knowledge, and continuously construct and reconstruct their expertise in a process of life-long learning (Hummels & Vinke, 2009) in which the notion of self-directed learning becomes central. In the Built Environment department, design studios, or *ateliers*, were created to integrate multidisciplinary design. Students collaborate in design teams supervised by teachers and experts from different disciplines, and receive feedback on individual design projects. Similarly, DBL at the Electrical Engineering and the Applied Physics departments emerged from practicals. In other departments, DBL was integrated following more or less similar forms. So, the DBL educational concept was implemented with great diversity and without a clear theoretical framework, as little was known about the characteristics of DBL and its effects on students.

The relevance of this investigation therefore lies in defining DBL and its characteristics, in providing a rationale for the theoretical framework, and in empirically studying design-based learning. The effects of DBL on students also have been studied to a very limited extent, and it is still unknown what exactly the success factors are of this educational approach.

1.2 Trends in engineering design education

When it comes to uncovering current trends in engineering design education, a wide amalgam of research abounds in the literature. Inevitably, we come across a broad scope of research on how students learn to design, i.e., design thinking (Dym, Agogino, Eris, Frey, & Leifer, 2005; Eris, 2011), by analyzing how students go about solving design problems, by studying what cognitive and reasoning activities they undertake, or by exploring the differences in design expertise of freshman and senior students, teaching novice students to design (Ehrlenspiel & Dylla, 1993; Ullman, Dietterich, & Stauffer, 1988; Radcliffe & Lee, 1989; Sutcliffe & Maiden, 1992; Mullins, Atman, & Shuman, 1999; Atman, Adams, Cardella, Turns, & Saleem, 2007; Dym & Little, 2009). We also find examples of how to outline a curriculum that embeds design in engineering study programs through cornerstone or capstone courses (Dutson, Todd, Magleby, & Sorensen, 1997) or a new dimension of rethinking engineering that embeds the practice of the engineers in all phases of a product, a process or a system lifecycle as the MIT Conceiving, Designing, Implementing, and Operating (CDIO) model advocates (Crawley, Malmqvist, Östlund, & Brodeur, 2007) to meet the criteria of accreditation boards (i.e., ABET, etc.).

Despite this substantial research, empirical studies on how to teach students to gather and apply knowledge while solving design problems are hardly available. In our investigation, we delineate design-based learning and its characteristics as an educational approach to teach students to gather and apply knowledge to solve complex design problems in the domain of engineering. In this regard, the process of teaching students the ability to scope open-ended and ill-defined design problems, discovering the unknown by proposing solutions and generating ideas from experiments in order to optimize the products in iterations, takes a central role.

1.3 Design-based learning as an educational approach

1.3.1 Design-based learning as an educational approach for science education

Grounded in active learning approaches, such as learning by design (LBD) (Kolodner & Nagel, 1999; Kolodner, 2002; Kolodner, Camp, Crismond, Fasse, Gray, & Holbrook, 2003), and design-based science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), DBL has appeared to be a promising method to teach science concepts in the context of sciences in secondary education (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009). DBL emphasizes planning and making decisions as students go through iterations in generating ideas based on predictions, experiencing and creating solutions, testing and communicating (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008) while engaging students in authentic engineering design assignments (Mehalik, Doppelt, & Schunn, 2008; Doppelt, 2009). Furthermore, the DBL approach also teaches students to learn and apply knowledge and reflect upon the construction process (Mehalik, Doppelt, & Schunn, 2008; Doppelt, 2009).

1.3.2 Design-based learning as an educational approach for engineering education

Some researchers argue there is sufficient evidence on the application of DBL in secondary education that may be appropriate to higher education. Although these approaches could be more or less similar, the rationale is different, as the context in engineering education also focuses on, among others things, teaching students to gather and apply knowledge to solve complex engineering design problems.

In the context of engineering education, DBL borrows pedagogical principles of problem-alike reasoning and project-oriented practices (De Graaff & Kolmos, 2003; Prince, 2004; Dym, Agogino, Eris, Frey, & Leifer, 2005). Although it becomes a difficult undertaking to strictly confine the differences between DBL and comparable methods, DBL can be regarded as an educational method that engages students in solving real-life design problems while reflecting on the learning process (Mehalik & Schunn, 2006).

Despite the fact that there is substantial research in secondary education relating students' gains in learning science concepts, there is, in contrast, hardly any empirical evidence with respect to the workings of DBL in engineering education. In this regard, little is known of the characteristics that could make DBL a powerful tool in this setting or the way these characteristics are integrated in design-based learning environments.

1.4 Problem statement and focus of this research

This study addresses a theoretical inquiry to define design-based learning as an educational approach. Furthermore, we pursue efforts to identify the DBL characteristics that are suitable for the context of engineering and technical studies. Our interest does not lie in investigating characteristics and approaches to teach students to design; instead, we aim to define the core features of DBL as a theoretical framework to teach students to solve engineering problems using design assignments as a vehicle for learning.

As a result, we are primarily interested in investigating relevant examples in the context of DBL and alike educational approaches implemented in international technical universities, from which we can discover how these features are operationalized in engineering projects. Second, our interest lies in designing a DBL framework, supported by the theory, which allows the redesign of DBL projects in order to improve them. Finally, we are eager to investigate the effects of this DBL framework on teachers, supervisors and students.

We will provide answers to these main questions in a series of research studies devoted to analyzing and investigating the effects of design-based learning as an educational approach. Each study carefully explores in-depth questions. Table 1 provides an overview of this dissertation and presents an outline of the research studies, the relevant research questions, and the research instruments.

1.5 The context of the studies

The rationale to initiate this investigation is built upon several considerations. As stated previously, research on DBL in engineering education is rare, so DBL currently lacks a sound theoretical and empirical basis. In addition, DBL is an educational approach that is, as far as we could ascertain, implemented only in one technical university: Eindhoven University of Technology (TU/e) in the Netherlands. The need to further develop and explore this educational concept, which is still ‘under construction’ from a theoretical and empirical perspective, therefore becomes of paramount importance. Investigating this concept can also bring about gains to the quality assurance and control aspects with respect to the implementation of DBL in the curriculum.

Another consideration relates to the need, as perceived by directors of study of a number of engineering curricula at TU/e, to implement innovations in DBL. The model has not been changed for a number of years, and in relation to curricular reforms, it became clear that the model might be innovated in some respects. Therefore, directors of study and departments were prepared to provide opportunities to research DBL *in vivo* and to assist in implementing professionalization.

Furthermore, the university reflected on its vision on education and the educational programs, which ultimately led to Vision 2030, a guideline for educational policy (Meijers & den Brok, 2013). One of the core elements is the need to provide education in small groups. In this regard, DBL plays a major role in fostering collaborative learning in groups and the development of professional skills in settings resembling engineers’ real-life work environments.

Finally, the ACQA framework of competencies and dimensions (Academic Competencies and Quality Assurance) an instrument developed to evaluate study programs, contributed to the decision to investigate DBL as an educational concept. In summary, we felt the university provided an excellent opportunity for researching DBL.

1.5.1 Relevance of this investigation

1.5.1.1 Relevance for educational theory

This study aims to contribute to the body of scientific knowledge in the domain of engineering education, specifically regarding educational approaches to support students’ learning in gathering and applying knowledge to solve complex engineering problems. In doing so, we look for a DBL theoretical framework based upon empirical research on DBL and similar engineering practices. From these practices, we will derive core educational elements (i.e., what are relevant project characteristics of DBL, what are the most important design elements, what should be the role of the teacher in DBL) to create a foundation upon which to construct a DBL theory. Furthermore, we intend to develop the DBL educational concept with support of the results of empirical research around *design-based learning,* and examples of the practical application of educational theories such as *situated learni*ng and *cognitive apprenticeship.* In this way, we will help illuminate the design-based learning practices used in teaching students to gather and apply knowledge to solve design problems.

1.5.2 Relevance for educational practice

The fact that this research will be conducted in conjunction with the teachers seeking to improve their own classroom practices (Fullan, 2001) adds to the ecological validity of the study and will foster sustainability of results. In addition, this research study should serve to inspire other teachers and educational practitioners at technical universities who wish to apply a theoretical framework based on empirical evidence and refine DBL practices in engineering study. This will be accomplished by providing guidelines for (re-)designing DBL or via guidelines for teachers on how to supervise students in DBL settings most effectively. In addition, the research seeks to provide practical examples, serving as eye openers and best practice models for other educational practitioners to adapt to their own context.

1.6 Methodology: Practice-oriented research

We plan to select an amalgam of research methods for this study, consisting of quantitative surveys; analysis of study materials and project documents following a protocol; observations of teacher, supervisor and student actions in DBL groups; and finally, interviews. All of these methods will be applied with an underlying research principle: to study DBL effects without altering the educational scenario in which DBL is implemented. In addition, we also studied the effects of a professionalization program on teachers and supersvisors. The methods we selected for the studies are therefore practice-oriented and build upon classroom practices. Moreover, our selection is supported by empirical research on the meaning of educational change, as well as factors influencing teacher professionalization (Fullan, 2001; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; van den Akker, 2003).

Research methods like thinking aloud and verbal protocol analysis are commonly used to study the cognitive activities of students solving design problems (Eris, 2008). We are aware of the fact that thinking aloud is a promising method that can serve as a unique source of information to investigate knowledge acquisition (van Someren, Barnard, & Sandberg, 1994). Likewise, verbal protocol analysis is used extensively for detailed empirical studies of design and student performance in solving open-ended engineering design problems (Christiaans & Dorst, 1992; Sutcliffe & Maiden, 1992; Guindon, 1990; Ennis & Gyeszly, 1991; Atman & Bursic, 1996). Despite the advantages of these methods, our intention is to investigate design-based learning in the real life setting of daily DBL students' activities. Our rationale is to study DBL 'in the classroom'. Consequently, we will not carry out in-depth longitudinal studies, but instead apply triangulation of methods to analyze and verify the results.

1.7 Overview of the dissertation

The structure of this dissertation follows the six research studies we conducted to investigate design-based learning. See also Table 1.

Chapter 2 and Chapter 3 are devoted to searching the literature to find characteristics of DBL and define a theoretical DBL framework as an educational concept. In Chapter 2, we explore what design activities are carried out in the professional engineering work setting. To do so, we will adopt the classification used by Mehalik & Schunn (2006) containing fifteen commonly used design activities in the context of software engineering. We then explore what design activities from this classification are also employed in students' projects in the context of technical and engineering education. The design elements are one of the dimensions of our DBL framework. In Chapter 3, we investigate DBL characteristics and classify them in the following dimensions: project characteristics, teachers' roles, assessment, and social context. Furthermore, we define DBL as an educational approach to gathering and applying knowledge in a process of going through many 'learning cycles' of proposing, experimenting, and adjusting.

In Chapter 4, we test the DBL framework developed in Chapter 2 within four engineering departments at the Eindhoven University of Technology: mechanical engineering, electrical engineering, industrial design and environmental building. We conduct a quantitative survey and collect perceptions of second-year bachelor students and their teachers on the DBL dimensions we identified. In order to determine whether there are significant differences between the departments or between the teachers, supervisors, and students, we will conduct relevant statistical analysis. We will also analyze project documents in order to learn whether there are differences between the departments involved.

In Chapter 5, we investigate the methods used in supervising projects at two departments, mechanical engineering and electrical engineering. We will conduct a qualitative study using interviews with teachers and interviews and observations of supervisors in each of these two departments to examine how supervision and facilitation actions are applied and whether these correspond to the DBL framework developed in Chapter 2.

Based on the results of this study, we will develop a teacher professionalization program that seeks to enable teachers and supervisors to redesign DBL projects according to our DBL theoretical framework (Chapter 6). The professionalization program focuses on interventions situated in the context of engaging teachers in inquiring and researching their own practices and in reflecting on their own concrete classroom situations and educational practices, together with colleagues. We will then evaluate the effects of the professionalization program.

Chapter 7 presents the main results of our explorative study of the effects of design-based learning in two departments using four projects. Finally, in Chapter 8 we summarize the main findings of our research. Subsequently, we reflect on methodological considerations, the theoretical impact, and the relevance of our research. We then consider implications for further research.

For a general summary of this investigation, see page 211.

Table 1 Overview of the dissertation

Study & Year	Phase and research area	Research questions	Instruments
Chapter 1	Introduction		
Chapter 2 2010	Research on DBL characteristics in international technical universities	1. Which design elements of the professional practice of engineering design are common in DBL and which are not? 2. In what respect is DBL either domain-specific or generic? 3. In what respect does DBL account for developing the expertise of learners? 4. Which elements of the professional practice of engineering design are common to DBL in authentic settings?	Literature review
Chapter 3 2010	DBL theoretical framework	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?	Literature review
Chapter 4 2011	Case study: Testing DBL theoretical framework in four engineering departments	1. To what extent do the perceptions of teachers and students in different engineering departments identify the presence of DBL characteristics in the projects assigned? 2. To what extent are DBL characteristics encountered in the projects assigned across the different engineering departments?	Quantitative – Likert scale survey Analysis of DBL project documents following a protocol Member check interview with teachers to verify

			findings of analysis of project documents
Chapter 5 2012	Inventory of teachers' and supervisors' supervision actions	1. To what extent do teachers' and supervisors' actions in facilitating and supervising students in our case represent the DBL characteristics found in the literature?	Qualitative – Interviews & observations of teachers, supervisors and students; Second researcher to verify findings
Chapter 6 2012	Professionalization program for teachers and supervisors	1. To what extent have the Mechanical Engineering and Electrical Engineering teachers applied the DBL theoretical framework in the redesign of the projects as a result of a professionalization program using the Experiential Learning Cycle as an educational method? 2. Are there improvements in the redesign of these projects when compared to the projects of our previous study?	Analysis of redesigned projects Second researcher to verify findings
Chapter 7 2012/2013	Exploring the effects of DBL characteristics on teachers, supervisors and students	1. What are the effects of the professionalization program on teachers' and supervisors' opinions and behaviors? 2. Does the program lead to changes in the project implementation? 3. What are the effects on students' opinions and behaviors in the projects as a result?	Quantitative – Likert scale survey Qualitative – Interviews and observations teachers, supervisors and students Second researcher to verify findings
Chapter 8	Conclusions & discussion		

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Chapter 2

… What is authentic is typically ill-defined but involves a strong emphasis on problems such as those students might encounter in everyday life…

Brown, Collins, & Duguid, 1989[2]

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Chapter 2

Towards characterising design-based learning in engineering education: a review of the literature[3]

Abstract

Design-based learning is a teaching approach akin to problem-based learning but one to which the design of artefacts, systems and solutions in project-based settings is central. Although design-based learning has been employed in the practice of higher engineering education, it has hardly been theorised at this educational level. The aim of this study is to characterise design-based learning from existing empirical research literature on engineering education. Drawing on a perspective that accounts for domain-specific, idiosyncratic and learner-centred aspects of design problems in the context of engineering education, 50 empirical studies on project-based and problem-based engineering education, to which the design of artefacts is central, were reviewed. Based on the findings, design-based learning is characterised with regard to domain-specificity, learner expertise and task authenticity. The implications of this study for the practice of engineering education are discussed.

Keywords: design-based learning; problem-based learning; project-based learning; design tasks

2.1 Introduction

Design-based learning (DBL) is an instructional learning approach, which students in engineering design embark upon (Mehalik & Schunn, 2006). Taking the design of artefacts as being central, it borrows features from problem-based learning (PBL) (Gijselaers, 1996) and from problem oriented project-based learning (Kolmos, 2002). In both secondary and tertiary education, DBL has been coined as a fruitful approach to learning engineering design (e.g. Wijnen, 2000, Mehalik, Doppelt, & Schunn, 2008).

Research has yielded empirical specifications for setting up and conducting DBL at the level of secondary science and technology education (e.g. Apedoe, Reynolds, Ellefson, & Schunn, 2008). However, in higher education DBL has been hardly investigated empirically and little is known of its characteristics at this level. Hence, the aim of this study is to characterise DBL as an approach to higher engineering education.

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In what follows, this paper first provides an overview of the practical and theoretical background of the state of the art of DBL in higher education. This background shapes theoretical perspective, which accounts for domain-specific, idiosyncratic and learner-focused aspects of engineering education. Next, by drawing on this perspective, 50 journal articles on project-based and problem-based engineering education, to which the design of artefacts and solutions is central, were reviewed. Based on the findings, DBL is characterised in both domain-specific and generic ways, thereby pointing out critical similarities and differences with the professional practice of engineering design itself. Finally, this characterisation is explained in light of educational considerations underpinning engineering education and the implications of this study for the practice of engineering education are discussed.

2.2 Background

This section sketches the practical and theoretical background of the review study. The practical educational context underlying this study concerns the introduction of DBL as a leading principle for engineering education at Eindhoven University of Technology, now more than 10 years ago. This introduction not only yielded some preliminary characterising principles of DBL but also induced a need for further theoretical clarification of the concept and hence this literature study. This section ends by pointing out the theoretical considerations underpinning this literature study.

2.2.1 Practical context

The transition towards more learner-centred (constructivist) curricula in higher education can be taken as a particular of a worldwide recognition that the amalgam of skills and knowledge required for complex activities such as design can best be learned by doing. In technology-oriented universities in particular, this resulted in an increased interest in both PBL and project-organised learning. DBL has been coined from these two active approaches, borrowing learner-centred educational principles as well. Consequently, the aim of this concept is to motivate students as creative professionals to collectively apply knowledge and skills in newly designed systems, thereby highlighting six features, such as professionalisation, activation, cooperation, authenticity, creativity, integration and multidisciplines (Wijnen, 2000).

DBL was introduced in 1997 at the Eindhoven University of Technology and it has adopted specifics from the PBL model from Maastricht University (Gijselaers, 1996) and from the Aalborg University model of problem-oriented, project-based learning (Kolmos, 2002). Initially, DBL had been developed as the university's central educational concept. The educational form that DBL took at the beginning in the different study programmes was based on discussions with directors of studies from the different departments (Wijnen, 1999). Likewise, study tours with groups of students and teaching staff were organised to learn from the project work model of Aalborg and Roskilde universities in Denmark (Perrenet & Pleijers, 2000). As a result of these experiences, DBL resembled project-like characteristics in each department. The introduction of DBL was initiated, therefore, to build experiences upon practices. This was taken as an initial step to create a platform for further innovation (Perrenet, Bouhuijs, & Smits, 2000). In this way, the six DBL-characteristics were typified and worked out to give direction for further development and integration of DBL in the study programmes (Wijnen, Zuylen, Mulders, & Delhoofden, 2000). For some programmes, the implementation of DBL led to the introduction of projects into the curriculum; whereas for others, it implied the incorporation of some educational elements in the existing projects (i.e. tutoring at the Mechanical Engineering Department). Another representation of the project work was the competence-based curriculum at the Industrial Design Department, which, as a very innovative model, has students and teachers work as junior-senior employees in realistic contexts.

DBL has been implemented for over the past 10 years but it is a concept that still needs further development. The aim of this study, therefore, is to characterise DBL as an educational concept in higher engineering education.

2.2.2 Design-based learning in higher engineering education

Approaches centred on design problems in project-based settings are widely employed in higher engineering education. Some researchers even more strongly suggest that design exercises traditionally shape the core of design education (e.g. Dorst & Reymen, 2004). Nevertheless, DBL is not always explicitly attributed to such ‘DBL-like’ exercises. For the purpose of this study, therefore, DBL is broadly defined to include both the concept of DBL as it has been introduced at the university as well as the many ‘DBL-like approaches’ described in the literature. Hence, DBL is taken as a teaching approach akin to PBL and to which the design of artefacts, systems or solutions in project-based settings is central.
In the empirical research literature, DBL has been studied mostly in the context of secondary science education (e.g. Roth, 2001; Ellefson, Brinkers, Vernacchio, & Schunn, 2008). Here, DBL has been employed as a vehicle for the learning of science rather than explicitly preparing for the professional practice of engineering design. This orientation does not account for epistemologies inherent to technology (van Eijck & Claxton, 2009). Consequently, empirical studies on DBL in the context of secondary education often do not account for the idiosyncratic and domain-specific nature of the practice of engineering design. Hence, the outcomes of these studies cannot be transferred straightforwardly to the practice of higher engineering education.

In the context of DBL in higher education, one theoretical framework has been developed in which a more integrated, meta-perspective on design points out ways by which design can be used as an effective vehicle for learning (Mehalik & Schunn, 2006). Drawing on 40 empirical studies on the nature of engineering design processes, this classification comprised both a taxonomy of engineering design elements and an indication of the frequency that these elements were reported to (potentially) constitute good design. The result is a classification of 15 design elements associated with (potentially) good design, which are reported with high, moderate or low frequency in the literature (Table 1). Particularly, the different reporting frequencies of the elements account for the idiosyncrasy.

Table 1 Database of reviewed journals

International Journal of Engineering Education	11
European Journal of Engineering Education	7
International Journal of Mechanical Engineering Education	3
Journal of Engineering Technology	1
American Journal of Physics	1
Design Studies (Elsevier)	1
Chemical Engineering Education	2
Biochemistry and Molecular Biology Education	1
Computer Applications in Engineering Education	1
Progress in Robotics, Communications in Computer and Information Science	1
IEEE Transactions of Education	16
Journal of Information Technology Education: Innovations in Practice	1
Computer Science Education	1
Journal of Learning Sciences	1
Journal of Professional Issues in Engineering Education	1
Interactive Learning Environments	1
Total	50

Although the classification of Mehalik & Schunn (2006) provides some detail of possible objectives and activities inherent to DBL, it also induces problems for further research. For instance, whereas this classification focuses on the professional practice of engineering design, it is yet unknown which activities support students' preparation for such a practice and what this implies for the nature of DBL-based curricula in higher engineering education. Inherently, there is a need to better understand the student expertise required for particular design activities. Furthermore, given that educational practices, as compared to professional practices, are constrained in several ways, more empirical detail is required to understand in what respect the professional practice of engineering design can function as a model for engineering design curricula. In addition to the practical aim to contribute to a better foundation of the concept of DBL in this university, this characterisation of DBL is oriented towards these gaps in the empirical literature to provide insights for educational practitioners.

2.1.3. Theoretical considerations

Given the foregoing, particular theoretical considerations are drawn on to further characterise DBL from the empirical literature. The first consideration follows from the given that the professional design enterprise is idiosyncratic in nature. On the one hand, it is recognised that characterisation of the practice of engineering design into elements such as those from Mehalik & Schunn (2006) is arbitrary. Inherently, such a classification renders design practices to particular generics that ultimately do not account for its idiosyncratic nature (Latour, 1987; Dorst, & van Overveld, 2009).

However, a classification system of design elements may be helpful to identify whether and how design elements common to professional engineering design play a role in DBL in higher engineering education. Because of its fine-grained typology of design elements, the instrument of Mehalik & Schunn (2006) is adopted. Yet, in using this instrument, it is recognised that these elements (see Table 2) in the professional practice of engineering design do not necessarily need to be sequenced one after another in time and may be present in various constellations in different forms of DBL.

Second, related to the intrinsic nature of design is its domain-specific nature. The present authors are committed to the overwhelming empirical evidence from the past 40 years that the learning of techno-scientific knowledge and skills is highly domain-specific (e.g. Duit, 2009). Therefore, in the characterization of DBL the differences between domains regarding the nature of design problems, as well as the relevance of particular design activities for solving these problems, are taken into account.

Third, the given that engineering design education is akin but certainly not identical to the professional practice of engineering design is drawn on. On the one hand, learning, especially in the context of preparation for complex practices such as design, can be taken as a form of participation in this practice (cf. Lave & Wenger, 1990). Accordingly, DBL may include activities akin to those in professional engineering practices, eventually being fully authentic and taking place in these practices. Indeed, the six DBL characteristics is an attempt to model DBL authentically according to professional engineering practices. On the other hand, newcomers, because of their underdeveloped professional expertise, conduct particular activities in order to become experts themselves. They are not employed by experts but help to develop that expertise gradually (Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007). Hence, it is recognised that higher engineering curricula employing DBL-like activities are simultaneously akin to and different from professional engineering practices and exhibit different levels of authenticity.

Table2 Design elements constituting good

Explore problem representation
Use interactive/iterative design methodology
Search the space (explore alternatives)
Use functional decomposition
Explore graphic representation
Redefine constraints
Explore scope of constraints
Validate assumptions and constraints
Examine existing designs
Explore user perspective
Build normative model
Explore engineering facts
Explore issues of measurement
Conduct failure analysis
Encourage reflection on process

∗According to Mehalik & Schunn (2006).

2.2.3 Research questions

Given the theoretical considerations, the aim herein is to answer the following questions in characterising current DBL as described in the empirical literature:
(1) Which design elements of the professional practice of engineering design are common in DBL and which are not?
(2) In what respect is DBL either domain-specific or generic?
(3) In what respect does DBL account for developing the expertise of learners?
(4) Which elements of the professional practice of engineering design are common to DBL in authentic settings?

2.3 Review approach

This section explains how the journals and articles were selected for the review. The analytical approach yielding the review of the literature is then illustrated.

2.3.1 Selection of journal articles

To obtain articles for review, journals were selected that are likely to publish on educational engineering design practices indexed in the ISI Web of Science and the Education Resources Information Centre databases. A list of accepted journals of The Interuniversity Centre for Educational Research[4] was also obtained. To obtain a selection of potential useful articles,

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[4] **Note:** The Interuniversity Centre for Educational Research is the Dutch PhD research school for educational sciences formally recognised by the Royal Netherlands Academy of Arts and Sciences. The academic board of the organisation maintains a list of non-ISI journals of acceptable academic quality in which its members can publish (http://www.ou.nl/eCache/DEF/1/93/759.html).

the 16 selected journals were screened by using the following keywords: ‘problem-based learning’; ‘project-based learning’; ‘design-based learning’; ‘engineering design process’; ‘design education’; ‘design tasks’; ‘engineering education’. In the selection of the articles emphasis has been made to cover a representation of engineering disciplines, such as mechanical engineering, electrical engineering, civil and environmental engineering, mining engineering, computer science, chemical, biomedical engineering and physics, among other subjects. In accordance with the definition of DBL, articles were finally selected that described problem-based, project-based learning or comparable instructional active learning methods (e.g. scenario assignments) to which the construction of artefacts or systems was central. The preliminary selection was limited to 50 articles.

2.3.2 Classification of articles

Drawing on the theoretical considerations, several characteristics potentially relevant to DBL were determined for each article. First, to get an understanding of elements of professional design processes common to the practice of design considered significant for DBL, the reporting frequency of design elements over all articles was counted. Here, the classification of design elements of Mehalik & Schunn (2006) was followed. Since this classification consisted of precise coding of design activities reported in the articles, a second researcher independently recoded dubious cases identified by the first researcher. Yielding an initial agreement of 84%, all disagreements were resolved through discussion. Furthermore, to allow comparison with the practice of professional design, the reporting frequency of design elements in the study were counted and they were compared with the design elements classified in the taxonomy of Mehalik & Schunn (2006).

An element was included in the ‘high reporting’ category if it was focused on in more than 50% of the articles. The element was considered to be in the ‘moderate reporting’ category if it was focused on in 25–50% of the articles. Finally, elements that were reported in fewer than 25% of the articles were included in the ‘low reporting’ category.

Second, to get an understanding of the domain-specificity of DBL, the articles were organised into three main areas according to a classification of engineering adapted from the university library. These are mechanical engineering, electrical engineering and the cluster of biomedical, chemistry and environmental engineering. Under electrical engineering, both electrical and computer engineering (hardware) and computer sciences and telecommunications engineering (software) have been clustered. One final category included the rest of the domains, such as physics, civil engineering, architecture or industrial design and graphics. Third, to account for the level of expertise, the articles were classified according to whether they concerned courses in either graduate or undergraduate programmes or in both.

Finally, to provide detail about the authenticity of design tasks, artificial design activities were distinguished from authentic design activities. The former activities were defined as being fully carried out in educational institutions without any involvement of experts in professional engineering practice.

2.4 Findings

The results are presented in Table 2. For each design element, its frequency in the articles is given, as well as how its frequency is divided over: (a) different engineering domains; (b) educational levels; (c) authentic and artificial design activities. In the remainder of this section, these findings are briefly sketched in light of the research questions.

2.4.1 DBL compared to studies on engineering design

To gain an overview of the design elements the classification of Mehalik & Schunn (2006) were compared (Table 1), emphasising engineering design, with the results of this study (Table 2), emphasising DBL-like engineering education. The present findings reveal differences in reporting frequencies of design elements between DBL and the professional practice of engineering design. Several design elements are reported with high frequency in engineering education (see Table 3) and with low or moderate frequency in professional engineering design (see Table 2): Build normative model; Explore issues of measurement; Validate assumptions and constraints; Explore graphic representation. Conversely, several design elements are reported with low or moderate frequency in the literature on DBL and with high frequency in the literature on professional engineering design: Use interactive/iterative design methodology; Search the space (explore alternatives); Use functional decomposition. All these cases point to differences between the professional practice of engineering and DBL. Reported frequencies in the literature on both the professional practice of design and DBL are comparable only for the design elements 'Explore problem representation', 'Explore scope of constraints', 'Explore user perspectives', 'Conduct failure analysis', and 'Encourage reflection on process'.

Table 3 Design elements constituting good design and their reporting frequency in empirical studies on DBL in higher engineering education categorised according to domain, educational level and authenticity

Design Stages	Domain (%)				Level (%)			Authenticity (%)		Total (%)
	ME (N=6)	EE (N=25)	BCEE (N=7)	Other (N=12)	UnGr (N=38)	Gr (N=9)	Both (N=3)	Artif (N=39)	Auth (N=11)	(N=50)
Explore problem representation	50	72	100	92	74	89	100	79	64	78
Use interactive/iterative design methodology	17	24	29	42	29	22	33	28	27	28
Search the space (explore alternatives)	50	36	57	33	42	11	100	38	45	40
Use functional decomposition	17	36	29	17	29	22	0	31	0	28
Explore graphic representation	83	80	71	75	79	78	33	85	36	78
Redefine constraints	33	16	29	8	18	0	67	15	18	18
Explore scope of constraints	33	32	29	8	26	11	67	26	18	26
Validate assumptions and constraints	67	80	100	92	89	78	67	92	55	86
Examine existing designs	17	0	29	0	5	11	0	8	0	6
Explore user perspective	17	28	14	33	21	33	67	21	45	26
Build normative model	100	92	100	92	95	100	100	100	55	96
Explore engineering facts	33	36	14	17	26	22	33	28	9	28
Explore issues of measurement	33	68	57	42	61	33	67	56	36	56
Conduct failure analysis	17	8	14	0	5	0	33	8	0	6
Encourage reflection on process	17	8	29	25	16	0	33	10	27	16

Notes Abbreviations used: ME = mechanical engineering; EE = electrical engineering; BCEE = biochemical, chemical, and environmental engineering; UnGr = undergraduate; Gr = graduate; Artif = artificial activities; Auth = authentic activities. Shading indicates a classification of reporting frequencies according to Mehalik and Schunn (2006): dark grey = high reporting frequency (100%-50%); light grey = moderate reporting frequency (50% to 25%); blank = low reporting frequency (25% to 0%). See also Table 1.

2.4.2 Domain-specificity

For particular design elements, some domains reveal reporting frequencies that deviate substantially from the other domains. For instance, the design element ‘Explore problem representation’ is reported with a lower frequency in mechanical engineering in comparison with the other domains. The difference in frequency among disciplines is also to be found in, for instance, ‘Explore issues of measurement’, which is remarkably lower in mechanical engineering than in the other disciplines, such as in electrical engineering. Interestingly, the design element ‘Build normative model’ does not differ substantially between all domains.

2.4.3 Learner expertise

Regarding the level of expertise, the differences between undergraduate and graduate level in reported frequencies of design elements are generally low. Exceptions are found in the design elements ‘Search the space (explore alternatives)’, ‘Redefine constraints’, ‘Explore scope of constraints’, ‘Explore issues of measurement’ and ‘Encourage reflection on process’, which are reported less frequently in articles concerning DBL in graduate programmes. In addition to this, there are some other design elements such as ‘Examine existing designs’, ‘Explore problem representation’, ‘Explore user perspective’, ‘Build normative model’, which are reported more frequently in articles focusing on the graduate level.

2.4.4 Authenticity

Finally, some substantial differences between authentic and artificial forms of DBL are observable. Particularly, the design elements ‘Use functional decomposition’, ‘Explore graphic representation’, ‘Validate assumptions and constraints’, ‘Build normative model’, ‘Explore engineering facts’ and ‘Explore issues of measurement’ are reported more frequently in articles on artificial courses than in articles on authentic courses. Conversely, counts for ‘Explore user perspective’ and ‘Encourage reflection on process’ are reported more frequently in articles on authentic courses than in articles on artificial courses.

2.5 Conclusions and implications

This section summarises the findings of the review and sketches some implications for both higher engineering design education and further research on DBL.

2.5.1 Characteristics of current DBL in higher engineering education

Regarding the reporting frequency of design elements, the characterisation of DBL reveals some critical differences with professional practice of engineering design. Most design elements are reported with either a substantial higher or lower frequency in the literature on DBL than in the literature of design studies. Furthermore, some design elements were found, which were reported in every article on DBL and in association with every domain, whereas others were reported in differing frequencies over different domains. Hence, DBL exhibits domain-specific elements as well as generic aspects. Strikingly, current DBL does not account substantially for developing expertise of learners with regard to either graduates or undergraduates. Regarding the reporting frequency of design elements in articles on DBL, only moderate differences were found between undergraduate and graduate courses. With regard to authenticity, some striking differences were found in reporting frequencies of design elements. That is, in articles on DBL in authentic settings, some design elements were reported substantially more frequently than in articles on DBL in artificial contexts.

Finally, in this study, several differences were found between DBL on the one hand, and good design as reported by Mehalik & Schunn (2006) on the other hand. Based on this, it is concluded that DBL is not necessarily equivalent to good design practice. Rather, DBL comprises a set of activities that prepare students for good design practices. Although DBL and good design may share many characteristics, a better understanding of DBL in educational settings implies, among other issues, considerations of how to adapt and adjust characteristics of good design practices to educational activities that support and prepare students for such a practice. This requires further research in curriculum design and in instructional approaches.

2.5.2 Implications for higher engineering design education

The substantial differences in reporting frequencies of design elements between the literature on professional design and current DBL induces the question of in what respect the latter can be considered either preparatory for the practice of design or a vehicle for learning specific design elements, such as ‘Building a normative model’ or ‘Exploring graphic representations’. On the other hand, since such design elements are relatively easily assessable as products, the high reporting frequency in DBL may also be caused by specific constraints of education in undergraduate courses in particular, such as efficiency, testability and accountability. Nonetheless, these findings imply that engineering educators should consider the precise pedagogical function of DBL in their educational programmes. The pertinence of this implication also follows from the substantial differences in reporting frequencies of design elements between either professional design practices or DBL, as well as between either authentic or less authentic contexts. Especially, the latter finding induces the question of in what respect is DBL in artificial settings preparatory for the professional practice of designers. This is not necessarily the case. For instance, DBL in artificial settings in undergraduate courses may be predominantly used as a vehicle to learn particular engineering skills more generally. If this is the case, such courses may be appropriate vehicles to learn skills associated with more generic design elements in DBL, such as ‘Building a normative model’, ‘Exploring problem representation’, ‘Exploring graphic representations’ and ‘Validate assumptions and constraints’. On the other hand, if expert participation in the professional practice of design is the ultimate aim of DBL, the developing expertise in the route from novice to expert through undergraduate and graduate courses should imply careful consideration. Particularly relevant are the nature of both the design activities to be practised and the authenticity of the context wherein these activities are conducted. Such considerations may support educators to develop curricula that reflect more substantial differences between undergraduate and graduate forms of DBL. Related to this implication is the consideration of the domain-specificity of design courses.

Given that DBL is domain-specific, every course should be developed accordingly. Nevertheless, educators should also be aware of more generic elements of DBL in the design of curricula, from novice to professional expertise.

2.5.3 Implications for further research on DBL in higher engineering design education

The outcomes point out a need for further research in several directions. One avenue for further explorations concerns the question of in what respect DBL can be considered either as preparatory for the practice of design or as a vehicle for learning specific design elements. This requires empirical research in association with educators who employ forms of DBL that are comparable to the ones reported in the literature. Of critical importance is the question of how the learning outcomes of these forms of DBL are considered and how these relate to levels of authenticity and learner expertise. Also relevant is the question of to what respect goals reported as relevant to DBL educators are either generic aims or specific to their domain. Another avenue for further research concerns the substantial differences in reporting frequencies of design elements in the literature on DBL either in itself or as related to the professional literature. This opens up the question of which design elements are considered relevant to educators for what particular reasons, as related to the domain they are working in, the outcomes of their courses and, related to the former implication, the authenticity and domain-specificity of the setting of their courses. Again, this requires empirical research in collaboration with professional educators developing and conducting DBL-like courses in higher engineering education. It also requires further research to gain insights from the literature in curriculum and instructional approaches related to the practice of engineering design education.

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Chapter 3

…DBL enables students to experience the
construction of cognitive concepts
as a result of designing and making individual,
inventive, and creative projects…

Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008[5]

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[5] 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.

Chapter 3
A sampled literature review of design-based learning approaches: a search for key characteristics[6]

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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3.1 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, De Graaff, & Du, 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-alike 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 analyse 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.

3.2 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 & 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, Agogino, Eris, Frey, & Leifer, 2005; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 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 & Kolmos, 2003; Mooney & 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, Agogino, Eris, Frey, & Leifer, 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, Reynolds, Ellefson, & Schunn, 2008; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 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, Reynolds, Ellefson, & Schunn, 2008), but also to engage students in authentic engineering design methods (Mehalik, Doppelt, & Schunn, 2008). Research studies have demonstrated the effectiveness of approaches such as learning by design (LBD) (Kolodner, Camp, Crismond, Fasse, Gray, & Holbrook, 2003) and design-based science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 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, Camp, Crismond, Fasse, Gray, & Holbrook, 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, Camp, Crismond, Fasse, Gray, & Holbrook, 2003; Scaffa & 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, Camp, Crismond, Fasse, Gray, & Holbrook, 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, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). In DBS, however, design takes place first and iteration focuses on different science concepts (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 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.

3.2.1 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, Agogino, Eris, Frey, & Leifer, 2005; Dym & 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 & 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, Collins, & Duguid, 1989; Miller & Olds, 1994; Roth 1995; Roth, van Eijck, Reis, & Hsu, 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, Boshuizen, & Schmidt, 1996; Dym, Agogino, Eris, Frey, & Leifer, 2005; Jonassen, Strobel, & Lee, 2006; Lawson & 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 & 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, Brown, & Newman, 1989; Collins, 2006); situated cognition (Lave & Wenger, 1991) and constructivist learning environments (Jonassen & Rohrer-Murphy, 1999), which advocate authentic learning tasks to stimulate meaningful and complex learning (van Merriënboer & Kirschner, 2007). Supporting students to learn to manage the complexity of real-life professional practice in authentic situated tasks (Kolodner, Camp, Crismond, Fasse, Gray, & Holbrook, 2003; Collins, Brown, & Newman, 1989; Lave & 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, Camp, Crismond, Fasse, Gray, & Holbrook, 2003, Collins, Brown, & Newman, 1989; Lave & Wegner, 1991). Thus, we are interested in project features of authenticity that guide students into the professional practice in particular.

3.2.2 Role of the teacher

The teacher has a role as a facilitator of learning in the literature on problem-based (Hmelo-Silver, Duncan, & Chinn, 2007; Moust & Schmidt, 1994; Moust, van Berkel, & Schmidt, 2005; Schmidt, van der Arend, Kokx, & Boon, 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, Duncan, & Chinn, 2007; Ramaekers, 2011; Schmidt, Loyens, van Gog, & Paas, 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, Adams, Cardella, Turns, Mosborg, & Saleem, 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, Magda, & Rikers, 2008; Vermunt & 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.

3.2.3 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, van de Watering, & Dochy, 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 & Wiliam, 1998; Hattie & 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.

3.2.4 Social context

Design tasks are generally conducted collaboratively in a community of practice in contextualized situations (Lave & 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 & Mohammed, 2006). Peer-to-peer activities such as providing feedback are also encountered in the literature as effective methods in collaborative learning (Tien, Roth, & Kampmeier, 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.

3.3 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?

3.4 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.

3.4.1 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, van Eijck, & Jochems, 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.

3.4.2 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 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.

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

3.5 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.

3.5.1 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, Atorf, Schwann, Neumann, Schnitzler, & Balle, 2010; Chinowsky, Brown, Szjnman, & Realph, 2006; Roberts, 2001; Hirsch, Shwom, Yarnoff, Anderson, Kelso, & Olson, 2001; Denayer, Thaels, Vander Sloten, & Gobin, 2003; Wood, Campbell, Wood, & Jensen, 2005; Mese, 2006; Maase, 2008; Nonclercq, Van der Biest, De Cuyper, Leroy, López, & Robert, 2010), authentic (Linge & Parsons 2006; Mckenna, Colgate, Carr, & Olson, 2006; Massey, Ramesh, & Khatri, 2006), hands-on (Wood, Campbell, Wood, & Jensen, 2005; Kalkani, Boussiakou, & Boussiakou, 2005; Lee, Su, Kuo-En Lin, & Gu-Hong, 2010), real-life (Macías-Guarasa, Montero, San-Segundo, Araujo, & Nieto-Taladriz, 2006; McKenna, Colgate, Carr, & Olson, 2006; Van Til, Tracey, Sengupta, & Fliedner, 2009), and multidisciplinary (Macías-Guarasa, Montero, San-Segundo, Araujo, & Nieto-Taladriz, 2006; Nonclercq, Vander Biest, De Cuyper, Leroy, López, & Robert , 2010; Selfridge, Schultz, & Hawkins, 2007; Kundu & 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, McKenna, & Youssefi, 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, Ramesh, & Khatri, 2006; van Til, Tracey, Sengupta, & Fliedner, 2009). In this authentic settings, faculty staff performs different roles as users, costumers, or consultants (Denayer, Thaels, Van der Sloten, & Gobin, 2003; Martínez Monés, Gómez Sánchez, Dimitriadis, Jorrín Abellán, & Rubia Avi, 2005).

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 & Deek, 2005;Kimmel et al., 2003; Linge & 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,2009; Wood et al., 2005; Zhan & 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 & 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 &Özyalçin, 2010; Nooshabadi & 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 & Fowler, 2009; Macías-Guarasa et al., 2006; Nonclercq et al., 2010; Selfridge et al., 2007.

3.5.2 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.

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, Yeh, Pan, Liao, & Chang, 2008; Etkina, Murthy & Zou, 2006; Roberts, 2001; van Til, Tracey, Sengupta, & Fliedner, 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 learners in learning to design. Other examples of scaffolding students’ gaining content knowledge include on-line quizzes, discussions (Cheville, McGovern, & Bull, 2005; Maase, 2008), worksheets with questions or the use of a solution plan (Etkina, Karelina, Ruibal-Villasenor, Rosengrant, Jordan, & Hmelo-Silver, 2010; Kimmel & Deek, 2005; Lyons & Brader, 2004).

We also find examples of guided instructional approaches focusing on meta-cognitive activities to help students to analyze learning processes. Geber, Mckenna, Hirsch, & Yarnoff (2010), Clyde & Crane (2003), Massey, Ramesh, & Khatri (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, Thaels, Van der Sloten & Gobin, 2003; Martínez Monés, Gómez Sánchez, Dimitriadis, Jorrín Abellán, & Rubia Avi, 2005; Massey, Ramesh, & Khatri, 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, Shwom, Yarnoff, Anderons, Kelso, & Olson, 2001; Mckenna, Colgate, Carr, & Olson, 2006).

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 & Crane, 2003; Denayer et al., 2003; Etkina et al., 2006; Etkina et al., 2010; Geber et al. 2010,; Hirsch et al., 2001; Kimmel et al. 2003; Mckenna et al., 2006; Martínez Monés et al., 2005; Maase, 2008; Massey et al., 2006; Lyons & Brader, 2005; Roberts, (2001; van Til et al., 2009.

3.5.3 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, Atorf, Schwann, Neumann, Schnitzler, & Balle, 2010; Chang, Yeh, Pan, Liao, & Chang, 2008). 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, Montero, San-Segundo, Araujo & Nieto-Taladriz, 2006; Martínez Monés, Gómez Sánchez, Dimitriadis, Jorrín Bellán, & Rubia Avi, 2005; Massey, Ramesh, & Khatri, 2006; Nooshabadi & Garside, 2006; Chang, Yeh, Pan, Liao, & Chang, 2008; Cheville, McGovern, & Bull, 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 & 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, 2005; Chang, Yeh, Pan, Liao, & Chang, 2008; Cheville, McGovern, & Bull, 2005; Baley, 2006; 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, Thaels, Van der Sloten, & Gobin, 2003; Cheville, McGovern, & Bull, 2005; Chang, Yeh, Pan, Liao, & Chang, 2008; Macías-Guarasa, Montero, San-Segundo, Araujo, & Nieto-Taladriz, 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 & Porter, 2010). In design scenarios (Mckenna, Colgate, Carr, & Olson, 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, Thaels, Van der Sloten, & Gobin, (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.

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 & 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, 2009; Stiver, 2010; Zhan & Porter, 2010.

3.5.4 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 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, Thaels, Van der Sloten, & Gobin, 2003; Linge & Parsons, 2006; Massey, Ramesh, & Khatri, 2006; Mckenna, Colgate, Carr, Olson, 2006; Shyr, 2010). Other examples of students resembling expert communication is by having students play roles as, for instance, engineers and customers (Martínez Monés, Gómez Sánchez, Dimitriadis, Jorrín Bellán & Rubia Avi, 2005; Nonclercq, Van der Biest, De Cuyper, Leroy, López, & Robert, 2010). We find also examples of active participation of students with their peers in the social environment by holding presentations of prototypes (Behrens, Atof, Schwann, Neumann, Schnitzler, & Balle, 2010; Mckenna, Colgate, Carr, & Olson, 2006; Cheville, McGovern, & Bull, 2005; Wood, Campbell, Wood, & Jensen, 2005; Zhan & Porter, 2010). Another feature related to the social context of the projects is motivation. Motivation is encouraged by holding competitions (Kundu & Fowler, 2009; Massey, Ramesh, & Khatri, 2006; Wood, Campbell, Wood, Jensen, 2005) or by giving students the ownership of both products and processes (Roberts, 2001; Nonclercq, Van der Biest, De Cuyper, Leroy, López, & Robert, 2010).

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 &Parsons, 2006; Martínez Monés et al., 2005; Massey et al., 2006; Mckenna et al., 2006; Nonclercq et al.; 2010; Shyr, 2009;
	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 &Fowler, 2009; Massey et al., 2006; Roberts,2001; Wood et al., 2005; Zhan & Porter2010.

3.6 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 formative 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.

3.7 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.

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Chapter 4

…Workplace engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom; therefore, learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems…

Jonassen, Strobel, Lee, 2006[7]

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Chapter 4

Empirical Validation of Characteristics of Design-Based Learning in Higher Education[8]

Abstract

Design-based learning (DBL) is an educational approach in which students gather and process theoretical knowledge while working on the design of artifacts, systems, and innovative solutions in project settings. Whereas DBL has been employed in the practice of teaching science in secondary education, it has barely been defined, let alone investigated empirically, at the level of the higher education setting. The purpose of this study is to investigate empirically to what extent pre-defined DBL characteristics are present in an exemplary DBL practice in technical studies. As an exemplary case, we took four different engineering departments from a technical university in which DBL has been implemented as a central form of instruction. First, we conducted a survey to collect teachers' and students' perceptions on whether DBL characteristics were, in fact, present in assignments and projects. Second, teaching materials and student products from three projects were analyzed qualitatively. We found that teachers and students recognized DBL characteristics as part of the instruction, albeit to a varied extent. We found considerable differences between departments, particularly in the characteristics of the projects, the role of the teacher, and the design elements. Analysis of DBL teaching materials and student products revealed that not all DBL characteristics are embedded in the projects over all departments. Implications for further research are discussed to optimize the instructional design of DBL environments.

Keywords: design-based learning; DBL; design thinking; engineering education; instructional design

4.1 Introduction

The vision of the engineer of the future is to work collaboratively in multidisciplinary teams of technical experts to develop solutions, communicate with stakeholders, and serve diverse societal problems (Clough, 2004). Contemporary trends and instructional design practices in engineering education advocate situated learning tasks in scenarios (Brown, Collins, & Duguid, 1989), in which students learn to perform as engineers to communicate, plan and organize information, and process it to solve ill-defined problems. Furthermore, attempts to characterize cognitive processes of how engineers think and iteratively approach design

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tasks refer to scoping the problem, making estimates and dealing with ambiguity, conducting experiments, and finally, making decisions by evaluating results to meet the needs of the users (Dym, & Little, 2009; Atman, Adams, Cardella, Turns, Mosberg, & Saleem, 2007). In doing so, students work on open-ended and hands-on experiences, approaching problems from multiple perspectives. In these assignments, students propose innovative solutions in assignments, experimenting, making decisions, and meeting the needs of end-users (Lawson, & Dorst, 2009; Dym, Agogino, Eris, Frey, & Leifer, 2005). In this educational approach, teams of students engage in multidisciplinary engineering assignments and integrate and apply knowledge to generate solutions, artifacts, and systems (Wijnen, 2000).

Design is an intrinsic activity in solving complex engineering tasks. Design is defined as a process of conceiving or executing a plan transforming initial ideas into a final product (Dym & Little, 2009). In this process of constructing devices, systems and processes, knowledge is acquired by looking at the problem from different perspectives, experimenting with various solution directions, making proposals, and learning from results (Lawson & Dorst, 2009; Dym, Agogino, Eris, Frey, & Leifer, 2005; Wijnen, 2000; Gómez Puente, van Eijck , & Jochems, 2013a). Engineering design emphasizes, however, the systematic and intelligent process of meeting the users' needs in creating, evaluating, and specifying devices or systems (Dym, Agogino, Eris, Frey, & Leifer, 2005). Although design is a central activity, the pedagogy of teaching students to construct knowledge using design as a vehicle has received little attention in the engineering education literature. Design-based learning (DBL) is an educational approach that engages students in solving real-life design problems while reflecting on the learning process using design activities as a means of acquiring engineering domain knowledge (Mehalik, & Schunn, 2006).

Considerable research has been conducted on newly coined approaches to DBL-like models, such as Learning by Design or Design-based Science (Kolodner, 2002: Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). Nevertheless, the majority of such scholarly work focuses on design as a pedagogical approach for the teaching of the natural sciences in secondary education. Literature on DBL in the context of secondary education emphasizes that engaging students in design activities as a means to learn science content also provides a significant venue to gain experience with the construction of cognitive concepts while meeting real demands and needs (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008). Furthermore, research on DBL in middle-school science activities indicates that DBL is a valid method to teach not only science but also engineering knowledge, as students approach authentic tasks following the same design process that an engineer does. Such activities enhance students' abilities to develop analytical thinking skills, using these ideas in functional parts, and synthesizing those in proposing alternatives and solutions (Mehalik, Doppelt, & Schunn, 2008). These DBL insights are built upon several promising approaches in using design as an educational approach to support learning.

In higher education, however, DBL has not been comprehensively investigated as an approach to support students in constructing knowledge, while having design assignments as a means to learn the application of engineering domain principles. Consequently, the characteristics of DBL in higher engineering education are still a topic that has not been researched in depth. In our prior research consisting of two extensive literature reviews, we defined such characteristics along five dimensions: projects' characteristics, role of the teacher, assessment, social context, and design elements (Gómez Puente, van Eijck, & Jochems, 2011; 2013a).

Based on what we found in the literature, we considered these characteristics to be critical elements of the instructional settings in DBL. The aim of this study is to investigate empirically to what extent these DBL characteristics are actually present in an exemplary DBL practice of higher engineering education. The subsequent sections provide a detailed description of the study conducted. Section 2 presents a brief review of the literature based on our prior research in this field (Gómez Puente, van Eijck, & Jochems, 2011; 2013a). Based on this literature review, we present our research questions in Section 3. In Section 4, we give an overview of the methods used to answer these research questions. Next, in Section 5, we report the results of this study. Finally, in Section 6, we outline our conclusions based on the results and summarize the implications for instructional design of DBL environments.

4.2 Background

4.2.1 Theoretical backgrounds of DBL

Design-based learning (DBL) has been characterized as an educational approach, but mostly as a means to teach science in secondary education (Apedoe, Reynolds, Ellefson, & Schunn, 2008). Approaches such as Learning by Design (Kolodner, 2002), and Design-based Science (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), embedded in classroom practices show empirically the gains of learning environments in which students use design assignments to acquire problem-solving and analytical skills common to the science curriculum.

In higher education, in particular, DBL is grounded in the educational principles of problem-based learning (PBL) (De Graaff & Kolmos, 2003). Accordingly, DBL inherited from PBL the idea of students who develop inquiry skills and integrate theoretical knowledge by solving ill-defined problems (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003). In DBL, the process of applying knowledge, science, and principles of the specific engineering domain by means of design activities of artifacts, systems or solutions in project-based settings is central. Furthermore, DBL emphasizes the planning process embedded in engineering assignments (Mehalik, Doppelt, & Schunn, 2008).

Despite the research conducted into design methods and engineering design processes (Lawson & Dorst, 2009; Dym, Agogino, Eris, Frey, & Leifer, 2005; Pahl, Beitz, Schulz, & Jarecki, 2007; Ulrich, & Eppinger, 1995; Ullman, 1990; Cross, 1990), evidence of the learning effects of design-based learning as an educational approach has not been comprehensively explored. Furthermore, although there is work that characterizes how engineers think (Dym & Little, 2009), and attempts to embed design in the engineering curriculum abound (e.g., course format, course duration, assessment methods, faculty experience in design, students design teams, etc.) (Dutson, Todd, Magleby, & Sorensen, 1997), so far, DBL has been incompletely defined. Moreover, recognizing this gap in the literature, in our research prior to this study, we conducted two review studies to define DBL within the context of higher education (Gómez Puente, van Eijck, & Jochems, 2011; 2013a).

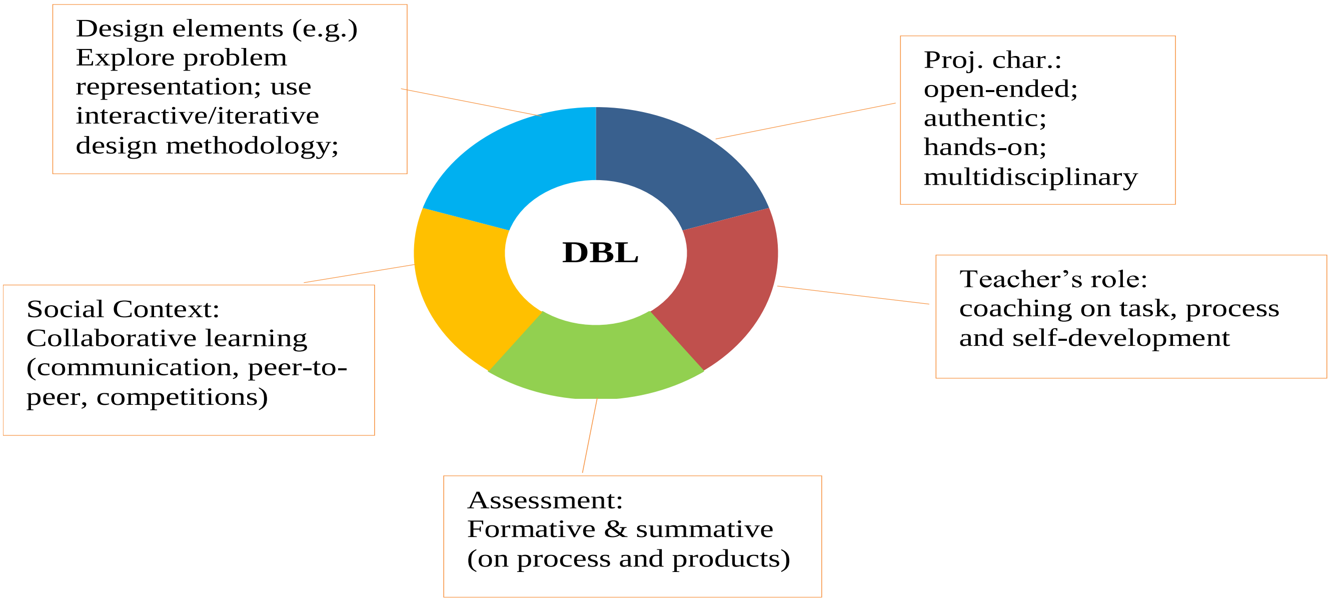

Figure 1 Overview of DBL dimensions and the characteristics.

4.2.2. Characteristics of DBL in higher education

In our prior research, we reviewed the literature on DBL-like projects in higher education (Gómez Puente, van Eijck, & Jochems, 2011; 2013a). Based on these reviews, we framed the characteristics of DBL in five dimensions: the project's characteristics, the design elements, the role of the teacher, assessment, and the social context. In what follows, we briefly sketch the characteristics that are central to these five dimensions. Figure 1 gives an overview of the DBL characteristics.

With respect to project characteristics, constructivist instructional approaches in engineering education situate students' learning activities and processes in authentic, open-ended scenarios to acquire and generate domain-specific knowledge (Gómez Puente, van Eijck, & Jochems, 2013a). Studies reporting on workplace engineering practices (De Graaff Kolmos, 2003; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003) address the multidimensional character of the processes that engineers go through to propose solutions and innovate. Solving problems in professional engineering settings involves navigating in ill-defined tasks, scoping and generating ideas, assessing and selecting by evaluating results and, finally, making decisions that meet the needs of the users (Martínez Monés, Gómez Sánchez, Dimitriadis, .Jorrıín Abellán, & Rubia Avi, 2005; Behrens, Atorf, Neumann, Schnitzler, Balle, Herold, Telle, Noll, Hameyer, & Aach, 2010). Examples of open-ended design assignment are represented by scenarios in which students work in the development of mobile applications by engaging the industry and presenting mobile solutions to an expert panel of judges from the industry, together with faculty members (Massey, Ramesh, & Khatri, 2006). Students need to conduct research on system features, foresee potential solutions and design a system, redesign functionality of a hand-held device, and test a prototype. In solving ill-defined design problems, students may propose creative alternatives in functionality make estimations about feasibility according to assumptions and, finally, make decisions about the design (i.e., choices of platform to implement Mobile Oncourse).

Likewise, in creating alternative solutions, students learn the nature of inquiry by solving cognitive conflicts while applying design strategies. Students learn, therefore, to: explore problems; make observations; employ tools to experiment, gather, analyze and interpret data; apply domain knowledge; and develop approaches in vaguely formulated authentic tasks. In these situations, DBL activities are focused on solving complex tasks and iteratively generating solutions to the unknown (Linge & Parsons, 2006). One example is having students develop a complete specification and produce an outline design of networks in collaboration with the client, and understanding how physical restrictions work using technical knowledge from the lectures.

In doing so, students learn to determine the clients' needs from a knowledge of their business operation and process to decide which technologies are best suited to overcome physical restrictions, identify risks, and suggest modifications. Students take the position of network design consultants working with the client. Hands-on assignments are conducted in collaborative communities in which the student team assumes engineering roles and interacts not only with peers, but also with the industry (Massey, Ramesh, & Khatri, 2006; Hirsch, Shwom, Yarnoff, Andersom, Kelso, & Colgate, 2001)

With respect to design activities, we have adopted as a design framework a classification of fifteen design elements (Mehalik & Schunn, 2006), found in authentic engineering scenarios in industrial contexts. For instance, these design elements include: exploring graphic representation, using interactive/iterative design methodology, validating assumptions and constraints, exploring user perspective, exploring engineering facts, exploring issues of measurement, and conducting failure analysis. This classification system draws on empirical results of a meta-analysis based on the most frequent design activities applied in software engineering design tasks. Although these design activities are collected from real-life practices in the industry, we have also reviewed the use of these design elements in DBL engineering projects in higher education (Gómez Puente, van Eijck, & Jochems, 2011). We found that these elements are all present in DBL-like practices, albeit at different levels of frequency in the design tasks that students conduct.

The role of the teacher in PBL-like settings traditionally has been to facilitate the group work (Hmelo-Silver & Barrows, 2008), and to boost self-directness (Boekaerts, 1997). The teacher guides the students and scaffolds the process in the development from a novice to an expert engineering level by, for instance, asking questions and having students explore alternatives and reflect upon the process. Guided instruction and scaffolding have been investigated as promising educational strategies in facilitating learning in reasoning and inquiry processes. We have found examples in the literature on facilitating processes by, for instance, asking students to take a deep approach to looking at the problem from different perspectives through comparison of measured results or test systems (Chang, Yeh Liao, & Chang, 2008). In DBL projects, the teacher may play the role of consultant and challenge the student team with questions and scaffolding processes (Linge & Parsons, 2006; Cheville, McGovern, & Bull, 2005), by providing benchmark lecture-by-demand (Maase, 2008), or by asking guiding questions (Massey, Ramesh, & Khatri, 2006), and stimulating discussion to use domain terminology (Lyons & Brader, 2004), in which the students critically revise their work. Teachers coach and provide formative feedback on students' learning processes by using a variety of methods such as rubrics (Etkina, Murthy, & Zou, 2006), and encouraging self-reflection (Etkina, Karelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silver, 2010; Geber, Mckenna, Hirsch, & Yarnoff, 2010), on their own design practices through Validation of Characteristics of Design-Based Learning 3 iterative prototyping by testing the viability of plans and communicating ideas.

Assessment in the context of DBL takes place both formatively and summatively. As students carry out design tasks, assessment on the process enhances opportunities to learn not only about the application of knowledge in design assignments, but also with respect to choices made in the planning, experimenting, and design processes. Design processes are assessed, for instance, by rubrics (Etkina, EKarelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silver, 2010). Design and reflection help students develop scientific abilities: learning in introductory physics laboratories, (Geber, Mckenna, Hirsch, & Yarnoff, 2010; McMartin, McKenna, & Youssefi, 2000), as a criteria tool to provide formative feedback and to assess students individually about their understanding of the engineering process, their ability to manage open-ended situations, their competency in devising a plan and proposing solutions, and supporting reflection on self-development. Other examples include holding presentations of individual reports and homework, individual or group lab reports, or online assessment quizzes (Zhan & Porter, 2010; Shyr, 2010). Assessment of design project work is conducted summatively as students present final products through presentations, oftentimes with the involvement of the industry, reports, prototypes, etc. (Massey, Ramesh & Khatri, 2006; Roberts, 2001). In addition, self-assessment (reflection on one's own progress or peer-to-peer assessment) and assessment of the acquisition of process competencies are encountered in studies as valid and frequent assessment methods. Social context is a core dimension in DBL.

Students work together in collaborative learning environments in which they exchange information and develop competencies. We found examples of collaborative learning in the literature on DBL, where design practices were implemented in the context of an engineering community. We encountered, for instance, learning situations in which students worked as peers by communicating ideas and giving feedback on one another's plans (Chang, Yeh Liao, & Chang, 2008). Other examples in the literature included presenting situational contexts in which students communicated ideas and presented plans to users or customers (Denayer, Thaels, Vander Sloten, & Gobin, 2003). By holding competitions and presentations, students practice engineering domain language and increase their motivation as they practice in social scenarios (McKenna, Colgate, Carr, & Olson, 2006).

These characteristics of DBL have been reported in various empirical studies on DBL-like educational engineering practices in higher education. That is, most of the engineering studies reported were grounded in PBL-like characteristics in higher education or exhibited core features that we considered critical to DBL. Although grounded in empirical literature, the set of characteristics representing the practice of DBL can still be taken as a theoretical construct. Indeed, little systematic research has been done on such characteristics of DBL in the actual engineering practice of higher education. In this study, therefore, we intend to empirically validate our DBL characteristics by exploring an example of engineering study programs in a technical university.

4.3 Research questions

To empirically investigate the extent to which DBL characteristics—project characteristics, social context, teachers' roles, assessment, and design elements—are present in an exemplary DBL practice in higher engineering education; we have identified two research questions:

1. To what extent do the perceptions of teachers and students in different engineering departments identify the presence of DBL characteristics in the projects assigned?
2. To what extent are DBL characteristics encountered in the projects assigned across the different engineering departments?

4.4 Method and design of the study

4.4.1 Research setting

Our study took place at the Eindhoven University of Technology. Following worldwide trends in engineering education, this university introduced DBL as an educational concept in 1997. The purpose was to educate engineers in developing innovative solutions in response to societal and industry demands (Wijnen, 2000). Grounded in Problem-Based Learning (PBL) educational and pedagogical insights, DBL was integrated into the engineering programs to have students gather and apply theoretical knowledge. Although DBL was introduced with a vision to stimulate innovation (Perrenet, Bouhuijs, & Smits, 2000), it has been molded in each department with a particular local flavor, generating different versions of this instructional concept in each departmental study program. In the Industrial Design department, for instance, the competency-based model builds upon context related, experiential and reflective learning (Kolb, 1984; Schön, 1983). Through project-based assignments, students perform professional experts' roles and tasks, and are prepared to create, apply, and disseminate knowledge, and continuously construct and reconstruct their expertise in a process of life-long learning (Hummels & Vinke, 2009), in which the notion of self-directed learning becomes central. In the Built Environment department, design studios, or *ateliers*, were created to integrate multidisciplinary design. Students collaborate in design teams, are supervised by teachers and experts from different disciplines, and get feedback on individual designs. In the Mechanical Engineering department, however, the problem based learning approach from the University of Maastricht was adapted to give form to teamwork assignments in which students gather and apply knowledge in problem-solving and design tasks. Similarly, DBL at the Electrical Engineering department emerged from the traditional practical instructional form.

4.4.2 Survey

4.4.2.1 Participants

For the purpose of this study, we have included the four engineering departments described in the previous section: Mechanical Engineering (ME), Electrical Engineering (EE), Built Environment (BE), and Industrial Design (ID). The rationale behind this choice was to collect the perceptions and the practices of two creative-type of engineering undergraduate studies (ID and BE) and compare them with two technology-oriented studies (ME and EE). Prior to the selection of participants, discussions with directors of studies of the four engineering departments took place in order to assess what role the DBL instructional approach holds within the curriculum.

We selected students from the second year of the undergraduate program for two main reasons. First, we assumed that first year students were not yet familiar with the educational context of engineering design assignments to the extent that their perceptions allowed reliable findings relevant to our research questions. Second, in some departments, some projects in the 'capstone courses' are carried out individually. As such, these projects do not feature DBL-characteristics at all. As a result ofthese considerations, we selected a population of second-year students who are familiar with the pedagogical concept of DBL and who have gained some experience in previous teamwork projects. Likewise, we approached teachers who have designed, coached, and assessed students in second-year projects.

4.4.2.2 *Instrument and sampling*

We designed a structured Likert-type questionnaire utilizing a 1 to 5 scale containing 40 items to collect teachers' and students' perceptions of the characteristics of DBL. The list of items was constructed from our literature review on DBL, in which we identified the relevant DBL characteristics along five dimensions (project characteristics, social context, role of the teacher, assessment, and design elements). Prior to sending our survey to the target group, the questionnaire was tested with two teachers, two tutors, and two students. We adjusted the questions according to their suggestions for improvement. In Table 1, sample items and the number of items are presented for each DBL dimension. Questions were aimed at gathering information on what extent teachers' and students' identify DBL characteristics within the program. Examples of items described in Table 1 are included in the questionnaire.

Table 1 Examples and number of items for each dimension of DBL-characteristics

Dimensions	k	Examples of items
Project characteristics	11	"Projects are open-ended, e.g. no unique solution is given in the end, looking for alternatives is encouraged" "Each project task opens up a new and different exploring and experiencing phase (e.g. tasks to look for information to solve next problem, to interpret and analyze results, to apply newly-gained knowledge, to try-out)"
Social context	3	"When working in project teams, student-to student feedback on group activities takes place (e.g. feedback on individual contribution to report, writing skills, presentations, analysis of findings)" "Project tasks encouraged competition among groups of students"
Teachers' role	8	"Teacher gives feedback on learning process (e.g. teacher gives feedback on selection of information, decisions made by the student, preparation, execution and evaluation of project activities" "During project implementation, teacher gives regularly individual feedback on content contributions to the project progress (e.g. conceptual and technical design, prototype)"
Assessment	4	"During project work students are assessed individually on subject matter through quizzes, presentations, interim reports, exams, technical design" "In projects, student-to-student assessment takes place (e.g. peer assessment on participation in project group, contributions on assignments)"
Design elements	14	"When student teams are involved in projects, students test hypothesis and explore the reasons for a design to fail" "In projects, students explore engineering facts by looking at specific properties of design aspects (e.g. to double-check a given; to articulate principles and compare with others' investigation)"

In the four engineering departments, we disseminated the survey among 398 potential participants (i.e., teachers, tutors and project leaders responsible for student supervision, and students). Two hundred and ninety-nine participants did not respond to all items or did not respond at all. We did not include incomplete responses in our analyses, yielding a total response rate of *N* = 98 complete responses to the questionnaire. Table 2 presents the sample size and the group composition for each department.

Table 2 Sample size and group composition for each department

Department	Group	N
ME	Student	21
	Teacher	12
EE	Student	10
	Teacher	11
BE	Student	13
	Teacher	11
ID	Student	2
	Teacher	18
Total response rate		98

4.4.3 Review of teaching materials

4.4.3.1 Collection of materials

We held a meeting with each of the directors of studies in the four departments selected to present the DBL theoretical framework and to get acquainted with DBL projects within these departments. We described the DBL framework in a general matrix to explain the DBL characteristics. Examples of DBL characteristics were discussed within the context of engineering projects (Denayer, Thaels, Vander Sloten, & Gobin, 2003), e.g., students work in a collaborative effort to design a shower in a developing country, navigating in open scenarios with no unique solutions. In this assignment, students transform customer requirements and specifications to conduct a functional analysis and use these to propose preliminary solutions in which the teacher plays a role as a customer. Other examples situate learning in engineering scenario assignments where students consider alternatives in defining a plan towards a solution and manage design approaches while building a prototype in a multidisciplinary team. In this project, students are assessed individually with rubrics (McMartin, McKenna, & Youssefi, 2000).

For the review of teaching materials, we requested a selection of the three best DBL projects in the second year of the undergraduate program. The objective was to have a selection of projects in which the DBL characteristics most likely would be present. In doing so, our intention was to gain an overview on the ideal curriculum in the eyes of the directors and compare this with the operationalized curriculum by the teachers. The basic rationale for this study is to know how this curriculum is actually implemented by the teachers and how this is perceived by the students (Yin, 2009).

Arguments used by the directors for the choice of the best projects centered on: the degree to which the design process is embedded in the project, students' satisfaction, students' above-average results, the relevance of products and results in regard to the students' development, and the DBL course's level of complexity in the curriculum year. The second year students participating in the survey are the same students involved in the DBL projects that we have analyzed. To create alignment in the analysis of the projects and the results of the survey, teachers taking part in the survey are also the ones involved in the projects.

To collect materials and gain access to project documents, we approached the teachers and the DBL coordinators in each department. For each project, we collected the project descriptions that students receive from teachers, manuals and study guides, mid-term and final reports, examples of peer-review assessments, templates for feedback, students' presentations, posters, action plans, and minutes of team meetings. Using several sources of evidence ensured a valid database construction for our analysis (Schön, 1983).

4.4.3.2 Analysis of materials

The materials used by the teachers and the products created by the students allowed us to gain an insight into the design assignments and examine whether the design characteristics were included in the instructional design of DBL projects. However, due to differences in the character of projects per department, project documents, and requested students' deliverables, we did not review the same amount and type of project materials for each course. Therefore, we have developed a case study database in the form of a protocol to assure reliability. Furthermore, we reviewed the documents using the same theoretical framework, including items of our classification of DBL characteristics used in the survey (the project characteristics, the social context, the teachers' role, the assessment, and the design elements). Table 3 shows examples of items included in our protocol and database for the analysis and documentation of project materials.

4.4.3.3 Member check technique

To improve the accuracy and validity of our analysis, we conducted a member check interview (Hoffart, 1991), with all responsible teachers of the projects (except one, who was not available). The purpose of this member check interview was to validate and gain feedback from our respondents on the interpretations of our analysis and check the authenticity of the work. The participating teachers (*N*= 10) were called up in individual one-to-one informant feedback sessions. The first step was to explain and summarize the approach taken to analyze the project materials. An introduction to the theoretical framework was provided and further explanation was given once it was noticed that the terminology used was unclear. The findings of the protocol were presented in the form of a short report and shared with the teachers for discussion.

To verify the accuracy of the findings and interpretations, the researcher explained the interpretations and provided an opportunity to comment. All participants confirmed that the interpretations reflected their views about the analysis of the projects. There were slight differences in two cases in which further clarification of the concepts ''open-ended'' and ''multidisciplinary'' and its classification in the protocol sheet originated discussion and marginal adjustment to the original interpretation was necessary. In this way, the use of the member check technique has served to correct errors and prevent personal biases in the results.

4.5 Results

4.5.1 Results and findings of the survey

A pooled analysis for reliability of the instrument revealed a Cronbach's alpha of 0.919. However, a reliability analysis per dimension, as presented in Table 4, revealed that Cronbach's alpha for each of the dimensions' characteristics, social context and assessment, was lower, indicating less reliability.

This may be due to the formulation of questions, in that the questions were perceived differently due to the differences in DBL models among departments, or in the low number of items included in these two dimensions. Owing to the low reliability of these dimensions, we are cautious about making further statements on the results. The correlations between the five dimensions are substantial, ranging from 0.33 to 0.68, suggesting that the five characteristics are connected.

Table 5 provides an overview of the results of the survey. Means and standard deviations are included, indicating the pooled perceptions for each department and those of the teachers and students in relation to the five DBL characteristics.

The analysis of the results reveals that the average of mean scores of the four departments varies just above the average, 3, in the Likert scale. There are differences in the means between all departments and Industrial Design in characteristics such as project characteristics, the teacher's role, the assessment, and the design elements. The results suggest that, in the Industrial Design department, the teachers and students perceive the projects to have more of the DBL characteristics and practices reported in the empirical literature. We have conducted an ANOVA to discover whether there are significant differences between groups on some characteristics. Results of the ANOVA confirm significant differences among all departments in project characteristics, the role of the teacher, and the design elements. No major statistically significant differences are perceived in the variables social context and assessment. Subsequently, we have conducted a post-hoc analysis to identify the significant differences among departments. Results reveal there are significant differences between ID and the rest of the departments regarding project characteristics and design elements. With respect to the teachers' role, significant differences are encountered between ID, ME and EE. In addition, the relatively high standard deviations illustrate differences in perceptions, not only among departments but also within the departments' respondents.

Table 3 Examples of items used in the protocol for the analysis of project materials and documents

DBL dimensions	Characteristics	Examples
Project characteristics	Open-ended	No unique solution is encouraged, more than one possible design solution/alternative is stimulated Project vaguely formulated: product specifications are not given or are intentionally unstructured
	Authentic	Realistic scenarios: assignments represent real-life engineering problems; Students approach industry to find out information about product specifications
	Hands-on	Experiential: iterations in analysis prototype design, implementation, and testing (learning-by-doing)
	Multidisciplinary	Integration of different disciplines
Teachers' role	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
Assessment	Formative assessment	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
	Summative assessment	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
Social context	Collaborative Learning	Communication with real-life stakeholders: Presentations of prototypes with company; Students manage processes as experts; Team work Peer-to-peer communication: peer learning processes within and across teams when students shared laboratory resources and engaged in debates Motivation through competitions; variation in design techniques and approaches: learning principles are the same by prototype is different

Regarding the teachers’ and students’ perceptions, the mean scores of the five DBL characteristics reveal differences in the perceptions of teachers (3.9) and students (3.1) with respect to the teacher’s role. No major statistically significant differences are encountered, however, in the teachers’ and students’ perceptions with regards to project characteristics, social context, assessment, or design elements. The overall results indicate that, regarding the project characteristics, these are encountered to a great extent in ID teachers’ and students’ perceptions, while the perceptions of teachers and students at the BE, ME and EE departments indicate that the projects have fewer of these characteristics. In addition, findings reveal that with regard to the teachers’ role, the perceptions of teachers and students conform to the DBL theory, as they recognized that these are present in the projects. Furthermore, in terms of design elements, these are perceived to a great extent by teachers and students in the ID department and to a lesser extent in BE, ME and EE. We conclude, therefore, that teachers and students at the ID department perceive more of the DBL characteristics in the projects and assignments, as described in the contemporary literature.

4.5.2 Results and findings of analysis of projects

In Table 6, we present an overview of the outcomes of the analysis of the DBL projects per department. The outcomes of the analysis of the project materials and documentation of the four departments highlight differences in the DBL projects. Our findings reveal that there are mainly differences at the level of project characteristics, the role of the teacher, and design elements, to a lesser extent in the social context, and even less in assessment.

Departments mostly differ with respect to project characteristics in the areas of open-endedness, authenticity and multidisciplinary elements within the project activities that students carry out. A variation between the departments can also be observed with respect to the role of the teacher. Both Industrial Design and Built Environment practices focus on coaching and supervision on technical design aspects, on process, and on self-development. This coaching concerns both individuals and groups. In Mechanical Engineering and Electrical Engineering, coaching is limited to coaching and supervision on technical design aspects and coaching and supervision on the design process.

Similarly, formative feedback, in this case consisting of addressing individual progress within design teams, is fostered and embedded in the assessment system in the Built Environment. In Industrial Design, formative and continuous individual feedback serves to improve design towards summative assessment. In Mechanical Engineering projects, however, students are assessed at the end, based on project reports, peer assessment on group dynamics and teamwork, and tutor assessment on participation and contribution to the groups’ activities. In Electrical Engineering projects, both formative and summative assessment takes place. The latest is based on final demonstrations and reports, together with the sum of the peer assessment distribution system.

Table 4 Cronbach's alpha for each dimension

Dimensions	α
Project characteristics	.78
Social context	.35
Teachers' role	.83
Assessment	.29
Design elements	.80

Table 5 Mean and standard deviation of teachers' and students' perceptions of DBL characteristics per department and per group

Dimensions	Department	Mean	SD	Group	Mean	SD
Project characteristics	ME	3.2	.41	Student	3.3	.46
	EE	3.2	.53	Teacher	3.7	.64
	BE	3.6	.51			
	ID	4.2	.40			
Social context	ME	3.4	.63	Student	3.3	.72
	EE	3.7	.54	Teacher	3.5	.59
	BE	3.1	.77			
	ID	3.7	.44			
Teacher	ME	3.1	.79	Student	3.1	.69
	EE	3.5	.38	Teacher	3.9	.54
	BE	3.7	.68			
	ID	4.2	.35			
Assessment	ME	3.6	.52	Student	3.6	.55
	EE	3.8	.53	Teacher	3.9	.52
	BE	3.6	.54			
	ID	4.1	.52			
Design elements	ME	3.5	.43	Student	3.4	.44
	EE	3.6	.39	Teacher	3.8	.49
	BE	3.5	.49			
	ID	4.1	.51			

Finally, a broader range of design elements can be found in Industrial Design and Built Environment projects as compared with projects from Mechanical Engineering and Electrical Engineering. The most common design activities encountered in Industrial Design and Built Environment practices are those referring to iteration, reflection on process, and communication with users through prototype exposure to external parties, stakeholders, or groups of teachers.

Examination of the project documents allows us to understand how these DBL characteristics work when they are present in the projects. Examples in ID projects regarding project characteristics include an open-ended scenario, e.g. a company specializing in electronic baby products focusing on end users with an interest in expanding product services. With a short description of the design problem, students are encouraged to navigate in vague and ill-defined settings. The students receive an assignment to investigate the topic, addressing knowledge from multidisciplinary themes from within the curriculum, e.g., healthcare, experiences, and emotions. The mid-term deliverables and presentations encourage students to work in iterations to understand user perspectives by including them in the data collection and analysis, and by developing prototypes that are evaluated by potential users. In this vaguely defined scenario, students make a plan, conduct research, use theory (e.g., Product Ecology Framework) to explore potential applications and propose alternatives, investigate those alternatives following prototype testing, and present them to users in intermediate deliverables.

In BE assignments, the role of the teacher in coaching and supervising focuses on different aspects, such as technical design tasks, process, and self-development. Students regularly present progress reports on technical designs, receiving feedback based on an assessment grid addressing technical tasks, conceptual design, functional organization, or the application of domain content. Feedback also addresses process elements such as planning, and self-development areas. In doing so, regular presentations are scheduled in which students practice using domain terminology and provide comments on each other's plans and present progress reports with respect to the process as well as the products, assessed in both a formative and a summative manner.

Design elements in ME design assignments take the form of projects such as the design of a propeller, including an analysis of the design problem, conducting a failure analysis using principles of aerodynamics, using a program, PropDesign, to carry out further calculations of performance, and validating constraints by testing and following a measurement plan. Likewise, the characteristics of assessment are to be found in one of the EE design assignments, where students present interim deliverables to the teachers' team of experts on the design of a prototype robot. These interim products (e.g., an action plan or prototype system) are subject to formative assessment and count toward the final mark.

Table 6 Overview of the outcomes of the analysis of DBL projects for each department

Department/ project	DBL dimensions				
	Project charact.	Social context	Teacher's role	Assessm.	Design elements
ME					
Project 1	O, H	-	Cp	S	1, 2, 5, 8, 11, 12, 13, 14
Project 2	O, H	-	Cp	S	1, 5, 8, 11, 13
Project 3	H	C	Cp	S	1, 5, 8, 11, 13, 15
EE					
Project 1	H	-	Ct, Cp	F, S	5, 8, 11, 13
Project 2	H, A	-	Ct, Cp	F, S	1, 8, 11, 13
BE					
Project 1	O, H, A, M	P	Ct, Cp, Cs	F, S	1, 2, 5, 8, 11, 13, 15
Project 2	O, H, A, M	C, P	Ct, Cp, Cs	F, S	1, 2, 5, 7, 9, 11, 13, 15
Project 3	O, H, M	P	Ct, Cp, Cs	F, S	1, 2, 5, 8, 9, 11, 13, 15
ID					
Project 1	O, H, M	C, I	Ct, Cp, Cs	F, S	1, 2, 5, 8, 11, 15
Project 2	O, H, A, M	C, I	Ct, Cp, Cs	F, S	1, 2, 5, 8, 9, 10, 11, 15
Project 3	O, H, A, M	C, I	Ct, Cp, Cs	F, S	1, 2, 3, 5, 8, 10, 11, 15

Notes. The following abbreviations are used for departments: Mechanical Engineering (ME), Electrical Engineering (EE), Built Environment (BE), Industrial Design (ID). The following abbreviations are used for DBL characteristics. *Project characteristics*: open-ended projects (O); hands-on projects (H); authentic projects (A); multidisciplinary elements in projects (M). *Social context*: competitions/motivating aspects, freedom of choice/self-management in projects (C); peer-to-peer activities (P); presentations or demonstrations of prototypes with industry stakeholders (I). *Teacher's role*: coaching and supervision on technical design aspects (Ct), coaching and supervision on process, including group dynamics (Cp); coaching and supervision on self-development (Cs). *Assessment*: formative assessment (individual or group tasks) and feedback on improvement of products (F); summative assessment, including individual contribution to project group and peer assessment (S). *Design elements* are coded as follows, according to the classification by Mehalik & Schunn (2006): Explore problem representation (1), Use interactive/iterative design methodology (2), Search the space (explore alternatives) (3), Use functional decomposition (4), Explore graphic representation (5), Redefine constraints (6), Explore scope of constraints (7), Validate assumptions and constraints (8), Examine existing designs (9), Explore user perspective (10), Build normative model (11), Explore engineering facts (12), Explore issues of measurement (13), Conduct failure analysis (14), Encourage reflection on process (15).

4.6 Discussion

The results of our quantitative study show significant differences between departments when looking at the level of DBL characteristics present. With respect to project characteristics, ID stands out in comparison with BE, ME and EE. The qualitative analysis of DBL project documents also shows differences in project characteristics, the role of the teacher, and design elements, although these differences are less visible in regard to assessment and social context. The fact that DBL project characteristics are more often present within teacher and student perceptions regarding ID and BE projects provides evidence that the DBL assignments in these departments include more characteristics from the literature. These aspects infer a more frequent exposure of students to the real life problems, in many cases, including contact with the industry. In addition, the assignments require students to meet the demands of actual or potential users, which implies that students are frequently involved with proposing, testing, and iteratively adjusting the prototypes and checking that the design meets clients' expectations. Iterations imply deep loops in integrating and constructing specific domain knowledge while learning from the creative process of investigating ill-defined information and applying newly generated knowledge. Working closer with the industry and stakeholders, especially with regard to feedback and assessment, provides additional learning moments and motivation for students to propose useful solutions that meet the needs of the customer.

The DBL practices in ME and EE take the form of teamwork-structured gathering and applying knowledge to solve problems. However, these practices include fewer mid-term presentations of prototypes or final demonstrations. This offers less frequent moments for feedback or reflection.

In terms of teacher roles, we identified through our quantitative analysis that ID and BE perceptions of teachers and students recognize DBL characteristics more than in the ME and EE departments. The characteristics and setup of the DBL projects in the ID and BE settings encourages frequent mid-term presentations as milestones to monitor progress. The role of the teacher is active in supervising the technical progress of the students' design assignments and coaching the process of gaining the technical knowledge, developing skills, and supporting the self-development through regular feedback. These intermediate interactive moments between teachers and students are encountered less frequently in the ME and EE departments.

With regard to design elements, our results indicated that ID teachers and students perceive DBL characteristics within projects to a great extent. Design elements are perceived less within the BE, ME and EE departments. In our analysis of the projects, we found that ID and BE projects include the design elements of our theoretical framework more often than in the ME and EE projects. This allows students to practice engineering design activities resembling the tasks engineers actually perform within the industry. Regarding assessment and social context, we are wary of drawing further conclusions, as these DBL dimensions seem to be less reliable. However, our analysis of projects points to the idea that assessment and social context in ID and BE, along with assessment in EE, tentatively reflect the DBL characteristics defined in the literature. These are rarely found at all in ME projects.

This study has included a limited representation of informants, e.g., teachers, tutors and project leaders responsible for student supervision, and students. In addition, the sample was taken from four departments of one technical university. The findings of our case are therefore descriptive. Nevertheless, the differences in the perceptions between teachers and students, as well as the differences encountered in the instructional materials of the students' project activities, are likely representative of other DBL-based engineering study programs, or at least applicable to them. Taking the characteristics as measures for the implementation and improvement of DBL, we think that the results of this case may be of interest to technical universities.

The findings of this study open up opportunities to critically revise curriculum practices and find ways to integrate activities using design as a vehicle to promote the application of knowledge. Examples from the literature illustrate forms of using situated and authentic scenarios resembling activities that encourage experiencing, testing, and adjusting. In these examples, the teachers' role is illustrated in a range of performances to facilitate, coach, assess, and stimulate the collaborative learning process.

Moreover, the results of this study provide guidelines for future interventions to adjust curriculum requirements and for the setup of project design. Given the considerable differences between the departments, the emphasis lies in the instructional design of projects and the learning activities, to include situated learning in contexts in which students perform authentic, professional engineering tasks. Accordingly, one focal point is the design of assignments in open-ended, problem-solving scenarios and the inclusion of activities involving design elements that support students in integrating and constructing domain knowledge.

Regarding teacher roles, it becomes evident from this study that differences exist not only between departments, but also between the teachers' and students' perceptions. In DBL, the teacher role includes student coaching and supervision and supporting the learning process of solving real-life problems. Likewise, facilitating learning involves guiding students in domains of expertise beyond the sole acquisition and integration of technical knowledge, and supporting students with individual, formative feedback in team assignments in the process tasks and in self-development. Therefore, teacher professionalization in facilitating this kind of learning process will also stimulate the adoption of educational strategies to support students in resolving cognitive conflicts and developing inquiry skills. Furthermore, making students aware of their own progress will incur gains in the self-development process. These aspects should be of special concern in more systematic investigations, not only because of the considerable differences between departments and between teachers' and students' perceptions, but because of the positive results reported in the literature. Improvement in the instructional design of DBL projects and in teacher roles requires further empirical research in collaboration with teachers, and in-depth exploration of how the resulting instructional practices may complement and fulfill academic and curriculum requirements.

Finally, recognizing the gap in the literature with respect to DBL in higher education, this research study contributes to academic discussion by shedding some light on engineering educational practices that use design activities to promote the construction of domain knowledge. This, together with the active role of the teacher in coaching, assessing, and encouraging collaborative learning environments, provides enough insight and inspiration to include or adjust DBL practices in engineering study programs in technical universities.

4.7 Conclusions

The purpose of this study was to investigate empirically to what extent pre-defined DBL characteristics are present in an exemplary DBL practice in a higher education program of study. In particular, we investigated whether DBL characteristics are present within the view of students' and teachers' perceptions. In addition, we have studied DBL projects in order to assess whether these characteristics are also present in this learning area within four different engineering undergraduate programs in a technical university where DBL has been implemented.

Our findings indicate that the DBL characteristics we derived from theory could all be empirically verified in an exemplary DBL practice within this particular higher education setting. Nevertheless, there are also considerable differences between the departments with regard to the presence of these characteristics. In some departments, such as Industrial Design, DBL characteristics stand out. Significant differences are found, however, when we look at project characteristics, the role of the teacher, and design elements. We can conclude that the educational DBL model, as implemented within the Industrial Design program, contains more frequent and more explicit DBL characteristics and strongly resembles the current trends in engineering design practices that we found in contemporary literature on the subject. We are cautious, however, about making further statements about these differences in relation to the dimensions of *assessment* and *social context*, since the outcomes regarding these two dimensions were less reliable.Referring to *perceptions*, significant disparities are encountered among these two groups in relation to the roles of the teachers. Our interpretation of this result is that students perceive the teachers' performance in the coaching and guidance role differently from the teachers.

We also initiated this study to discover whether DBL characteristics were present in the projects assigned throughout the various departments. An analysis of project documents indicates that not all DBL dimensions are embedded in the projects throughout all departments. We find significant differences in some aspects of project characteristics, the role of the teacher, and the design elements. These differences are encountered mainly in Mechanical Engineering and Electrical Engineering when compared with the practices in Built Environment and Industrial Design.

Finally, with regard to the design elements, we found that the Industrial Design and Built Environment projects include more design elements than those in the other two departments. Design elements are less common in Mechanical Engineering and Electrical Engineering projects.

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Chapter 5

> *…the mastering of a skill often fails to take into account the implicit processes involved in carrying out complex skills when they are teaching novices…cognitive apprenticeship is to bring these tacit processes into the open, where students can observe, enact, and practice them with help from the teacher…*
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> *Collins, Brown, & Newman, 1987*[9]

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[9] Collins, A., Brown, J. S., & Newman, S. (1989). Cognitive apprenticeship: Teaching students the craft 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: Lawrence Erlbaum.

Chapter 5

Facilitating the learning process in design-based learning practices: An investigation of teachers' actions in supervising students[10]

Background:
In research on design-based learning (DBL), inadequate attention is paid to the role the teacher plays in supervising students in gathering and applying knowledge to design artifacts, systems, and innovative solutions in higher education.
Purpose*:* In this study, we examine whether teacher actions we previously identified in the DBL literature as important in facilitating learning processes and student supervision are present in current DBL engineering practices.
Sample: The sample (N=16) consisted of teachers and supervisors in two engineering study programs at a university of technology: mechanical and electricalengineering. We selected randomly teachers from freshman and second-year bachelor DBL projects responsible for student supervision and assessment.
Design and method: Interviews with teachers, and interviews and observations of supervisors were used to examine how supervision and facilitation actions are applied according to the DBL framework.
Results: Major findings indicate that formulating questions is the most common practice seen in facilitating learning in open-ended engineering design environments. Furthermore, other DBL actions we expected to see based upon the literature were seldom observed in the coaching practices within these two programs.
Conclusions: Professionalization of teachers in supervising students need to include methods to scaffold learning by supporting students in reflecting and in providing formative feedback.

Keywords: design-based learning; supervision; inquiry; scaffolding; formative, feedback; question prompt

5.1 Introduction

Facilitating and supervising students' learning processes are a teacher's main tasks in design-based learning (DBL). Empirical evidence regarding stimulating engineering students' design thinking in constructing knowledge in open-ended and authentic scenarios has emerged from the research (Eris, 2008; Jonassen, Strobel, & Lee, 2006; Land, & Zembal-Saul, 2003). Examples from the literature on the teacher's role in DBL projects refer to formulating and

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prompting questions (Etkina, Karelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silver, 2010; Linge & Parsons 2006), providing formative feedback (Lyons & Brader, 2004; Maase & High, 2008), supporting students in their approach to problem-solving tasks and aiding students in exploring alternatives iteratively (Chang, Yeh Liao, & Chang 2008; Geber, Mckenna, Hirsch, & Yarnoff, 2010).

The role of the teacher in the DBL framework is not well studied, and there is little discussion about which teacher actions facilitate the learning process in the context of DBL. In particular, it is still unknown which DBL-related actions are of importance in supervising student groups. In a previous study, we explored teacher actions that illustrate common practices in facilitating and supervising students (Gómez Puente, van Eijck, & Jochems, 2013a). The purpose of the current study is to investigate not only the teachers, but also the actions of supervisors (e.g. tutors and project leaders) in the practice of facilitating the learning process and in supervising students. We framed our study using two engineering programs at a technical university (the Eindhoven University of Technology) as a setting for investigating how teacher and supervisor actions are employed in DBL as exemplified in our literature framework. In the following sections, we briefly introduce the theoretical considerations of this research and, more specifically, focus on the role of the teacher in design-based learning. Next, we present the research method and design of this study, followed by a presentation of the results. In the final section, we present our conclusions and describe the considerations and implications for further research.

5.2 Theoretical background

Design-based learning is an educational approach in the context of the high school science curriculum (Apedoe, Reynolds, Ellefson, Schunn, 2008; Doppelt, Mehlaik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009). Grounded in activating learning approaches, such as problem-based learning (PBL; Barrows, 1985), learning by design (LBD; Kolodner, 2002; Kolodner, Camp, Crismond, Fasse, Gray, & Holbrook, 2003) or design-based science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), design-based learning has served as a vehicle to introduce concepts in secondary science education. Although there are positive experiences in the context of learning sciences in high school, empirical evidence of this instructional model in higher technical education is scarce; in particular, the role of the teacher is not yet comprehensively recorded.

In higher technical education, design-based learning helps students engaged in design activities investigate the context of the problem presented (Mehalik & Schunn, 2006). DBL is an educational approach that engages students in solving ill defined, real-life design problems/assignments using design activities as a means of acquiring engineering domain knowledge. In such scenarios, students explore alternatives, make use of multiple solution methods, select the criteria, redefine constraints and make/apply decisions in a new iteration (Cross, 1990; Dym, Agogino, Eris, Frey, & Leifer, 2005; Lamancusa, 2006; Lawson & Dorst, 2009).

5.3 Design-based learning: Theoretical framework

We have defined the theoretical underpinnings of design-based learning in previous studies (Gómez Puente, van Eijck, & Jochems, 2011, 2013a). Following a literature review, we frame DBL within five dimensions: project characteristics, design elements, the role of the teacher, assessment and social context. We then describe insights into these dimensions and their characteristics.

In the context of project characteristics, design assignments are open-ended, authentic, hands-on and multidisciplinary. In design scenarios, students cope with ill structured assignments working with incomplete information (Mese, 2006), devising their own design work plan (McMartin, McKenna, & Youssefi, 2000), seeking alternatives and considering design solutions (Roberts, 2001). Authenticity is represented by real-life design projects in which students work on multidisciplinary problems similar to, linked to or in co-operation with the industry (Hirsch, Shwom, Yarnoff, Andersom, Kelso, & Colgate, 2001; Massey, Ramesh, & Khatri, 2006; van Til, Tracey, Sengupta, & Fliedner, 2009). Regarding design elements, the classification outlined by Mehalik & Schunn (2006) provides an overall picture of an empirically based taxonomy of design elements. This taxonomy envelopes activities from an industry context, such as exploring graphic representation, using interactive/iterative design methodology or conducting failure analysis, among others, that are also found in DBL-alike educational practices with variations in frequency, specificity, authenticity and year of study (Gómez Puente, van Eijck, & Jochems, 2011).

Assessment in DBL practices has many faces in the literature, employing assessment instruments such as rubrics, presentations of individual reports and homework, individual/group lab reports, mid-term projects or online quizzes (Massey, Ramesh, & Khatri, 2006; Roberts, 2001; Shyr, 2010; Zhan & Porter, 2010).

Features of the social dimension of DBL practices refer to collaborative learning activities in which students provide feedback on one another's plans, experiment results, individual assignments (Chang, Yeh Liao, & Chang, 2008; Denayer, Thaels, Van der Sloten, & Gobin, 2003), presentation of ideas, prototypes or final products, or via competitions that encourage students to practice domain terminology (McKenna, Colgate, Carr, & Olson, 2006).

In our previous study (Gómez Puente, van Eijck, & Jochems, 2013b), we concluded the teacher's main role in a DBL framework is to facilitate students' learning processes. Facilitating learning involves guiding students by, for instance, questioning and stimulating deep thinking by modeling the kinds of questions students should ask themselves (Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007; Collins, Brown, & Newman, 1989; Hmelo-Silver, 2004; Hmelo-Silver & Barrows, 2006).

In our literature review, we found some instances involving teacher supervision actions, such as formulating questions to facilitate understanding of design tasks (Etkina, Karelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silver, 2010; Hirsch, Shwom, Yarnoff, Andersom, Kelso, & Colgate, 2001; Roberts, 2001; van Til, Tracey, Sengupta, & Fliedner, 2009); providing feedback on technical design progress (e.g. data collection, problem analysis, testing methods; Chang, Yeh Liao, & Chang 2008; Massey, Ramesh, & Khatri, 2006); or stimulating reflection on and explicating rationale for technical design, procedures, or processes (Geber, McKenna, Hirsch, & Yarnoff, 2010; Massey, Ramesh, & Khatri, 2006), among others. Within this context, we are interested in learning whether teachers and supervisors in a technical university facilitate learning processes and supervise students according to the findings from our literature review.

5.4 The role of the teacher

Empirical studies on DBL illustrate the teacher's role as a facilitator and a supervisor of the student learning process. In a previous study, we identified several examples of the types of actions teachers undertake in this regard (Gómez Puente, van Eijck, & Jochems, 2013b). These examples refer to scaffolding learning by, among other things, providing pieces of information in a just-in-time format tailored to the needs of students, or through moments devoted to mini-lectures in a lecture-by-demand strategy typifying 'benchmark lessons' (Maase & High, 2008).

Likewise, other examples illustrate teachers' actions in stimulating discussions in which students articulate and reflect upon practice (Cheville, McGovern, Bull, 2005; Hirsch, Shwom, Yarnoff, Andersom, Kelso, Colgate, 2001; McKenna, Colgate, Carr, Olson, 2006; Maase & High, 2008), by using worksheets with questions or through the use of a solution plan (Etkina, Karelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silver, 2010; Kimmel & Deek, 2005; Lyons & Brader, 2004). Other examples include prompting questions to support students in formulating a deep analysis in scaffolding and constructing knowledge during design tasks, such as scoping the problem, inquiring and troubleshooting (Chang, Yeh Liao, & Chang, 2008; Etkina, Murthy, & Zou, 2006; Roberts, 2001; van Til, Tracey, Sengupta, & Fliedner, 2009).

5.5 Research questions

Building upon these considerations, we investigate the following research question: To what extent do teachers' and supervisors' actions in facilitating and supervising students in our case represent the DBL characteristics found in the literature? From this investigation, we expect to document to what degree teacher and supervisor actions in our case represent the DBL actions found in the literature.

5.6 Method

5.6.1 Research context

DBL was introduced at the Eindhoven University of Technology in 1997. Following worldwide educational developments and inspired by the problem-based learning models at Aalborg University and Roskilde University in Denmark, DBL aimed to motivate students as creative professionals to collectively apply knowledge and skills. DBL was featured within a framework of characteristics, such as professionalization, activation, co-operation, authenticity, creativity, integration and multidisciplinary aspects (Wijnen, 2000).

The educational organization of DBL projects varies within different engineering departments and has evolved differently over the years. In the Mechanical Engineering department (ME), the PBL model from the University of Maastricht was adopted as a source of inspiration for curriculum innovation and integrating projects as educational form. Additionally, these DBL projects have adopted some specific educational aspects from the Maastricht PBL case, e.g. a tutoring system to supervise students and the 7-jump model to analyze problems and formulate assignments (Moust, Bouhuijs, & Schmidt, 1997). The supervision model used in the ME department involves both teachers and tutors, assigning the tutor a facilitating/supervising role during group discussions on group performance. Supervision includes monitoring progress against expected learning outcomes, motivating students, monitoring and facilitating the process, providing feedback on team roles and participation in group assignments and assessing students. Depending on the semester and project complexity level, tutors are master’s and PhD students, as well as scientific and technical staff who act as content experts.

The DBL model used in the Electrical Engineering department (EE) emerged from the traditional instructional form of practicals and has evolved into a project set-up in which students work in groups on design project assignments. As content experts, the teachers’ tasks mainly concern the design of the DBL projects, supervision of technical design tasks and assessment. Supervision of the process, in terms of planning, project management and group processes, is carried out by project leaders. Project leaders are master’s students who follow a master’s course on project management with predetermined learning outcomes upon which they are assessed.

5.6.2 Selection of participants

The participants in this study were teachers and supervisors within the above-mentioned engineering departments. The teachers’ roles include the design of DBL projects, teaching supportive lectures and student assessment. In the ME department, teachers hold weekly meetings with student teams to supervise progress and answer questions. In the EE department, teachers hold intermediate review meetings to monitor progress. The role of tutors in the ME department and project leaders in the EE department is supervision of the process and of students in group meetings. Their role mainly concerns monitoring the group and assessment based on team process-related subjects, e.g. participation in the group and contribution on the assignments, giving and receiving feedback, commitment, etc. The composition of the group included in the study is presented in Table 1.

For participant selection, we contacted key personnel in the two departments. The assistant director of studies at the ME department provided a list of teachers and tutors supervising first-year students involved in DBL projects. From this list, we selected teachers for interviews based on a specific set of criteria:

- Those responsible for DBL projects in the coming academic year at the freshman level;
- Those responsible for the design of the DBL projects and lectures supporting these projects; and
- Those responsible for student supervision and assessment of final group products, i.e. reports.

In all, six teachers matched the criteria. From this list, we considered a selection of four teachers as illustrative for our purpose. The focus on the freshman year was a requirement imposed by ME department management as a result of an ongoing process of educational re-innovation.

Next, from the list of tutors provided, we made a random selection. The list included both experienced tutors and less experienced master's and Ph.D. students involved in DBL project supervision. We selected four of the 10 active tutors as optimal for the purpose of characterizing tutor supervision actions in DBL group meetings. We contacted several tutors and selected those tutors who voluntarily agreed to be observed and interviewed for this research study.

With respect to the EE department, we contacted the teachers responsible for the two second-year DBL projects, as it was the focus of a larger dissertation research project (Gómez Puente, van Eijck, & Jochems, 2013c).

Table 1 Participants' composition for this study

Department	Participants	Interviews	*Observations
ME	Teachers	4	
	Tutors	4	4
EE	Teachers	4	
	Project leaders	4	4

*The four ME tutors and EE project leaders (PL) have been observed twice.

The criteria for teacher selection was similar to that used for the ME department: teachers with sound experience with DBL, who design the DBL projects and who carry out technical supervision and assessment of students at the second-year level of the bachelor program. There were eight teachers who satisfied these criteria. From this list, we again considered four teachers, two from each of the two projects, as an appropriate representation for the purpose of our study. Subsequently, we selected the two teachers responsible for the two second-year DBL projects and another two teachers at random.

We then requested the teachers responsible for the DBL projects to provide a list of the project leaders who supervised students during that semester. As noted, the project leaders are master's students who, within the project management master's course, fulfill this role with specific goals in relation to the curriculum. Project leaders monitor the process, provide feedback to students on participation and contribution in the design assignment and assess individual performance. Those who agreed to act as key informants for this research study were preliminarily selected. Five out of six project leaders responded positively. We then selected four project leaders at random, and those who agreed to be observed and interviewed were selected to participate in this research.

5.6.3 The selection and context of design-based learning projects

For this study, we selected two projects: the 'air compressor design analysis' and the 'robotic surgery.' These entail a freshman ME project and a second-year bachelor EE project, respectively. In the air compressor design analysis project, students act as engineers working at the engineering bureau, SnH. Students are instructed to design a user interface for pumps. In this project, students learn to analyze, experiment, take measurements, test and make decisions based on the results. The robotic system assignment is to design a prototype robot for a smart medical instrumentation company to assist medical staff during surgeries. In this project, students work on two prototypes following specifications provided. Students are to design, test and simulate the models.

5.6.4 Design of research instrument

We developed interview and observation instruments based on our definition of teachers' roles outlined during our previous empirical studies (Gómez Puente, van Eijck, & Jochems, 2013b). In order to provide a framework for the observations, we created a selection of items from the examples provided in the literature, as shown in Table 2.

Furthermore, in the interview design phase, we included a set of instructions and guidelines for the researchers to use during semi-structured interviews. The goal of the interviews was to uncover teacher and supervisor views and practices regarding their roles in facilitating the learning process and supervising students. We were also interested in whether supervisors consistently apply criteria or similar supervising patterns during groups. These instructions and guidelines also contained questions on how, when and what type of questions are asked to facilitate learning; how supervision and feedback takes place within the DBL context; and on what grounds the supervisors make decisions about performing actions that facilitate the learning process.

Table 2 Items for teacher interviews and tutor observations

Teacher/tutor…	Articles
1- formulates questions (e.g., open-ended questions)	Van Til et al., 2009 Roberts, 2001; Etkina et al., 2010; Hirsch et al., 2001; Lyons & Brader, 2004.
2- acts as an expert, customer; gives information on specifications	Denayer et al., 2003; Massey, Ramesh, & Khatri, 2006; Martínez Monés et al., 2005;
3- provides feedback on progress on presentation skills, team work	Maase & High, 2008; Chang, Yeh Liao, & Chang, 2008; Hirsch et al., 2001; Mckenna et al., 2006;
4- reviews progress on plans, proposal, etc.	Cheville et al., 2005; Mckenna et al., 2006; Lyons & Brader, 2004.
5- provides feedback on evolving efforts (e.g., coaching on progress in technical design, design process, data collection, testing methods)	Massey, Ramesh, & Khatri, 2006; Chang, Yeh Liao, &Chang, 2008.
6- supports students in reflecting on and explicating rationale for technical design, argument formulation, and decision making	Etkina, Murthy, & Zou 2006; Hirsch et al., 2001;
7- supports students in case of difficulties (just-in-time teaching)	Maase & High, 2008.
8- uses methods/tools (worksheets, drawings, examples, etc.) to guide the team	Cheville, McGovern, & Bull, 2005; Roberts, 2001; Etkina et al., 2010; Clyde & Crane, 2003; Kimmel &Deek, 2005.
9- encourages students to articulate engineering terminology during regular meetings and presentations	Hirsch et al.,2001; Mckenna et al., 2006.
10- encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives	Massey, Ramesh, & Khatri, 2006; Geber et al., 2010; Etkina et al., 2010;
11- encourages students to learn from other students' plans, knowledge application in problem solving experiments	Chang, Yeh Liao, & Chang, 2008; Etkina et al., 2010;
12- observes students during implementation of activities	Maase & High, 2008.

5.6.5 Testing the interview and observation instrument

To improve the accuracy of our research instrument, we tested the interview and observation tools. We chose one teacher and one tutor at random from a list provided by the ME department. We observed one tutor during a meeting with a group of first-year students and subsequently interviewed the tutor. We then interviewed a teacher. To test our instrument, we compared the results of the observations recorded by the first researcher with those of a second to verify the consistency of the findings and interpretations. Upon observing a recordable action by a tutor during the supervising session, the first researcher put a tally mark in the observation and schedule instrument and subsequently described the content and character of that action. The same procedure was followed during the interview with the teacher.

The second researcher watched the video recording of the tutor observed by the first researcher. The second researcher also tallied recordable actions in the schedule observation instrument and described the content and the context in which the action took place. In addition, the second researcher was instructed to describe actions carried out by the tutor that were not included in our framework.

We compared the results of both researchers. Analysis showed that out of the 20 actions identified by both researchers, 15 were the same and five were different, indicating concurrency of 75%. We used comments and suggestions for improvement noted by the second researcher to fine-tune the instrument and adjust it to make it more consistent and less ambiguous. Items that seemed to be similar, were repetitive or were difficult to interpret were eliminated. The definitive interview and observation instrument was composed of 12 items (Table 2).

5.6.6 Application

We used the same instrument to interview teachers in both departments. We interviewed the teachers in order to learn more about their views and practices regarding their roles in facilitating learning and supervising students. In addition, we wanted to know (1) what questions are asked during meetings and presentations that they felt facilitate the learning process, (2) how feedback or supervision is provided and (3) whether specific criteria are used.

We also used this instrument when observing tutors and project leaders during student supervision activities. At the ME department, we observed four tutors on two different occasions with two different groups. Our goal in structuring the study in this manner was to determine whether tutors’ supervision patterns responded to a specific group situation and to ensure their behavior was not influenced by the presence of the researcher. We also interviewed the tutors to gain further insight into their views about their supervision practices.

Next, we observed the project leaders (PLs) at the EE department. In this department, however, the PLs are responsible for only one group. We observed the PLs twice with the same group of students. We interviewed the PLs after the observations concluded. In addition, we observed one teacher–student coaching meeting in both departments to learn about the context in which teachers supervise students and whether the DBL actions take place within this context. At the ME department, supervision meetings take place once a week. In this meeting with only one representative of each student group, the teacher answers the most crucial content-related questions students have at that time. At the EE department, however, we followed one of the regular expert meetings held by the technical teachers with the student groups to explore the supervision situations and feedback patterns. All interviews and observations took place within a three-month project implementation period.

5.6.7 Data analysis of interviews and observations

To analyze the data, we developed a coding system based on whether the actions were present or not present at all. We transcribed and analyzed the interviews. We coded answers and tallied a mark on the interview instrument every time the teacher mentioned that he or she carried out a listed action. We compared these actions against the actions in the DBL literature framework. In addition, in our analysis of interviews, we tried to examine and interpret the teachers' views and practices on facilitating learning and on supervising students. Subsequently, we made an interpretation based on those results.

With respect to supervisors, the same data analysis procedure was followed as we observed the tutor/project leader. For example, actions focusing on formulates questions (item 1) were marked every time a question was asked by the teacher, tutor or project leader. In addition, questions clearly intended to support(s) students to reflect on and explicate rationale for technical design and procedures (item 6) were also marked in that item category.

To classify actions mentioned during the interviews that were outside our theoretical framework, we used codes with the name representing the action. For instance, we coded actions such as learning by doing, correcting, motivating, etc., as these are relevant actions pertaining to the teachers' own practices, even though they are not part of the classification system pulled from the literature review.

5.7 Results

In the next sections, we first summarize the results of the ME department, followed by those of the EE department. The analysis corresponds to the teachers' actions codified in a system of 'present' or 'not present'. Next, we analyze the tutor–project leader findings following the same procedure. Finally, we compare the results of the teachers and those of the tutors/project leaders to interpret how facilitation and supervision is performed in our case.

5.7.1 Teachers' and tutors' actions in the Mechanical Engineering department

An overview of the results of the interviews with ME teachers and the observations of ME tutors are provided in Figure 1 and Figure 2, respectively. Items are those referred to in Table 2. The items representing supervising actions shown in the figures have been replaced by a coding system added below the figures.

Interviews with teachers at the ME department reveal that the items formulates questions (item 1), uses some methods such as worksheets, drawings, examples, etc., to guide the team (item 8) and supports students in case of difficulties (just-in-time teaching) (item 7) are actions teachers said they perform most frequently. These actions are not only performed in the process of facilitating and supervising students, but also during teaching situations. Using examples or drawings is a common teacher practice, especially during supportive lectures to help students understand concepts. This shows a general teaching pattern focusing on transferring information during lectures by visually explaining ideas and concepts. The fact teachers mentioned they formulate questions may correspond to situations in which teachers ask questions during lectures to check students' understanding or in which they do not lecture but supervise students in weekly meetings.

Our findings also reveal that actions listed in Table 2 related to the items *encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives and observes students during implementation of activities* are mentioned by only one teacher as regularly performed activities. The items *provides feedback on their evolving efforts, e.g., technical design, etc. and supports students to reflect on and explicate rationale for technical design, formulation of arguments,* among others, are rarely or never encountered among teacher actions. The clearly defined teacher roles in teaching and assessing students, depending on the organization of feedback moments within the projects, may be explanatory for this. Feedback usually occurs at the end of the project (e.g., a report, demonstration or presentation); therefore, opportunities for formative feedback on technical design and learning through reflection are significantly limited. Actions related to reflection on progress, such as *encourages students to articulate engineering terminology (item 9) and encourages to explore alternatives for problem solving (item 10),* among others, are not common supervision actions. Again, this may be explained by the fact that teachers provide instruction during the lectures and no supervision takes place at this time.

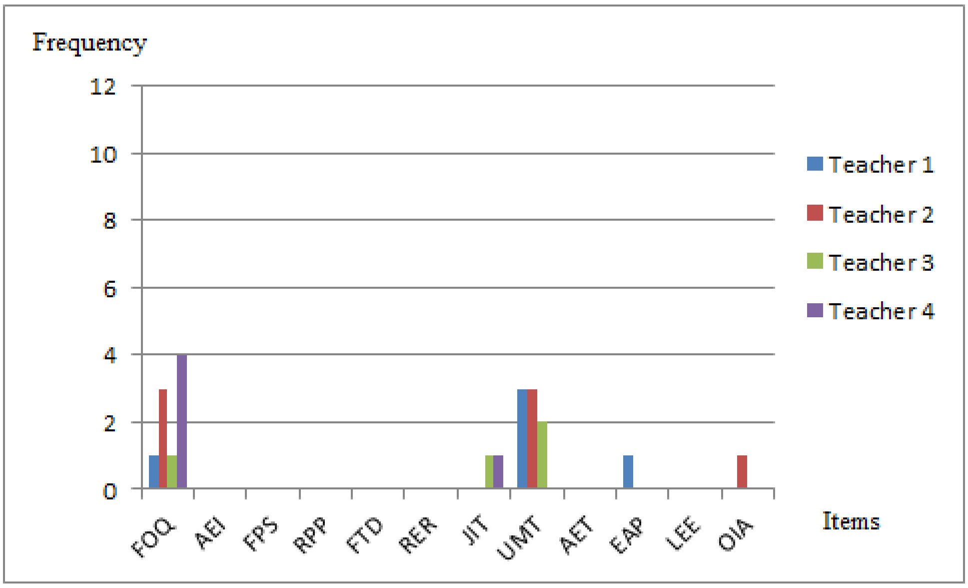

Figure 1 ME teachers' actions based on interviews

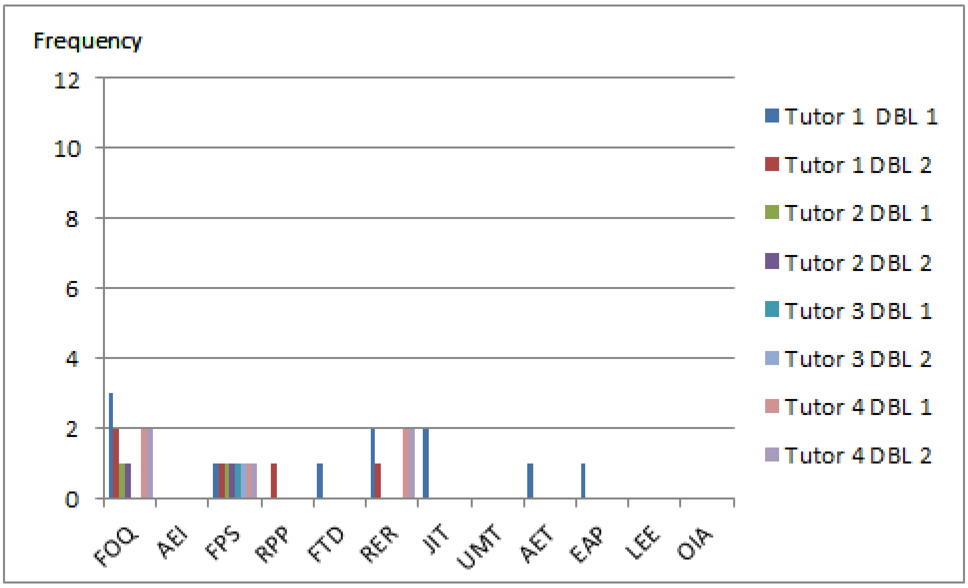

Figure 2 ME tutors' actions based on observations

Note: *Description of DBL supervising actions following a coding system:* (Item 1) Formulates questions (e.g. open-ended questions) – FOQ; (Item 2) Acts as an expert, customer; gives information on specifications – AEF; (Item 3) Provides feedback on progress on presentation skills, team work – FPS; (Item 4) Reviews progress on plans, proposal, etc., RPP; (Item 5) Provides feedback on evolving efforts (e.g. coaching on progress in technical design, design process, data collection, testing methods) PTD; (Item 6) Supports students in reflecting on and explicating rationales for technical design, argument formulation, and decision making, RER; (Item 7) Supports students in case of difficulties (just-in-time teaching) JIT; (Item 8)Uses methods/tools (worksheets, drawings, examples, etc.) to guide the team, UMT; (Item 9) Encourages students to articulate engineering terminology during regular meetings and presentations, AET; (Item 10) Encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives, EAP; (Item 11) Encourages students to learn from other students' plans, knowledge application in problem solving experiments, LEE; (Item 12) Observes students during implementation of activities, OIA.

To expand and verify our interpretation of the findings, we cross-checked these results with teacher actions during one of the weekly supervision meetings. The organizational set-up of supervision meetings consists of one student from each group asking crucial questions related to technical design. Teachers answer simply by providing the missing information. There are, therefore, fewer opportunities to formulate questions, support reflection or have students explicate rationale.

Finally, regarding *plays a role as a user, expert or customer* (item 2), we found neither the teachers nor the tutors take on such an authentic role. Situated learning contexts resembling an engineering working situation are lacking within these DBL projects. The set-up of the projects is less realistic and the teacher's main task here is to transfer knowledge in lectures.

In our observations of ME tutor behavior, we found that tutors formulate questions (item 1) as part of the common activities involved in facilitating learning and supervising students during DBL group meetings. This is in line with what the teachers report they do in facilitating students. Examples of questions from the 'air compressor design analysis' include: *What is the essence of the problem? How are the components linked to each other? How do they work together?* These questions were posed during the analysis of an experiment designed to help students synthesize the knowledge gathered in order to reach a design solution. Other examples of questions we noted include: *How much power can you use from the motor? How are you going to measure the efficiency of the motor?* Tutors used these types of questions to stimulate reasoning on technical design aspects so students could make sound decisions for the next design step.

Actions such as *provides feedback on progress on presentation skills, team work, etc. (item 3), support students to reflect on and explicate rationale for technical design, formulation of arguments, and decision making* (item 6) *and supports students in case of difficulties (just-in-time teaching)* are more frequently encountered when tutors are supervising performance. The presence of these actions corresponds to a more active role we saw with some tutors in supervising group work (see Figure 2).

In Figure 2, there are differences among tutor performance, as not all tutors support *students to reflect on and explicate rationale for technical design, formulation of arguments, and decision making* (item 6). These differences among tutor actions are a result of personal supervision style and/or varying understanding about the tutor's tasks, roles and practices. Actions such as *provides feedback on evolving efforts, e.g., coaching on progress in technical design, etc.; encourages students to articulate engineering terminology; encourages students to explore alternatives for problem solving, etc.* (item 9) and *uses some methods such as worksheets, drawings, examples, etc. to guide the team* (item 8) were performed less often by the tutors. Actions related to *acts as an expert, customer, etc.* or scaffolding reasoning by us(ing) worksheets, drawings or examples are also uncommon among tutors. Findings reveal that tutors are less representative of the DBL actions reported in the literature, as their focus is on supervising progress.

Tutors are involved in student supervision during group discussions but not during actual teaching. Furthermore, even though tutors supervise and assess the process, during the meetings we observed that tutors do not employ a systematic set of criteria to monitor such processes. This finding was substantiated during the interviews with the tutors.

Although *formulates questions* is a common practice, we perceived this is often not employed as intended by the DBL framework. Tutor questions are geared to return the group to the main discussion point and objectives or to ensure the team takes a deeper approach during the discussions. Examples of these types of questions found during our observations include: *Is the subject clear? What was the objective of your experiment? Wouldn't it be better to find out that information first, to know how it works?* These actions correspond to the tutor's role in process supervision but not in the supervision of technical aspects of the design. During the tutor interviews, it became clear that supervision and feedback on technical aspects do not take place systematically during the design process. One explanation may be that the tutor largely maintains a specific role in monitoring the group process, while being less involved in content. Tutors understand their role in monitoring the project process and progress according to the objectives and the plan. Furthermore, although tutors provide feedback on teamwork and assess students at the end on group participation and individual assignments, the criteria or guidelines for feedback and assessment on teamwork and progress on technical assignments are not consistently employed. This finding came out of the tutor interviews.

5.8 Teachers' and project leaders' actions in the Electrical Engineering department

An overview of the results of interviews with EE teachers and observations of EE PLs is provided in Figures 3 and 4. A coding system is provided below the figures representing the supervising actions. *Formulates questions (open-ended) (*item 1*) and provides feedback on evolving efforts, e.g., coaching on progress in technical design, data collection, testing methods, etc.* (item 5) are the two actions teachers perform as reported during the interviews. *Feedback on technical design progress* often takes place during regularly planned meetings with technical experts and/or teachers specialized in domains, wherein students present their progress on technical designs in the form of plans of action, measurement plans or prototypes. Although actions such as *reviews progress on plan* (item 4) *and supports students to reflect on and explicate rational for the technical design* (item 6) take place, these occur less frequently. We saw the same results for *uses some methods such as examples of drawings* (item 8), *encourages students to articulate engineering terminology* (item 9) and *encourages students to explore alternatives for problem solving* (item 10).

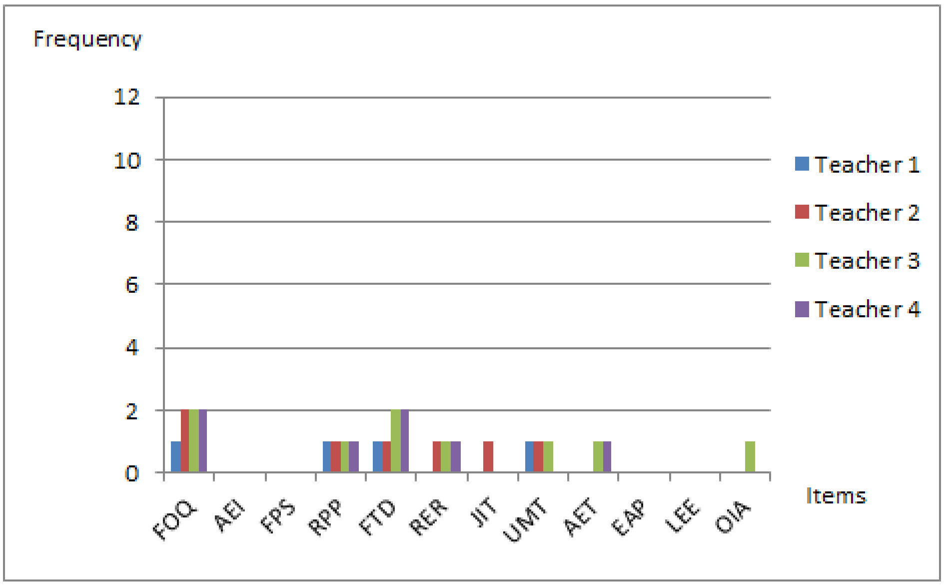

Figure 3 EE teachers' actions based on interviews

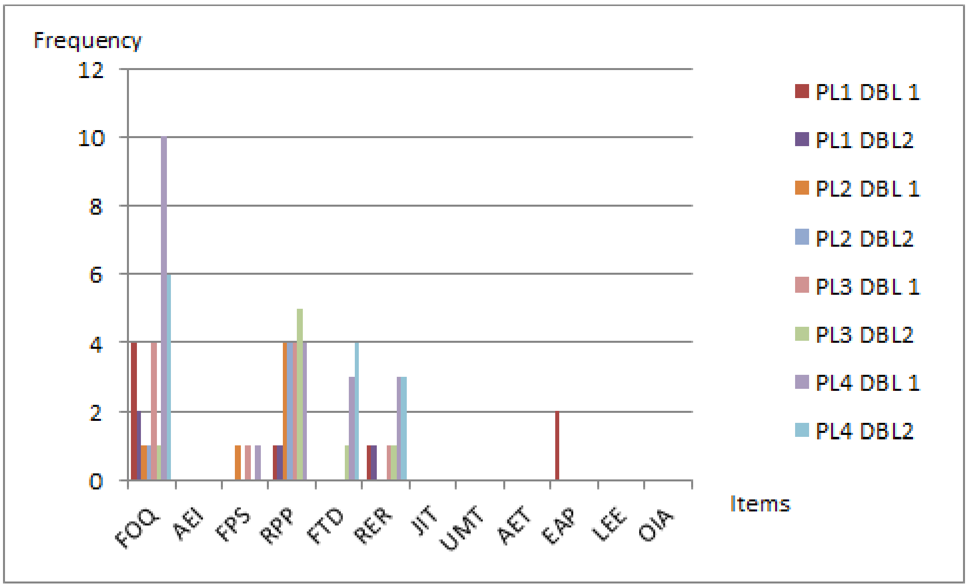

Figure 4 EE project leaders' actions based on observations

Note: *Description of DBL supervising actions following a coding system*: (Item 1) Formulates questions (e.g. open-ended questions) – FOQ; (Item 2) Acts as an expert, customer; gives information on specifications – AEF; (Item 3) Provides feedback on progress on presentation skills, team work – FPS; (Item 4) Reviews progress on plans, proposal, etc., RPP; (Item 5) Provides feedback on evolving efforts (e.g. coaching on progress in technical design, design process, data collection, testing methods) PTD; (Item 6) Supports students in reflecting on and explicating rationales for technical design, argument formulation, and decision making, RER; (Item 7) Supports students in case of difficulties (just-in-time teaching) JIT; (Item 8) Uses methods/tools (worksheets, drawings, examples, etc.) to guide the team, UMT; (Item 9) Encourages students to articulate engineering terminology during regular meetings and presentations, AET; (Item 10) Encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives, EAP; (Item 11) Encourages students to learn from other students' plans, knowledge application in problem solving experiments, LEE; (Item 12) Observes students during implementation of activities, OIA.

To crosscheck these findings, we monitored teachers during one of the project's technical meetings. We observed that *formulating questions* (item 1) is a common practice used to *encourage students to explore alternatives for problem solving* (item 10) or *to reflect and explicate rationale for technical design* (item 6). Likewise, as the student submits progress plans, teachers review progress on plans (item 4), providing feedback. The context in which teachers address these questions occur during the presentation of an action plan and the design of the first prototype. Examples of questions and actions include: *What sensor and what actuator do you use? To present this prototype to a client, it needs to be validated and in detail in the planning specifying the material,* and *Have you not met the requirements because…* Teachers encourage students to think outside the box to explore alternatives for prototype representation. During these meetings, teachers provide feedback on progress in technical design and assess the mid-term products.

With respect to project leader actions, we see that formulates questions (item 1) is frequently performed. Likewise, *reviews progress on plans* (item 4) submitted by students is a common practice of this group (performed eight times), as it corresponds to the PL's responsibility to monitor planning. Examples of the questions are: *What methods have you used to measure the frequency? How are these related to measure the parameters?* These questions are meant to supervise the process and to support students' deep thinking.

Other actions, such as *provides feedback on technical design (*item 5*), uses methods such as drawings or worksheets* (item 8), *encourages students to articulate engineering terminology during regular meetings* (item 9) and *explores alternatives for problem solving* (item 10) are not encountered in supervising DBL practices. These actions are not included in the scope of the PL's supervision tasks, and therefore PLs are not involved in supervising and providing feedback on technical design or application of knowledge in this setting. The PL's main role lies in monitoring the process and group performance. This is in line with the presence of project leaders' actions in, for instance, *provides feedback on team work* (item 3). No major differences among project leaders are found in the supervision actions, as seen in Figure 4. This is because PLs follow the objectives of the project management master course.

However, reviewing progress does not necessarily mean project leaders check progress from a content point of view. They focus rather on the progress and the process, such as project planning. Differences between teachers and project leaders in supporting students to build domain-specific knowledge are well demarcated.

Regarding *plays a role as a user or customer* (item 2), this action is encountered neither in teachers' nor in PLs' actions. Modeling real-life engineering work environments in which students can practice designing products by meeting users' demands, for instance, is not encountered.

5.9 Conclusions

Our first conclusion is that ME teacher and tutor facilitation and supervision actions do not represent, comprehensively, the actions described in the literature on design-based learning. The results show that *formulate(s) question* is a part of both teachers' and tutors' views regarding their roles in student facilitation and supervision. Although teachers' views on this matter are consistent, the set-up and organization of feedback and supervision settings do not support the formulation of questions. With respect to *uses some methods such as worksheets, drawings and examples to guide the team, and supports students in case of difficulties (just-in-time teaching), and encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives*, these items are mentioned by the teachers, though sparingly. With regards to other actions reported in the literature, these are not present in neither the teachers' views nor practices within DBL.

The tutors' views and actions confirm that question formulation takes place during student facilitation and supervision, although there are differences among the tutors regarding implementation. Furthermore, although this is a common practice among tutors, these questions do not always fully and accurately represent the DBL actions encountered in empirical studies. However, actions such as *reflects on and explicating rationale for technical design, argument formulation, and decision making, and, in provides feedback on progress on presentation skills, team work, etc., supports students in case of difficulties (just-in-time teaching), encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives,* are present, although these actions are not performed by all tutors and only minimally represent the performance described in the literature. Tutors' roles in this setting have a limited scope of supervision – mainly the project process and team performance.

Teacher actions within the EE department represent, more frequently, the actions described in our literature review on design-based learning practices. The set-up of the mid-term presentations may foster the proper setting to formulate questions, and more importantly, questions that induce students' reflection *on and explicating rationale for technical design, argument formulation, and decision making. In addition, teachers do review progress on plans, proposal, etc.; provide feedback on evolving efforts (e.g., coaching on progress in technical design, design process, data collection, testing methods); support students in case of difficulties (just-in-time teaching); uses methods/tools (worksheets, drawings, examples, etc.) to guide the team; and encourage students to articulate engineering terminology during regular meetings and presentations*, as these actions were mentioned during the interviews and were encountered to some extent in the mid-term presentation we observed. PL actions, however, are limited to monitoring progress of the process and team performance. We find, therefore, that *provides feedback on progress on presentation skills, teamwork, and reviews progress on plans, proposals, etc.* are the main actions performed by the PL in this setting.

Actions such as provides *feedback on evolving efforts (e.g., coaching on progress in technical design, design process, data collection, testing methods) and supports students in reflecting on and explicating rationale for technical design, argument formulation, and decision making* are present in PL supervision actions, though to a very limited extent.

5.10 Discussion

From our results, we learn that actions deemed part of the DBL framework of empirical studies on facilitating and supervising students are not comprehensively represented in the DBL practices by teachers in either of the two studied engineering departments. Furthermore, our findings indicate there are differences in the facilitation of the learning process and supervising patterns between the mechanical engineering and the electrical engineering departments, as compared to the literature. At the ME department, learning facilitation is mainly limited to formulates questions (open-ended) as part of both teachers and tutors actions. However, the presence of actions taken in the technical design process (see Table 2) is relatively limited with respect to the supervision role. This indicates formative feedback on technical process and actions aimed at encouraging deep reasoning are rare, and consequently, not representative of the common DBL practices identified in the literature (e.g., Etkina, Murthy, & Zou, 2006; Etkina, Karelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silver, 2010; Hirsch, Shwom, Yarnoff, Andersom, Kelso, & Colgate, 2001; Massey, Ramesh, & Khatri, 2006). Teacher interviews reveal feedback comes at the end of the process, during the last meeting, and is restricted to feedback on a final report, presentation, or demonstration. Opportunities are limited to provide feedback, promote reflection, or to scaffold the development of specific domain knowledge during design stages.

Although the ME tutors' most frequent action is *formulates questions*, these questions do not always aim at stimulating reflection of alternatives or different approaches in technical design tasks. Furthermore, tutor interviews show they do not provide feedback in a systematic way. Feedback is given by intuition and is not formalized. No social events (formative presentations) are organized to provide feedback or help students articulate engineering terminology, explicate deep reasoning or reflect upon technical design aspects. As neither teachers nor tutors observe students during the implementation of activities, fewer opportunities for reflection are afforded.

At the EE department, we observed the characteristics of student supervising in DBL practices are more commonly found, corresponding to the DBL literature; however, they occur less frequently. Teacher interviews and observations indicate supervision and feedback take place regularly but no guidelines are used. Students present progress in the form of action plans, prototypes and measurement plans with the support of experiment results, and therefore more frequently encounter educational moments ideal for providing feedback on technical processes. There are more opportunities to provide support during the engineering design process to stimulate reflection-in-action during the learning process. Moreover, as students regularly present the progress of design tasks, they have more opportunity to utilize and practice electrical engineering terminology and use authentic engineering instruments that belong to the real-life work environment.

In the second-year DBL EE projects, teacher actions take a more prominent role in facilitating and scaffolding students' knowledge and learning process by, for instance, providing feedback on progress following plans or interim products, supporting student reflection upon knowledge building during presentations and encouraging the use of engineering terminology. Formative feedback varies, as no guidelines on technical design aspects are used.

Finally, although this study has included a limited representation of informants, i.e. teachers and supervisors, and the sample was taken from two departments of one university of technology, the results have served to emphasize the shortcomings in the facilitation and supervision practices by comparing the DBL practices from empirical studies to real-life engineering departments. Despite the fact these results may not be representative or generalizable for other technical programs, the findings from this research may be illustrative for other engineering institutions applying DBL.

5.11 Implications for further research

The analysis shows opportunities for teacher intervention and professionalization. The use of adequate criteria, embedding coaching and feedback moments to monitor the process and the application of educational methods (e.g. formulating questions, reflecting and articulating engineering design, etc.) to model engineering design thinking could function as a catalyst to foster development actions as engineers. Preparing educational practitioners to facilitate the learning process, to coach and to supervise students in DBL projects requires different interventions. Teachers and facilitators need to be exposed to 'best practices' from engineering design experiences which can serve as an eye-opener to develop educational settings that promote reflection-in-action and feedback moments. These feedback moments are devoted to preparing students' thinking to confront complex engineering design tasks, as they will face real-life situations in which they have to articulate engineering terminology, reflect iteratively upon design results and make sound decisions. Reflection will encourage self-development as the progress of the design process is monitored regularly. Practices regarding facilitation and supervision need to be embedded in the DBL curriculum activities as a formalized process. Modeling the engineering work context implies the need to have teachers roleplay as experts and encourage student deep thinking by formulating questions that allow diverse ways of approaching design tasks.

Finally, preparing teachers for DBL practices requires close co-operation with them in the design, implementation and evaluation of DBL assignments. Learning from experience how DBL features work in practice will support teachers in developing their own learning environments as they experience, validate, test, optimize and apply learned DBL strategies to their own contexts.

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Chapter 6

…In de huidige discussies wordt professionele ontwikkeling verondersteld effectiever te zijn als de leraar zelf actief kennis construeert, als er samen met collega's, wordt geleerd, als de inhoud aansluit bij en is ingebed in de eigen dagelijks werkcontext en als er rekening wordt gehouden met de beperkingen en mogelijkheden van de werkplek…

Van Veen, Zwart, Meirink, & Verloop, 2010 (p.8)[11]

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[11] Van Veen, K., R. Zwart, J. Meirink, & N. Verloop. (2010). *Professionele ontwikkeling van leraren: een reviewstudie naar effectieve kenmerken van professionaliseringsinterventies van leraren*. Leiden: ICLON.

Chapter 6

Professional development for design-based learning in engineering education: A case study[12]

Abstract

Design-based learning (DBL) is an educational approach in which students gather and apply theoretical knowledge to solve design problems. In this study we examined how critical DBL dimensions (project characteristics, design elements, the teacher's role, assessment and social context) are applied by teachers in the re-design of DBL projects. We conducted an intervention for the professional development of the DBL teachers in the mechanical and the electrical engineering departments. We used the Experiential Learning Cycle (ELC) as an educational model for the professionalization programme. The findings show that the program encouraged teachers to apply the DBL theoretical framework. However, there are some limitations with regard to specific project characteristics. Further research into supporting teachers to develop open-ended and multidisciplinary activities in the projects that support learning is recommended.

Keywords: design-based learning, experiential learning, situated learning

6.1 Introduction

Design-based learning (DBL) is an educational approach in which students gather and apply theoretical knowledge to solve design problems. DBL is rooted in active learning methods that facilitate students' learning processes. Five dimensions are relevant to the context of DBL. Based on a literature review we defined these dimensions as project characteristics, design elements, role of the teacher, assessment, and social context (Gómez Puente, van Eijck, & Jochems, 2011, 2013a).

DBL has been used to help students apply natural science concepts in secondary education. There are successful examples of DBL practices in high school curriculum to teach science (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009). Despite the fact that DBL has been investigated empirically in high school settings, in engineering education, however, research on DBL is scarce and the DBL characteristics in design projects have not been comprehensively investigated. In this study we explore how teachers apply the DBL characteristics in redesigning their projects.

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Mechanical engineering and electrical engineering teachers take part in a professional development programme, based on the Experiential Learning Cycle (ELC) as an instructional method to introduce the DBL theoretical framework, as well as to present good practices from engineering projects in order to encourage teachers to reflect critically on their own DBL projects.

In the next section, we provide a snapshot of the design-based learning theoretical framework. Subsequently, we present previous empirical research on DBL. We then describe the guiding educational principles that have given form to the professionalization intervention with the DBL teachers and supervisors. We present the research method and the participants of this study. Next, we describe how we have used the ELC model as an instructional design approach during the professional development programme. Thereafter, we give examples of the application of DBL characteristics in the redesign of projects. Finally, we present our conclusions and discussion, along with implications for further research.

6.2 Background

6.2.1 The theoretical framework of design-based learning

Design-based learning (DBL) is an educational approach that has been mostly used in the context of secondary education to teach science (Apedoe, Reynolds, Ellefson, & Schunn, 2008). Grounded in active learning methods, such as Learning by Design (Kolodner, 2002) and Design-based Science (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), DBL has served to help students acquire problem-solving and analytical skills common to science classes while they work on design assignments. In the context of higher education, however, DBL is rooted in the educational principles of problem-based learning (PBL) (De Graaff & Kolmos, 2003), as a way to develop inquiry skills and integrate theoretical knowledge by solving ill-defined problems (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003). Distinctive elements of the approach emphasise the planning process embedded in engineering assignments (Mehalik, Doppelt, & Schunn, 2008) while applying knowledge of the specific engineering domain through student involvement in the design activities of artefacts, systems or solutions.

Drawing on the findings of two literature studies (Gómez Puente, van Eijck, & Jochems, 2011, 2013a), we framed DBL within five dimensions: project characteristics, design elements, the role of the teacher, assessment and the social context. With regards to project characteristics, our findings reveal that engineering design assignments are open-ended, authentic, hands-on, and multidisciplinary. Examples of these characteristics are, for instance, assignments in which students work with incomplete information (Mese, 2006), devise their own design work plan (McMartin, McKenna, & Youssefi, 2000), seek alternatives and consider design solutions (Roberts, 2001) in scenarios representing industry problems (Hirsch, Shwom, Yarnoff, Anderson, Kelso, & Olson, 2001; Massey, Ramesh, & Khatri, 2006; Van Til, Tracey, Sengupta, & Fliedner, 2009).

The design elements included in our DBL framework represent design activities conducted in real-life software engineering work places. We have adopted the classification used by Mehalik and Schunn (2006) based on an empirical taxonomy of design elements involving activities from the industry context, such as exploring graphic representation, using interactive/iterative design methodology, or conducting failure analysis (Gómez Puente, van Eijck, & Jochems, 2011).

The role of the teacher is to facilitate the learning process and coach and supervise students in DBL assignments. In these assignments, students gather and apply knowledge while working on design projects. In doing so, the teacher formulates questions to facilitate deeper understanding of design tasks (Roberts, 2001; Hirsch, Shwom, Yarnoff, Anderson, Kelso, & Olson, 2001; Van Til, Tracey, Sengupta, & Fliedner, 2009; Etkina, Karelina, Ruibal-Villasenor, Rosegrant, Jordan, & Hmelo-Silverm, 2010), provides formative feedback on technical design progress as a meaningful method in the process of building domain knowledge (Massey, Ramesh, & Khatri 2006; Chang, Yeh Liao, & Chang, 2008), encourages students to articulate engineering terminology during regular meetings and presentations (Hirsch, Shwom, Yarnoff, Anderson, Kelso, & Olson, 2001; McKenna, Colgate, Carr, & Olson, 2006; Maase & High, 2008), and supports reflection to explicate rationale for technical design, procedures, or processes (Massey, Ramesh, & Khatri, 2006; Geber, Mckenna, Hirsch, & Yarnoff, 2010), all while playing an authentic role as a client or manager (Denayer, Thaels, Vander Sloten, & Gobin, 2003; Martínez Monés, Gómez Sánchez, Dimitriadis, Jorrín Abellán, & Rubia Avi, 2005; Massey, Ramesh, & Khatri, 2006).

The literature on assessment uncovers multiple forms and examples of assessment instruments, such as rubrics, mid-term reports or prototypes, online quizzes, individual or group reports, presentations, homework and lab reports (Roberts, 2001; Massey, Ramesh, & Khatri, 2006; Zhan & Porter, 2010; Shyr, 2010).

Examples of the social dimension include collaborative learning tasks, such as providing feedback to one another's plans or experiment results; collaboration on portions of individual assignments (Chang, Yeh Liao, & Chang, 2008; Denayer, Thaels, Vander Sloten, & Gobin, 2003); presentation of prototypes or final products, sometimes with representatives of the industry; and competitions (McKenna, Colgate, Carr, & Olson, 2006).

The characteristics of DBL present in engineering education at university level have not been comprehensively researched, and therefore, we don't know what the benefits are of this approach for gathering and applying knowledge in solving design problems. The need to empirically investigating DBL as an educational concept and what the effects of the DBL characteristics are on the students becomes essential to shed light on DBL as an educational approach suitable for engineering disciplines. We are particularly interested in learning how these DBL characteristics can be introduced in design projects in order to facilitate students' learning processes. In this study, we aim, in particular, to explore how teachers apply DBL characteristics in the re-design of DBL projects. The redesign of the projects to include DBL characteristics will be the first step towards changing teachers' behaviour, as it is expected they will introduce this approach within the projects, according to our framework. This will allow us in a later stage to research the effects of DBL characteristics. We assume that working closely with the teachers will contribute to their professionalization and assure ecological validity in educational practice.

6.2.2 Research context

Design-based learning was introduced in 1997 at the Eindhoven University of Technology following a worldwide trend to provide students in engineering with knowledge and competencies to develop innovative solutions in response to societal and industry demands (Wijnen, 2000). Although DBL is grounded in the educational principles of Problem-Based Learning (PBL), it was integrated into engineering programmes to in order to encourage students to gather and apply theoretical knowledge in design assignments. We organised a number of visits and study tours with both teachers and students to Aalborg and Roskilde universities in Denmark (Perrenet, Bouhuijs, & Smits, 2000) with the purpose of presenting problem-oriented, project-based learning from the PBL model (Kolmos, 2002).

DBL was introduced as an educational approach consisting of six features: professionalization, activation, cooperation, creativity, integration and multidisciplinary. However, this educational approach has developed into different forms according to the needs of each engineering programme and curriculum purpose. At the Mechanical Engineering department, the problem-based learning approach from University of Maastricht was adapted to give form to teamwork assignments in which students gather and apply knowledge in problem-solving and design tasks. Other features adapted from the PBL model were the supervision system with tutors and the ‘7-jump’ group work methodology. DBL at the Electrical Engineering department emerged from the traditional practical instructional form.

As the practice of DBL has evolved over the years and has been adapted to give form to the different engineering study programmes and curriculum purposes, we were interested to know how DBL is performed in practice within the different engineering disciplines. Furthermore, our interest lies in learning how we can improve these DBL practices by comparing the results of our previous study (Gómez Puente, van Eijck, & Jochems, 2013b) with the redesign of DBL projects after our intervention in this study.

6.2.3 Previous research on design-based learning

We conducted a quantitative survey of teachers’ and students’ perceptions of second-year DBL projects with respect to DBL characteristics in four engineering departments: Mechanical Engineering (ME), Electrical Engineering (EE), Built Environment (BE), and Industrial Design (ID). In addition, we carried out a qualitative analysis of DBL projects to identify whether the DBL characteristics included in our theoretical framework actually are present in the projects assigned (Gómez Puente, van Eijck, Jochems, 2013b).

Results from the survey reveal there are differences in perceptions between the departments with respect to the presence of DBL characteristics. Industrial Design teachers' and students' identify the DBL characteristics to a greater extent than those in the other departments. Significant differences are found when we look at project characteristics, the role of the teacher, and design elements among the departments. With respect to assessment and social context, we cannot make rigorous statements since the outcomes regarding these two dimensions appeared less reliable. This might be due to the formulation of questions, to the low number of items included in these two dimensions, and to differences between departments in the implementation of DBL.

When analysing projects, findings indicate that not all DBL dimensions are embedded in the projects throughout all departments. We find differences in some aspects of project characteristics, the role of the teacher and design elements. These differences are encountered mainly in Mechanical Engineering and Electrical Engineering when compared to the practices in Built Environment and Industrial Design.

Furthermore, we reviewed the second-year DBL projects following a protocol we developed (Gómez Puente, van Eijck, & Jochems, 2013b), comprising characteristics of DBL projects from the literature. We followed Yin's (2009) model to design and validate this protocol. Examples of DBL characteristics encountered in the literature included in our protocol are: *'Projects are open-ended, e.g., no unique solution is given in the end, looking for alternatives is encouraged'; 'During project implementation, teacher gives regularly individual feedback on content contributions to the project progress (e.g., conceptual and technical design, prototype)';* and *'When student teams are involved in projects, students test hypothesis and explore the reasons for a design to fail'.*

The outcomes of the analysis of the project materials indicate there are differences in the DBL projects with respect to project characteristics, the role of the teacher and design elements, and to a lesser extent with regards to the social context and assessment. When looking at project characteristics, we find differences in the areas of open-endedness, authenticity and multidisciplinary elements. Variation between the departments also exists with respect to the role of the teacher. At Industrial Design and Built Environment, coaching and supervision takes place on technical design aspects, on process and on self-development. In Mechanical Engineering and Electrical Engineering, however, coaching is limited to technical design aspects and coaching and supervision on the design process. Formative feedback is encountered in the Built Environment, Electrical Engineering and in Industrial Design practices; in Mechanical Engineering projects, however, students are assessed at the end based on project reports. With respect to design elements, differences mainly refer to iteration, reflection on process and communication with users through prototype exposure to external parties, stakeholders or groups of teachers.

Thereafter, we conducted research on teachers' and supervisors' actions in coaching students (Authors, accepted). Results of this research, based on observations and interviews, show that teachers' and supervisors' do not always perform the coaching actions we see in the DBL literature. In addition, interviews with the supervisors reveal that coaching and feedback was intuitive, not formalised, and rarely took place with the use of criteria.

According to the above research findings, we have conducted an intervention for the professional development of DBL teachers with the aim of enabling them to redesign their projects according to the DBL theoretical framework. In doing so, we looked for a vision to frame the teachers' professionalization path following currents trends. In the coming section, we specify the professional development programme we used for the DBL teachers.

6.2.4 The professional development of the teachers

In contemporary research on the professional development of teachers, interventions considered promising are those situated in the context of engaging teachers in inquiry and reflection about their own concrete classroom situations on educational practices, together with colleagues (Schön, 1983; Van Veen, Zwart, Meirink, & Verloop, 2010; McAlpine, 1999; Healey, 2000; Hoekstra, Brekelmans, Beijaard, & Korthagen, 2009). Likewise, other examples of interventions are those involving the teachers in the analysis and formative evaluation of their own educational experiments and practices used iteratively to develop education (van den Akker, 1999; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003).

Building upon the above-mentioned principles and in line with the educational theories and models from the engineering projects in our literature review (Gómez Puente, van Eijck, Jochems, 2013a), we were interested in exposing teachers to best practices in situated design scenarios representing realistic engineering design activities. In these scenarios, learning is situated in real-world, complex tasks that engage students in solving meaningful problems. Displaying these types of examples will inspire teachers to construct authentic and realistic design assignments (Jonassen, Strobel, & Lee, 2006).

We selected the Experiential Learning Cycle (ELC) by Kolb (1984) as a constructivist learning model to work with teachers during professionalization sessions. This inquiry model, based on inductive and deductive principles, builds upon experiencing insights and situations, reflecting upon own practices (Schön, 1983), generalising and understanding the new DBL insights and applying new ideas in the redesign of DBL projects. This process resembles analogies of design easily recognised by teachers in engineering disciplines. The iterative character of this model reproduces the engineering design approach of developing products and systems following a process of analysis, reflection and communication on a prototype, and finally, application and testing in a new context. This approach allows teachers to review practices and redesign DBL projects.

We have taken the ELC model and adapted it to our own context for the professionalization sessions with the teachers. Figure 1 shows how we have adapted it to give structure to our programme.

Figure 1 Adapted from the Experiential Learning Cycle, David Kolb (1984)

6.2.5 *Research questions*

Following a line of investigation from our theoretical framework to the analysis of the implementation of DBL in the engineering study programmes and the professionalisation of DBL teachers, we were interested in exploring the following research questions:

- To what extent have the Mechanical Engineering and Electrical Engineering teachers applied the DBL theoretical framework in the redesign of the projects as a result of a professionalization programme using the Experiential Learning Cycle as an educational method?
- Are there improvements in the redesign of these projects when compared to the projects of our previous study?

6.3 Selection of participants and method

6.3.1 *Selection of projects and selection of participants*

For the purpose of this study, we selected four projects at two departments, Mechanical Engineering and Electrical Engineering, following the results of a previous investigation (Gómez Puente, van Eijck, & Jochems, 2013b). At the ME department we chose the two projects compulsory for all ME students at the freshman level. The EE projects included in our study were the only two projects assigned in the second year. In Table 1 we provide an overview of the engineering departments and the name of the projects we have employed for this study.

Table 1 Overview of engineering departments and projects

Name of department	Name of project
Mechanical Engineering (ME)	
First-year projects	Project ME1 – Truss Construction Project ME2 – The Propeller
Electrical Engineering (EE)	
Second-year projects	Project EE1 – Power Conversion Project EE2 – Robotic Surgery

The participants at the Mechanical Engineering department were teachers responsible for the design, supervision and assessment of the four DBL projects at the freshman level. In addition, technical staff deeply involved in the supervision and to a certain extent in the project design process was also selected. In total N=6 teachers took part in the professionalization meetings. The selection of participants was made by the educational director of the department.

At the Electrical Engineering department, the participants were second bachelor year teachers who participated in a previous research study (Gómez Puente, van Eijck, & Jochems, 2013b). The total number of teachers pertaining to the two DBL projects at the electrical engineering department was N=7.

Regarding the supervision of students, both the coaches at the Mechanical Engineering department and at the Electrical Engineering department responsible for the supervision of the weekly group meetings were also selected. A total of N=24 ME and N=15 EE coaches were trained. The main function of the coaches in DBL is to supervise the student groups in weekly meetings. Coaches provide feedback on weekly assignments as well as group performance. In addition, coaches also assess the group and individual work. Coaches at the ME department were master students, senior teachers and technical staff. In principle, master students act as coaches. However, in case of lack of coaching staff, technical staff and teachers can also act as coaches. At the EE department, coaches were master students. Due to a lack of master students for the second EE project, second-year students were also selected for the supervision of the DBL groups, and consequently, for the training.

6.3.2 The method and set-up of professional development for the DBL teachers

The professionalization programme consisted of four meetings with, in total, seven hours contact time. The first meeting consisted of an introduction to the research context on DBL. The other three sessions were devoted to the main content areas: the design of projects focusing on project characteristics and design elements, the role of the teacher in supervising and coaching students, and the assessment and social context. In addition, individual feedback was provided on the redesign of the projects.

The professionalization sessions were structured according to an adaptation of the ELC model as presented in Figure 1. Each session followed the same approach in applying the Experiential Learning Cycle phases to inspire analysis, reflection through discussion, understanding DBL insights, and finally, application of ideas in the redesign of DBL projects.

During the *concrete experience* phase, teachers were exposed to examples of best practices from the literature on the five dimensions. Exposure to these experiences served as an eye-opener to stimulate inspiration for their own projects. During this phase, examples of open-ended and authentic tasks were presented. For instance, we provided an example from our literature review (Massey, Ramesh, & Khatri, 2006) students working on the development of mobile applications by engaging the industry and presenting mobile solutions to an expert panel of industry judges and faculty members. Examples provided concerning the teachers' role refer to the teacher who, during project implementation, provides regular individual feedback on content contributions to the project progress (e.g., conceptual and technical design, prototype). Other examples demonstrate students applying design elements, such as 'test hypothesis and explore the reasons for a design to fail', that stimulate further research on system features to develop a complete prototype.

During the *reflective observation* phase, teachers reflected on their own practices by comparing their projects to the practices from the DBL literature. Teachers critically analysed their own projects, recognised the limitations and possibilities of DBL within the context of their own classrooms, identified differences between their own projects and defined opportunities to integrate and reproduce in the context of those projects. With respect to the teachers' role in coaching and supervision, results of research previously conducted on teachers' and supervisor's actions at the mechanical and electrical engineering departments (Gómez Puente, van Eijck, & Jochems, 2013c) were presented along with examples from the literature on supervising students. Other illustrations of the teachers' role from our literature (Chang, Yeh Liao, & Chang 2008; Etkina, Murthy, & Zou, 2006; Etkina, 2010; Geber, Mckenna, Hirsch, & Yarnoff, 2010) displayed teachers' actions by formulating questions, stimulating students to look at the problem from different perspectives, providing formative feedback on students' learning processes, and encouraging self-reflection on their own design practices through iterative prototyping that fostered a critical reflection.

In the *abstract conceptualization* phase, teachers gained a better understanding of the DBL characteristics and educational theories. The teachers re-interpreted their ideas and experiences to transform them on engineering design scenarios to enhance students' learning implementation activities as real engineers solving realistic industry problems. In addition, some theory was explained, for instance, on how to design rubrics as an instrument to provide feedback and assessment.

Finally, the *active experimentation* phase consisted of the redesign and integration of the DBL characteristics into their current projects. Feedback was used to further adjust the projects. The result of the application phase was the project setup and description for the students. The project documents were used for the analysis of the redesign of the projects. In Figure 2 we present an example of the setup of an open-ended project, ‘Power conversion and distribution system as applied to electric vehicle chargers’, at the Electrical Engineering department. In this assignment, students need to design the whole electrical system with few specifications and no architecture to the design.

The professional development programme also included the tutors and project leaders at both departments, as they perform a key role in the supervision and coaching of students groups. Following the DBL model from the literature, the supervisors were trained in the use of rubrics as an instrument for feedback and assessment. In addition, as engineering design is a question-driven process, the focus on questioning and inquiry was a prominent topic during the sessions with the tutors and project leaders. Examples of questions and feedback were presented to generate understanding in the actions that supervisors carry out during the coaching of students. These new topics were included in the regular programme for supervisors and consisted of two hours.

6.3.3 Analysis of the redesign of the projects’ study materials

We have analysed the project documents the teachers redesigned during the professionalization meetings. In doing so, we have used a protocol we developed in a previous study (Gómez Puente, van Eijck, & Jochems, 2013b). This protocol has been tested before in the analysis of second-year engineering study programmes to examine whether the projects included the DBL characteristics from our theoretical framework. The results of our analysis on second-year projects with the protocol were verified via a check interview with the teachers.

For the purpose of this study, we adapted this protocol slightly with respect to the role of the teacher. The original protocol included items under the teachers’ role element that were meant to be used during the interviews. This specific information, however, is not applicable for this study and is therefore not found in the project description and materials developed by the teachers during the instant study. We provide in Table 2 a general overview of some of the DBL characteristics we used in our protocol to analyse the projects’ redesign.

Table 2 Examples of items used in the protocol for the analysis of project materials

DBL dimensions	Characteristics	Examples
Project characteristics	Open-ended	No unique solution is encouraged, more than one design solution/alternative is possible Project vaguely formulated: product specifications are not given or are intentionally unstructured
	Authentic	Realistic scenarios: assignments represent real-life engineering problems; Students approach industry to find out information about product specifications
	Hands-on	Experiential: iterations in analysis prototype design, implementation, and testing (learning-by-doing)
Design elements		Explore problem representation, use interactive/iterative design methodology, search the space (explore alternatives), use functional decomposition, explore graphic representation, redefine constraints, explore scope of constraints, validate assumptions and constraints, examine existing designs, explore user perspective, build normative model, explore engineering facts, explore issues of measurement, conduct failure analysis, encourage reflection on process
Teachers' role	Coaching on task, process and self	Challenge students by asking questions Teacher gives just-in-time teaching or lecture-by-demand strategy; feedback upon mid-term deliverables: project plans, project proposal, prototype
Assessment	Formative assessment	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
	Summative assessment	Individual contribution to project group; oral exams; final exam; presentations; reports
Social context	Collaborative Learning	Team work; communication with real-life stakeholders: presentations of prototypes to company; Peer-to-peer communication: peer learning processes within and across teams when students share laboratory resources and engage in debates Motivation through competitions; variation in design techniques and approaches: learning principles are the same, but prototype is different

6.3.4 Verification of findings of the redesign of projects

To verify the findings of our analysis of the redesign of the projects, we requested an outside researcher, who was not included in this research study, to analyse and review a sample of the projects. We selected the second researcher according to the following criteria: experience in research methodologies, knowledgeable about engineering education and activate learning approaches, expertise in project-based education, and familiar with the DBL characteristics used in this study. We selected one project from each department. The second researcher was instructed in the DBL characteristics, and subsequently, was asked to analyse the projects following our protocol.

Results of the inter-rater reliability (Gwert, 2012) between the two researchers show a moderate to good level of agreement (Cohen's Kappa). The level of agreement for the ME project is .70 (good), and in the EE project .54 (moderate). The major discrepancies among the two researchers are encountered in the interpretation of open-endedness. This may be caused by the fact that the project description and materials to be analysed may not be sufficiently illustrative of the open-ended character of the assignment. Despite the discrepancy between the researchers regarding this EE project, we still considered this project to include substantial DBL characteristics from our framework, as shown by a comparison of the figures 3(c) and 3 (f), indicating a significant improvement after the intervention. The results of the redesign were sufficient for the researchers to determine that the EE department had met the expected standards.

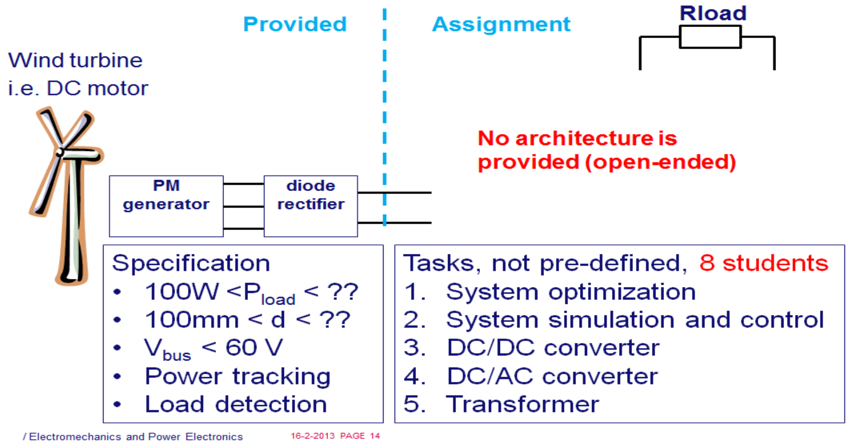
However, being aware of this limitation, a possible remedy in conducting future studies will include adjusting the protocol document used to analyze the projects. This will include more examples from the literature, clarifying precisely the concept of open-endedness to make external researchers more familiar with this aspect.

6.4 Results

Section 4.1 presents in detail the results of the analysis of one of the four projects, serving as an example of how the DBL characteristics of our theoretical framework have been employed by the teachers in the redesign of this project. Section 4.2 describes in a more outlined fashion the results of the analysis of all four redesigned projects. We also present the projects from our prior study (Gómez Puente, van Eijck, & Jochems, 2013b) in order to compare those with the current redesigns.

6.4.1 The redesign of the 'Power conversion' EE project

Table 3 shows that the project characteristic *open-ended* is represented as ill-defined tasks that launch students in the design and of a power transfer system for electric cars. Not all specifications for the architecture for all sub-systems (e.g., power tracking, load detection, DC/DC and DC/AC convertors) are provided, and no unique solution or result is indicated, as shown in the left-hand side in Figure 2. *Hands-on* approach is to design the system, to determine the functionality and interactions of each subsystem, to research the properties and search alternatives by doing simulations, to build and test prototypes, and finally, to improve models in iterations.



Provided

Assignment

Rload

Wind turbine
i.e. DC motor

No architecture is
provided (open-ended)

PM generator

diode rectifier

Specification
- 100W <P_{load} < ??
- 100mm < d < ??
- V_{bus} < 60 V
- Power tracking
- Load detection

Tasks, not pre-defined, 8 students
1. System optimization
2. System simulation and control
3. DC/DC converter
4. DC/AC converter
5. Transformer

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Figure 2 Example of the open-ended assignment of the “Power conversion’ project

Authentic characteristics are represented by a realistic scenario with students playing the role of engineers in an electronics company hired by a wind turbine manufacturer.

We noticed that *no multidisciplinary* aspects are encountered or linked to the context of societal, environmental, or economic problems. Theory of different courses, however, is integrated, providing a more interdisciplinary character to this project.

With respect to the *design elements*, the project includes new design activities, such as *encourage reflection on process, explore user perspective, use interactive/iterative design methodology, redefine constraints, and explore scope of constraints,* among others.

We notice in the redesign of this project that *the role of the teacher* is displayed by providing supervision of students’ technical design tasks, monitoring the progress using rubrics and also encouraging the students’ development.

Regarding *formative and summative assessment,* the project assignment focuses on process and products (i.e., planning and design system, reports and demonstrations of sub-systems). Furthermore, with the development of rubrics, students are coached and assessed during the process, providing opportunities for learning and self-development. Assessment with rubrics has been included to bring objectivity and content validity into the assessment process.

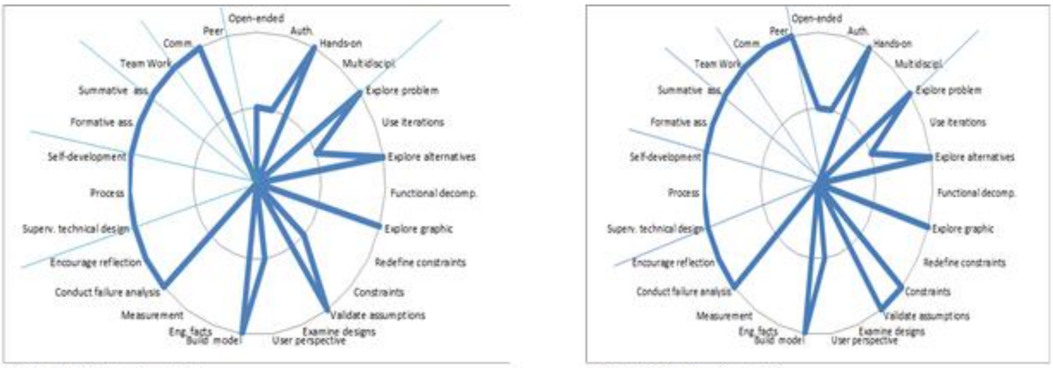
Finally, the *social context* (*e.g., competitions, presentations and peer-to-peer*) is represented in this project by a competition and a mid-term presentation with the client and the expert panel, although no representation of industry stakeholders is included.

Table 3 Example of the ‘Power conversion’ project at the Electrical Engineering department

DBL dimensions	Examples DBL characteristics	Examples of DBL characteristics integrated in the project
Project characteristics	Open-ended	Architecture of the system is not given. Students work on given specifications of the energy transfer system.
	Authenticity	Students act as engineers in an electronic engineering company. Engineering company is hired by wind turbine manufacturer to demonstrate the *technical* feasibility of a ‘green’ contactless energy transfer based on a small wind farm. System might be sold to companies offering electric vehicle charging on their parking lots as well as to homeowners. Approximately 700 hours are available for the project team, representing a commercial value of EUR 50000-70000.
	Hands-on	Students work in an iterative process in design and operate a generation, distribution and contactless power transfer system for electric cars. Students model and construct electric circuits; design and test a contactless power delivery system; manufacture printed circuits boards (PCB); make demonstrations, try-outs and adjustments. There is a client (the teacher) and the experts of the company (content teacher experts)
	Multidisciplinary	No representation of multidisciplinary, but project content embraces four courses.
Design elements		New Design Elements included in the project after the redesign: use interactive/iterative design methodology, redefine constraints, explore scope of constraints, explore user perspective, explore issues of measurements, conduct failure analysis, encourage reflection on process
Teachers’ role	Coaching on: - Technical design; - Process; - Self-development	Teacher acts as the client and domain teachers are the experts. Supervision on: - technical design: reports, demonstrations, presentations; - process: progress of planning, regular short presentations within the group; - self-development: regular feedback with rubrics by PL.
Assessment	Formative	Architecture and planning; draft specification; design review and the pitch to the client (15% of final grade); pitch and advice to client: go/no-go decision based on the pitch to the client; PCB designs; individual reports; 4 sets of rubrics on individual student performance to the responsible lecturer;
	Summative	- Demonstration (15% of final grade); - Final reports (40% of final grade); - Grade including motivation for each student to the responsible lecturer at the end of the project (15% of final grade); - Peer-review: give each other feedback (15% of final grade).
Social context	Team work/ Competitions Communication/ Presentations/ Peer-to-peer	Competitions: After final demonstration, a prize is awarded to the best team based on: demonstration, functionality of designed system, accuracy of final specification, dimensions, design of coils and printed circuit boards; Presentations with (fictitious) industry representative, i.e., (fictitious) client.

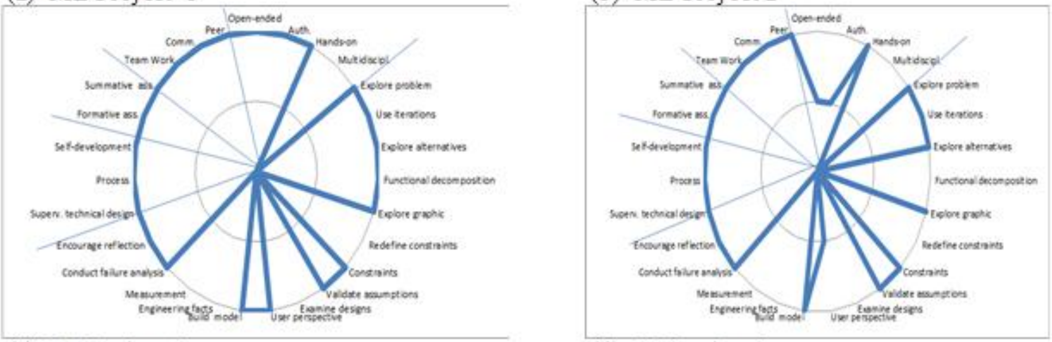
6.4.2 The redesign of the ME and EE projects: Overview of outcomes

We describe in this section the results of the analysis of the ME and EE projects. For each of the projects we carried out a detailed analysis as presented in Table 3. The results of the analysis of these projects are outlined in Figure 3 (a) (b) (c) (d). In the figure, we separate the DBL characteristics with extant lines. Lines touching the outer boundaries on the top of the spider web diagram indicate that the DBL characteristics are present in the project. Lines in the middle point out that the DBL characteristics are represent to certain extent. No lines coming from the centre of the spider web diagram indicate that no DBL characteristics are encountered. To gain a better scope of changes implemented through this study, we compare the redesigns with those projects before our intervention (Gómez Puente, van Eijck,& Jochems, 2013b), as shown in Figure 3 (e) (f) (g).



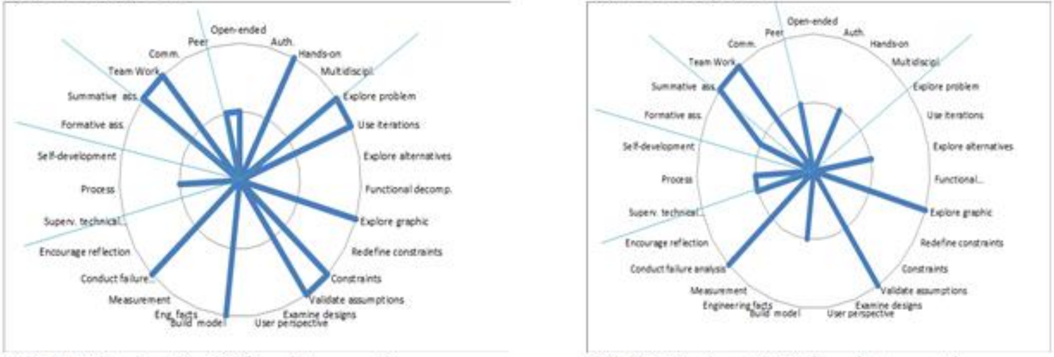
(a) ME Project 1

(b) ME Project 2



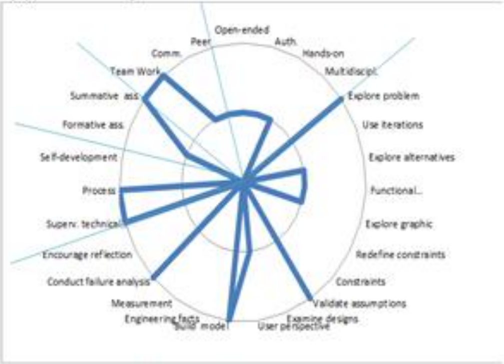
(c) EE Project 1

(d) EE Project 2



(e) ME Project 2- Before intervention

(f) EE Project 1-Before intervention



(g) EE Project 2-Before intervention

Figure 3 (a) (b) (c) (d) (e) (f) (g)

Description of the DBL characteristics following the clockwise direction: Project characteristics: open-ended projects; hands-on projects; authentic projects; multidisciplinary. *Design Elements*: Explore problem representation, use interactive/iterative design methodology, search the space (explore alternatives), use functional decomposition, explore graphic representation, redefine constraints, explore scope of constraints, validate assumptions and constraints, examine existing designs, explore user perspective, build normative model, explore engineering facts, explore issues of measurement, conduct failure analysis, encourage reflection on process. *Teacher's role*: Supervision on technical design aspects; supervision on process; supervision on self-development. *Assessment*: Formative assessment (individual or group tasks); summative assessment. *Social Context*: Team work; communication; peer-to-peer activities.

With respect to *project characteristics* (*open-endedness, authenticity, hands-on*, and *multidisciplinary*) encountered in ME projects, the two projects include *open-ended* tasks to a certain extent, as illustrated in Figure 3 (a) (b). In the 'Truss Construction' project, the design specifications are provided; however, students may choose the 2D model to construct based on calculations and explorations on sketches and prototypes. Likewise, in the 'The Propeller' project, some product specifications are given. Students are to investigate the design properties and make decisions around the diameter of the propeller, the setup of the motor, etc. *Hands-on* approach is used to carry out experiments, design and build, and test prototypes.

With respect to *authenticity*, the redesign of the ME projects resembles realistic scenarios to solve an assignment for a company representing a real-life situation. Other representations of authenticity include mid-term presentations to a panel of experts in the 'Truss Construction' project. In the 'Propeller' project, *authenticity* is embedded in engineering practical tasks, having a manufacturer advising on a special motor and battery in the propeller. *Multidisciplinary*, however, is not found in any of the ME projects, nor are the aspects of other contexts.

Concerning the *design elements*, we observe that these elements are applied as a tool kit to model project activities. The 'Truss Construction' project includes new design elements, such as *explore user perspective* in the form of an expert panel during a mid-term presentation, with the purpose of encouraging students' reflection based on results, and consequently, interaction. 'The Propeller' project comprises elements such as *explore issues of measurement, explore problem representation,* and/or *build a model,* but *use iterative design methodology* and *encourage reflection* are new to this setting following our intervention.

With regards to *the role of the teacher,* in *supervising technical design tasks, the process* and *the students' development,* the projects include more formative feedback on processes and products. Students are supervised based on mid-term presentations or on a measurement plan. Furthermore, teachers have developed rubrics and criteria lists to monitor the technical progress, the group process and students' individual development. In terms of *formative* and *summative assessment* on process and products, there is a focus on both individual and group contribution and performance.

In our analysis, we perceived that the *social context* in the form of *competitions, presentations to stakeholders, peer-to-peer feedback, etc.*, is represented in the project 'Trust Construction' by, for instance, a mid-term presentation. Although no company representatives are included in this presentation, an expert panel with representatives of a technical university and a fictitious company client was organised. The competition element was previously included in this project. The redesign of 'The Propeller' includes presentations within the group meetings to enhance students' presentation skills. This is a new element in the social context of the project that responds to new educational policies. In this regard, the ME educational department together with the researchers in this study have developed a rubric instrument to provide objectivity and validity in the peer-to-peer review process.

Regarding the EE project characteristics, *open-ended* tasks are found in both projects, although in the 'Robotic surgery' project, these are encountered to a lesser extent. In this project, students select different alternatives on sub-system levels and the performance specifications are not given. However, some information is provided. *Hands-on* characteristics are represented by designing systems following a series of experiments, simulations and test(s) of the prototypes.

From our analysis we noticed that *authenticity* is represented in the 'Power conversion' project by students working as engineers in an electronic engineering company, which is hired by a wind turbine manufacturer. The teachers act as clients and experts. Regarding the 'Robotic surgery' project, the scenario previously included an authentic scenario to design a robot arm for a company working with medical equipment. The redesign does not include any new authentic elements in this regard**.**

No *multidisciplinary* aspects are encountered in the projects, although the projects are linked to courses holding a more interdisciplinary character. Looking at the *design elements*, both projects include new activities, such as *use iterative design methodology, explore user perspective,* and *encourage reflection on process*; these are the new elements encountered in the setup of project activities following our intervention.

The teachers' role in the projects is to supervise students on *technical design, process and development of students.* Technical supervision takes place by the teacher as the client and by the different domain teachers during mid-term presentations in the 'Power conversion' project. In the 'Robotic surgery' project, supervision on technical design was already included based on interim deliverables of prototypes. The technical process is now supervised with the use of rubrics as feedback instruments.

Regarding *formative and summative assessment* on process and products, this element is now integrated and formalised via the use of rubrics. *Social context* is now represented by competitions, peer-to-peer collaborative activities, and presentations to fictitious stakeholders, as well as giving feedback and assessing peer interventions.

Concerning the ME projects, we can only compare 'The Propeller' project in general terms, as this was a second-year project that is now taught at freshman level. In Figure 3 (e), we observed that changes were applied in all DBL dimensions in comparison to the former version of this project. Regarding ME1, unfortunately, we cannot make comparisons in the redesign of this project because it is a first-year project, and therefore, it was not part of our previous research study on second-year projects.

Reviewing the EE projects before our intervention, we identified in Figures 3 (f) and (g), that, for instance, concerning *open-endedness* the projects, and in particular EE1, information provided to students was well-structured in the previous version and included step-by-step instructions to carry out activities. Likewise, we perceived in Figure 3 (f) that the former design did not include *authenticity* dimensions, as the tasks comprised solving a guided problem. In our analysis of the EE teachers' role, we found that supervision focused on technical aspects but also included technical progress and student development.

In our analysis, we have also identified differences among the projects and the departments, which are found mainly in some aspects of *project characteristics*, i.e., *open-endedness.* Although all projects show *open-ended* features in the design assignments, the setup of the EE projects reveal a broader character of openness than the ME projects in some aspects. This difference may respond to the fact that the ME projects are at the freshman level, where the emphasis of the curriculum lies on teaching students to work in groups and familiarise themselves with the DBL approach, and later to learn about the heuristics of the design process. The EE second-year projects, however, put students in a higher level of complexity of the design process, building upon the design experiences in the projects assigned during the first year.

With regards to *authentic character of the teacher's role*, in ME projects the teacher does not play a lifelike role as a client, user or manager of a company. In the EE projects, the teachers play a more realistic role, as they act as clients and experts regarding the first project, the 'Power conversion'. The supervision role focuses now on the technical feedback, such as prototype design and the process based on intermediate deliverables. In addition, in the EE project teachers plan more frequent supervision opportunities on technical design.

6.5 Conclusions

In this study, we examined to what extent mechanical engineering and electrical engineering teachers apply the DBL theoretical framework in the redesign of their projects as a result of a professionalization programme using the Experiential Learning Cycle as an educational method. Furthermore, we also explored whether there are improvements in the redesigned projects in comparison with the projects of our previous study.

Based on our analysis, we can conclude that there are improvements in the redesign of the projects in both departments as a result of the professionalization intervention. As described above, the projects comprise the DBL characteristics to a greater extent than in the previous study. The fact that this method appears to be suitable to carry out changes in current teacher practices in DBL within two engineering departments allows us to think it can be successfully applied in other engineering departments at this university, having comparable design projects in their curricula. Furthermore, this result serves to encourage faculty to apply this method and to introduce it in the projects in different engineering disciplines at other technical universities. Moreover, following the research done in previous studies (Gómez Puente, van Eijck, & Jochems, 2011; 2013a) the examples encountered in the literature upon which we have built our framework are embedded in a broad range of engineering disciplines, showing the suitability of similar practices and approaches in different domains. Therefore, it seems likely that the method is effective in (re-)designing DBL-like projects, but of course, additional evidence is necessary. The core element, however, is to work together with teachers in the analysis and reflection of daily projects in their own classroom situations and discover the opportunities allowing for contextualization. Obviously, educational change can be implemented by developing own scenarios following the DBL educational principles and examples.

In addition, we learned from this experience that the approach used in the professionalization program is promising as an instructional method to work with teachers in educational change. To evaluate the effects of our intervention we have followed Kirkpatrick's evaluation model. We have mainly focused on the level of reactions of participants and their opinions about the program's usability and practicality regarding the context in which they develop projects. Further, focusing on Kirkpatrick's' level of behaviour, we have carried out observations of and interviews with teachers and supervisors. We have measured some effects of DBL characteristics on students (Gómez Puente, van Eijck, & Jochems, submitted to journal). The results of this study verify that teaching and supervising staff have changed their behaviour as they apply the DBL characteristics from our framework.

6.6 Discussion and implications for further research

From the results of this study we learn that, although the DBL characteristics *project characteristics* and *multidisciplinary* are integrated in the projects, they still are present to a lesser degree. We understand that these characteristics are aligned to the organisation of the curriculum and project learning outcomes.

The degree of *open-endedness* is linked to transferring the responsibility in the learning process from the teachers to the students (Shuell, 1996; Vermunt & Verloop, 1999; Hmelo-Silver, Duncan, & Chinn, 2007; Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007). From our study, we perceive that some projects taught in the freshman year contain more limitations regarding open-endedness than the projects carried out in upper levels. In addition, teachers' considerations are that students best learn to design following a heuristic path and that openness grows in the curriculum over the years. In this regard it can be understood that *open-ended* is limited in some projects. However, as *open-ended* also implies a shift in teachers' roles to give students a wider level of autonomy in learning to solve design tasks independently, it is essential to support teachers to develop and implement supervision tools. Creating a means to supervise students' self-direction will help to generate a balance between the openness of the projects without jeopardising students' leaning. Strategies to promote *open-endedness* in the projects are included already in the DBL framework of characteristics. These can be utilized as resources to design scenarios integrating *open-endedness* in the projects. Furthermore, to create a balance between the degree of freedom given to the students and supervision methods, the emphasis on the teaching paradigm shift should be intensified. On the other hand, forms of shared regulation at cognitive, affective and regulative learning function level (Vermunt & Verloop, 1999) have to be included in the supervision during DBL group work. These learning strategies could be embedded in the supervision of students in technical aspects, the process and the self-development of the student as a means to remediate the complexity that *open-endedness* brings about in undertaking design problem solving tasks.

Likewise, *multidisciplinary* is not present in the projects. Interestingly, the projects do not include aspects from different contexts, such as social, economic or environmental, which would allow a broader investigation of the design perspective. Involving *multidisciplinary* elements from this viewpoint infers the development of a more elaborate project setup, outcomes and assessment criteria, without endangering the time allotted for project work and the orientation of the curriculum.

This study presents also some limitations. Although we perceive adjustments in the redesign of DBL projects of our study, we unfortunately cannot strictly compare the original and the redesigned projects at the ME department. The analysis of the ME projects of our preliminary study focused on the second-year bachelor projects; however, the redesigned projects included in our current intervention are part of the freshman year. The change in scope in the bachelor years responds to management decisions at the departmental level.

Moreover, other limitations in this study are encountered in that this study has been carried out in one university and therefore we are unable to generalise the results. However, these results can be seen as an inspiration for other technical universities to critically review their DBL practices.

Finally, one of our premises was that working closely with educational practitioners in a collaborative environment provides a suitable platform for the professionalisation of teachers, which may influence teachers' behaviour (Kirkpatrick, 1975; Fullan, 2001). However, we are cautious to make rigid statements in this regard, as we cannot assess the impact of our intervention in teachers' daily practice at this stage.

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6.7 References

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Chapter 7

… engineers 'scope, generate, evaluate and realize ideas' - a characterization that emphasizes how engineers think and highlights how ideas are created (i.e., scope and generate), assessed and selected (i.e., evaluated), and brought to life (i.e., realized)…

Sheppard, 2003[13]

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Chapter 7
Exploring the effects of design-based learning characteristics on teachers and students[14]

Abstract

In design-based learning (DBL) projects, engineering students are to gather and apply knowledge while working on the design of artefacts, systems and innovative solutions in project settings. The characteristics of the projects, the design elements, and the role of the teacher are pivotal components within the DBL framework that foster students' design problem-solving process. This article investigates the changes and effects of DBL characteristics on students in solving design problems. Our study also explores the effects of a professionalization program on DBL teachers and supervisors. We conducted a survey of teachers' and students' perceptions about DBL characteristics. We then observed teacher, supervisor, and student actions during DBL group settings in solving design problems. We triangulated the findings with student interviews on design problem-solving steps. Semi-structured interviews with teachers served to analyze the effects of these DBL characteristics on the students and any changes in project implementation. In gathering and applying knowledge, students take a broader approach in exploring problems and searching for design alternatives as a result of open-ended, authentic, and hands-on activities within DBL. DBL characteristics enhance gathering and applying solutions to design issues during the problem-solving process, generating artefacts, systems, and innovative engineering solutions.

Keywords design-based learning, open-ended, authenticity, solving design problems

7.1 Introduction

Rapidly increasing societal challenges demand skillful engineers to design solutions to technological problems. Current developments in engineering education advocate programs that integrate the professional practice of the work of engineers to foster the ability to design systems and to innovate in constantly changing environments and conditions (Lamancusa, 2006; Sheppard, Macatangay, Colby, & Sullivan, 2008). Solving engineering design problems implies an intrinsic activity of discovering the unknown by proposing solutions that oftentimes include complex, open-ended and ill-defined technical tasks (Atman, Adams, Cardella, Turns,

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& Saleem, 2007; Dym & Little, 2009). Designing engineering solutions comprises an iterative decision-making process that opens up the venue for multiple and nonunique answers. In essence, the nature of solving engineering design problems requires analyzing, abstracting, and synthesizing knowledge in order to arrive at innovative solutions through integrating knowledge from different disciplines (Sheppard, 2003; Lamancusa, Zayas, Soyster, Morell, & Jorgensen, 2008). This process requires the appropriate know-how to uncover a vaguely formulated job task, to function within given constrains and specifications articulating a problem, and to ask the right questions and communicate with the user. Research on design engineering and teaching students to solve engineering design problems abounds in the literature (Jonassen & Rohrer-Murphy, 1999; Jonassen, Strobel, & Lee, 2006). Although there are numerous studies investigating students' processes and activities in problem solving and engineering design solutions, there is still little research on the pedagogy of design-alike approaches in higher education. Design-based learning (DBL) is an educational approach in which students gather and apply knowledge in creating artifacts and systems. In the DBL framework, students are engaged in conceiving a plan and using design activities as a means to acquire and employ knowledge to produce innovative solutions (Mehalik & Schunn, 2006).

DBL is a promising approach in secondary education curriculum within the science context. Research on DBL practices in upper secondary science classroom practices shows interesting student gains in learning science concepts (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009). Rooted in similar approaches, such as Learning by Design (LBD) (Kolodner, 2002; Kolodner, Camp, Crismond, Dasse, Gray, Holbrook, Puntambekar, & Ryan, 2003), Design-based Science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), and PBL (Barrows, 1985), DBL builds upon those educational principles and uses real-life and hands-on design scenarios to construct new science knowledge in iterations and to develop inquiry reasoning skills while solving science problems. Based upon significant research results, DBL has become a promising educational approach to foster authentic engineering design practices (Apedoe, Reynolds, Ellefson, & Schunn, 2008).

Based on two extensive literature review studies (Gómez Puente, van Eijck, & Jochems, 2011; 2013a), we describe DBL along five dimensions: project characteristics, design elements, the role of the teacher, the assessment, and the social context. We considered these dimensions crucial aspects in the learning environments of DBL projects. In this study, we investigate the effects of these DBL characteristics on students. In particular, we explore the effects of *project characteristics, the design elements,* and *the teachers' role* in students' ability to solve design problems. Furthermore, we also examine the effects of a professionalization program for DBL teachers and supervisors.

In the next sections, we describe in detail the five DBL dimensions. Following, we present a snapshot of research on design problem processes. Next, we describe the methods and research questions. Subsequently, we summarize the results of our analysis. Finally, we outline the conclusions and summarize the implications for further research.

7.2 Design-based learning theoretical framework

Design-based learning (DBL) is an educational approach in which students gather and apply knowledge in the design of artifacts, systems, and innovative solutions in project settings (Wijnen, 2000). Based on our previous research (Gómez Puente, van Eijck, & Jochems, 2011; 2013a), we framed DBL in five dimensions we will describe briefly.

Regarding *project characteristics*, literature on projects indicates that assignments are open-ended (Behrens, Atorf, Schwann, Neumann, Schnitzler, Ballé, Herold, Telle, Noll, Hameyer, & Aach, 2010), hands-on (Martínez Monés, Gómez Sánchez, Dimitriadis, Jorrín Abellán, & Rubia Avi, 2005), and resemble workplace engineering authentic scenarios. In these scenarios, students are given ill-defined tasks representing the multidisciplinary character of engineering processes in scoping and generating ideas, assessing and selecting, and in making decisions (Massey, Ramesh, & Khatri, 2006). The *design activities* of our DBL framework that engineers undertake are adopted from a classification of fifteen design elements from industrial contexts (Mehalik & Schunn, 2006). These elements represent engineering activities such as exploring problems and constraints, validating assumptions, and conducting failure analysis. With respect to the *teachers' role* in student supervision, the teacher scaffolds the thinking process by asking open-ended questions (Linge & Parsons, 2006), encouraging reflection and supporting students in analyzing design problems from different perspectives (Etkina, Karelina, Ruibal-Villasenor, Rosengrant, Jordan, & Hmelo-Silver, 2010), and providing formative feedback. With regards to examples of *assessment*, design processes are assessed by rubrics (Etkina, Murthy, & Zou, 2006) and through mid-term products and prototypes, oftentimes with the involvement of the industry. Finally, the social context encounters collaborative learning environments in which students give feedback to each other (Chang, Yeh, Pan, Liao, & Chang, 2008) and communicate and practice engineering terminology (Denayer, Thaels, Vander Sloten, & Gobin 2003). In this research study, we explore the effects of these DBL dimensions on students in a university engineering program setting. In addition, we also look at the effects that a professionalization program had on teachers and supervisors.

7.3 Research on solving design problems

In previous studies, we drew the boundaries of design-based learning as an educational approach that emphasizes applying and acquiring knowledge through solving authentic design problems in engineering (Gómez Puente, van Eijck, & Jochems, 2013a). While working on the design of artifacts and systems, students explore the problem from different perspectives, give form to the specifications, make predictions, test and communicate (Dym, Agogino, Eris, Frey, & Leifer, 2005; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Dym & Little, 2009), and evaluate in learning cycles while creating a design solution (Lawson & Dorst, 2009).

Our DBL theoretical framework, consisting of five dimensions, provides a rationale of characteristics, based on empirical research, to apply in the design and implementation of DBL engineering projects. Therefore, we explored empirical literature classifications of students' design problem solving steps. By doing so, we wanted to validate that our analysis of students' actions recorded during observations and interviews corresponds to our DBL definition. Numerous authors have investigated the design problem-solving process by analysing how students go about solving design problems, by studying what cognitive and reasoning activities they undertake, or by exploring the differences in design expertise of freshman and senior students (Cross, Christiaans, & Dorst, 1994; Atman, Chimka, Bursic, & Nachtmann, 1999; 2007; Ramaekers, 2011). Researchers frame, in general, students' design problem-solving steps in problem scoping and information gathering, conceptual design, testing prototypes, making conclusions and decisions, and finally, communicating and refining (Ullman, Dietterich, & Stauffer, 1988; Radcliffe & Lee, 1989; Sutcliffe & Maiden, 1992; Mullins, Atman, & Shuman, 1999).

Following the literature on research of design problem-solving processes in educational contexts, we adopted a common framework of activities in solving design problems, e.g., analysis of the problem (ANAPRB), selecting criteria (SELCRT), exploring alternatives to solve problem (EXPSTR), interpreting information (INFINT), making judgements (MAKJUDG), and making decisions leading to adjustments and iterations in the design (MAKDEC). We applied this framework to observe and analyze the effects on group discussions and meetings as a result of supervisors' change in behavior.

Our hypothesis is that integration of the DBL characteristics from our theoretical framework in the projects will foster and enhance students' solving design problems.

7.4 Research questions

In this study we investigated the following research questions:

1. What are the effects of the professionalization program on teachers and supervisors opinions and behaviors? Effects are expected regarding a change of behaviour in coaching and supervision of students in comparison to our previous study and findings (Gómez Puente, van Eijck, & Jochems, 2013b; 2013c). It is hypothesized that after the professionalization program both teachers and supervisors apply the DBL features from our theoretical framework to a larger extent.
2. Does the redesign of the projects lead to changes in the project implementation? The redesign encloses a number of characteristics from our framework to be implemented in the DBL project (submitted). The expectation in this regard is that teachers observe changes in students' approach in solving engineering design problems.
3. What are the effects on students' behaviors and opinions as a result of the redesign of the DBL projects? We expect to observe students applying different approaches in problem solving due to the introduction of the DBL characteristics.

7.5 Method and design of the study

7.5.1 Research context

DBL was introduced at Eindhoven University of Technology in 1997 as an educational approach to promote students' process skills and encourage them to work in teams in gathering and applying knowledge in solving problems. DBL was promoted as a framework that encouraged professionalization, activation, cooperation, authenticity, creativity, integration, and multidisciplinary (Wijnen, 2000). Over the years, DBL has been adapted gradually to give form to the educational context in each engineering department.

Following the results of research studies on DBL at this university (Gómez Puente, van Eijck, & Jochems, 2013b; 2013c), we conducted an intervention to enhance the professional development of DBL teachers and supervisors (Gómez Puente, van Eijck, & Jochems, accepted). The professional development program consisted of a series of sessions to expose teachers to DBL practices from international technical universities. The aim was to redesign the projects and integrate DBL characteristics.

In this study, we investigate the effects of the professionalization program on teachers and supervisors. Moreover, we study the changes in the projects and effects on students as a result of the introduction of targeted DBL characteristics.

To investigate these questions, we carried out research on four DBL projects in the mechanical and electrical engineering departments. The projects were redesigned during the professionalization program, and they include DBL characteristics taken from our framework.

7.5.2 Participants

The participants in this study were teachers at the mechanical and electrical engineering departments who are responsible for the design of the DBL assignments and the supervision and assessment of the students. These teachers took part in the professionalization intervention. The supervisors were also trained in our DBL approach. Supervisors are master students, Ph.D. students, technical staff, and teachers in the mechanical engineering department, and master students in the electrical engineering department. For the purpose of this study, we selected two supervisors to follow closely in each project. From the mechanical engineering (ME) department, two supervisors with experience in supervising students in DBL projects were selected to be recorded and interviewed. At the electrical engineering (EE) department, supervisors did not have previous experience in supervising students in DBL groups. Therefore, two project leaders who agreed to participate in this study were selected.

In one of the projects, however, supervisors were not available, and a member of the group took on some of the supervision tasks.

We chose the projects at the mechanical engineering and electrical engineering departments that were already under investigation in a previous study on the professionalization of teachers (Gómez Puente, van Eijck, & Jochems, accepted). These projects were consequently redesigned as a result of the professionalization program and included the DBL characteristics from our theoretical framework. With respect to the ME projects, we analyzed the two compulsory first-year projects, the “Trust Construction” (ME1) project and the “Propeller” (ME2) project, at the mechanical engineering department. At the electrical engineering department, we analyzed the only two second-year bachelor projects available, the “Power conversion” (EE1) project and the “Robotic surgery” (EE2) project. The participants’ composition, the projects, and the research method are presented in Table 1.

7.5.3 Research methods and instruments

We conducted a quantitative and qualitative study (see Table 1 for an overview of methods and instruments). The quantitative study consisted of a survey carried out with freshmen in mechanical engineering and second-year bachelor students at electrical engineering. In a previous study, we developed a five-point Likert-scale questionnaire. This questionnaire was tested and consequently used in our survey with second-year students in four engineering departments at our university to collect students’ perceptions on the DBL dimensions (Gómez Puente, van Eijck, & Jochems, 2013b). For the purpose of this study, the questionnaire focuses on three DBL dimensions: *project characteristics, design elements,* and *the role of the teacher*. The questionnaire contained N=33 questions.

Table 1 Overview of research methods, instruments and sample size per department*

Methods	Instruments	Group	ME1	ME2	EE1	EE2
Quantitative	Likert questionnaire	Students	98	70	38	34
		T/S**	14	14	12	11
Qualitative	Observations teachers		4	2	4	8
	Observations supervisors		8	8	8	8
	Observations student groups		8	8	8	8
	Interviews teachers		1	1	5	3
	Interviews students		10	10	10	10
	Interviews supervisors		7	7	7	7

** Number of teachers’ observations varies per project due to the differences in project setup*
***T – Teachers; S- Supervisors*

At the ME department, the questionnaire was disseminated among approximately 400 respondents participating in the two compulsory freshman projects. We analyzed only the completed questionnaires, yielding a total response rate of N=168 complete responses. Furthermore, we distributed the questionnaire to two teachers responsible for the ME1 and ME2 projects, as well as 26 tutors in charge of supervising student groups in these two projects. The total response was N=28.

For the EE projects, we distributed the questionnaire to about 90 students in the EE1 and EE2 projects. We collected a response of N= 72 students and N= 23 teachers and supervisors. We present the sample size per project in Table 1.

We conducted qualitative research to investigate the effects of the professionalization program on teachers and supervisors and the effects of the DBL characteristics on students. We observed and interviewed teachers, supervisors, and students. The purpose was to crosscheck and triangulate our analysis in order to validate the findings.

We employed an observation instrument to record teachers' actions during the DBL group meetings. This instrument was tested previously in other studies (Gómez Puente, van Eijck, & Jochems, 2013c). We tallied students' actions and perceptions during DBL group meetings every time they mentioned a category from our coding system in order to analyze design problem-solving processes during the interview. We calculated the mean and standard deviation of the frequency of the students' actions, both in our observations of and interviews with the students. To interview the teachers, we followed a *member check* (Hoffart, 1991) semistructured procedure.

A second researcher reviewed three video recordings of three different groups and three different supervisors from two different projects using our coding system. An analysis of the two researchers' coding results showed an overall overlap of 69%. The inter-rater level of agreement between the two researchers in coding student actions showed Cohen's Kappa's of .65 for the first observation, .70 for the second, and .50 for the third observation (Gwert, 2012). The overall Kappa score was 0.67, indicating a "good" level of agreement.

7.6 Results

In this section, we report the findings of our research study. We first summarize the results of the quantitative research gathered from the mechanical engineering department, followed by that of the electrical engineering department. Subsequently, we report on the qualitative results on the four projects in both departments.

7.6.1 Results of the quantitative survey

With respect to the quality of our instrument, Cronbach’s alpha showed a 0.789 score overall. The reliability analysis per dimension, presented in Table 2, revealed the Cronbach’s alpha for each of the dimensions has substantial internal consistency, but less with respect to project characteristics. The correlations between the three dimensions are considerable, ranging from 0.37 to 0.49, suggesting that the three characteristics are somewhat associated.

Table 2 Cronbach’s alpha for each dimension

Dimensions	α
Proj. char.	.50
Teachers’ role	.62
Design elements	.71

Tables 3 and 4 provide an overview of the results of the survey in both departments. Means and standard deviations indicate the pooled perceptions of the teachers and students in relation to the three DBL characteristics.

Table 3 ME results of survey in 2013

Dimensions 2013	Dep.	Group	Mean	SD
Project characteristics	ME	Students	3.5	.40
		Teachers	3.3	.35
Teachers’ role	ME	Students	3.3	.54
		Teachers	3.6	.48
Design elements	ME	Students	3.6	.36
		Teachers	3.4	.36

Table 4 EE results of survey in 2013

Dimensions 2013	Dep.	Group	Mean	SD
Project characteristics	EE	Students	3.6	.36
		Teachers	3.7	.38
Teachers’ role	EE	Students	3.5	.43
		Teachers	3.9	.33
Design elements	EE	Students	3.6	.47
		Teachers	3.6	.46

Analysis reveals the overall average of mean scores of the two ME projects is above 3.4 on the Likert scale. An ANOVA was conducted to identify whether there are significant differences between students’ and teachers’ perceptions on the three characteristics. The ANOVA confirms significant differences regarding the three DBL characteristics: project characteristics $(F\ 3.57)$, $p < .01$; the role of the teacher $(F\ 3.07)$, $p < .03$; and the design elements $(F\ 3.00)$, $p < .03$. Comparing these results with our previous research, students’ perceptions of the teacher’s role in the previous study averaged 2.8, while in this study, the mean score is 3.3. These findings suggest that the professionalization program has had an effect on the *teachers’* *role* as perceived by the students. Surprisingly, teachers' perceptions in this regard are just slightly lower.

With respect to the EE projects, the means are well above 3 on the Likert-scale, as presented in Table 4. We conducted an ANOVA to identify whether there are significant differences between students' and teachers' perceptions on the three characteristics. The ANOVA confirms significant differences regarding the teachers' role *(F 9.43) p = 00)*. With respect to project characteristics, *(F 1.66) p < .18,* and design elements, (*F .95) p < .41,* the ANOVA results indicate no significant differences.

Students' perceptions regarding the *teachers' role* are slightly higher than in the previous study (M 3.3 vs. 3.5, respectively), and also in *project characteristics* (M 3.6. vs. 3.3). Regarding *design elements* there is little variation *(M 3.6 vs. 3.5)*. Teachers' perceptions, however, are higher in all dimensions, except *design elements*, which had the same result as in our previous study. Although teachers' behavior has changed as a consequence of the professionalization program, this is not perceived to a greater extent by the students.

7.6.2 Results of qualitative research

In the following section we report our findings regarding the observations of the ME and EE teachers the supervisors, as well as the students. We then present the results of the interviews with the teachers.

7.6.2.1 Teachers' and supervisors' observations

We observed the ME and EE teachers and supervisors within two groups during the supervision meetings with their students. The number of observations in each project varies from 2 to 4, according to the different setup of supervision activities. These supervision meetings consisted mainly of group presentations and weekly consultations with representatives of students' groups. We present the results our teachers' observations in Table 5.

In order to analyse the observations and to identify whether there are changes on the supervision actions of teachers and supervisors we developed an observation instrument. This instrument focuses on actions from our DBL framework consisting of coaching patterns applied in the coaching of students groups. This instrument was previously verified in another study by a second researcher, adjusted according to results of the verification process, and consequently tested (Gómez Puente, van Eijck, & Jochems, 2013c). We, therefore, used this instrument as an objective evaluation rubric upon which to judge whether there are changes in teachers and supervisors' coaching actions according to our DBL teachers' performance framework.

Results indicate there are changes in the teacher and supervisor behavior as we observed more frequent use of DBL actions in all projects. The most frequent actions are

formulate open-ended questions (FOQ); supports students in reflecting on and explicating rationale for technical design, argument formulation, and decision making; supports students in case of difficulties (just-in-time teaching) (RER); encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives (EAP); reviews progress on plans, proposal, etc. (RPP);provides feedback on evolving efforts (e.g., coaching on progress in technical design, design process, data collection, testing methods) (FTD); and *supports students in case of difficulties (just-in-time teaching) (JIT).* Actions that are less common are *provides feedback on progress on presentation skills, team work (FPS); encourages students to articulate engineering terminology during regular meetings and presentations (AET);* and *encourages students to learn from other students' plans, knowledge application in problem solving experiments (LEE).* These actions have a low frequency due to the fact that, for instance, feedback on progress on presentation skills only takes place once at the end of the meeting, and activities
to encourage these actions are less explicit. *Acts as an expert, customer and gives information on specifications (AEF), observes students during implementation of activities (OIA),* and *uses methods/tools (worksheets, drawings, examples, etc.) to guide the team (UMT)* are not encountered at all.

Comparing ME findings with our former research, we perceived there are substantial differences in both teachers' and supervisors' behavior in almost all DBL teachers' actions, according to our DBL framework. In EE projects, supervisors' behavior covers a wider range of DBL actions in comparison to previous results. EE teachers show patterns similar to the former study, except *encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives (EAP),* which is now performed. Despite the similarity in actions, these actions are carefully and more consistently aligned to the feedback and the assessment of the learning outcomes.

From these observations, we conclude that the professionalization program has influenced the coaching of both teachers and students in DBL groups. Changes include providing consistently constructive and formative feedback upon technical tasks, processes and products, and finally on the students' self-development. The fact that there are now instruments, such as rubrics to monitor the progress during the project implementation acts as a vehicle for learning. In addition, the frequencies of supervisors actions indicate that coaching takes place now actively stimulating students in developing reasoning strategies while solving engineering problems. The active role of the supervisors following the DBL model has been a result of the professionalization program.

Table 5 Mean of frequency of teachers’ and supervisors’ actions during DBL supervision group meetings

Actions	FOQ		AEF		FPS		RPP		FTD		RER		JIT		UMT		AET		EAP		LEE		OIA	
Group	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
ME1 T1	3.00	.00	1.00	.00	1.00	.00	1.00	.00	1.00	.00	2.00	.00	1.00	.00	.00	.00	1.00	.00	1.00	.00	.00	.00	.00	.00
ME1 T2	2.00	.00	1.00	.00	1.00	.00	1.00	.00	1.00	.00	3.00	,00	1.00	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00
ME1 S1	5.00	2.94	.00	.00	.75	.50	.75	.50	1.00	.00	3.75	3.77	2.50	1.73	.00	.00	.00	.00	1.25	.95	.00	.00	.00	.00
ME1 S2	6.75	3.20	.00	.00	1.00	.00	1.00	.00	1.00	.00	6.50	5.50	2.75	1.50	.00	.00	.75	1.50	6.75	2.06	.75	.95	.00	.00
ME2 S3	8.25	.957	.00	.00	1.50	1.00	.50	.57	2.00	.00	7.25	.957	1.75	1.50	.00	.00	.75	.95	2.25	1.50	1.00	.00	.00	.00
ME2 S4	7.75	3.59	.00	.00	2.00	.00	1.00	.00	1.50	1.00	9.75	5.56	2.00	1.41	.00	.00	.50	.57	1.25	1.89	1.00	.00	.00	.00
EE1 T1	19.00	4.24	.50	.70	.00	.00	3.50	2.2	3.50	.70	7.50	4.95	2.00	1.41	.00	.00	2.00	.00	3.00	1.41	.00	.00	.00	.00
EE1 T2	11.50	4.95	.50	.70	.00	.00	2.00	.00	4.50	.70	9.50	.70	2.50	2.12	.00	.00	1.00	1.41	8.50	2.12	.00	.00	.00	.00
EE1 S1	10.00	7.25	.00	.00	.75	.50	5.50	3.00	5.50	3.87	6.00	6.16	1.25	1.25	.00	.00	.25	.500	3.75	2.63	4.75	.95	.00	.00
EE1 S2	5.25	4.34	.00	.00	1.00	.00	5.25	3.50	2.25	2.63	.25	.50	2.50	.577	.00	.00	1.00	2.00	.25	.500	4.75	.95	.00	.00
EE2 T1	6.25	5.56	.00	.00	.50	.57	1.75	2.21	2.25	2.21	6.25	2.63	5.00	2.58	.00	.00	2.00	2.16	2.75	1.70	1.00	.81	.25	.50
EE2 T2	10.00	4.08	.00	.00	.75	.957	1.00	.81	4.50	3.31	9.00	2.16	2.25	1.70	.00	.00	1.50	1.00	4.50	5.,26	1.50	1.29	.00	.00
EE2 S3	6.25	2.50	.00	.00	.00	.00	4.25	4.78	1.50	2.38	4.25	4.03	1.50	1.73	.00	.00	.25	.50	1.75	1.50	.75	.50	.00	.00
EE2 S4	7.25	3.30	.00	.00	.00	.00	4.50	3.69	.00	.00	5.50	1.29	.00	.00	.00	.00	.50	.57	1.00	1.41	.75	.95	.00	.00

* *Number of teachers’ observations varies per project due to the differences in project setup*

Description of DBL supervising actions following a coding system: Formulates questions (e.g. open-ended questions) – FOQ; Acts as an expert, customer; gives information on specifications – AEF; Provides feedback on progress on presentation skills, team work – FPS; Reviews progress on plans, proposal, etc., RPP; Provides feedback on evolving efforts (e.g. coaching on progress in technical design, design process, data collection, testing methods) FTD; Supports students in reflecting on and explicating rationale for technical design, argument formulation, and decision making, RER; Supports students in case of difficulties (just-in-time teaching) JIT; Uses methods/tools (worksheets, drawings, examples, etc.) to guide the team, UMT; Encourages students to articulate engineering terminology during regular meetings and presentations, AET; Encourages students to explore alternatives for problem solving and problem representation by utilizing different perspectives, EAP; Encourages students to learn from other students’ plans, knowledge application in problem solving experiments, LEE; Observes students during implementation of activities, OIA.

7.6.2.2 Teachers' interviews

In this section, we present the results of the interviews with the ME and EE teachers. All quotes in this section come from these interviews. The purpose of the interviews was twofold: to test whether there are changes in the projects as a result of professionalization and to gain an overview of what effects the implemented DBL characteristics had on the students. Table 6 provides a summary of the results of the changes we observed from the professionalization. In this table, we indicate whether there are changes or not in the projects, or whether these were not mentioned or not applicable as the DBL characteristics were not part of the redesign of the projects.

Table 6 Overview of the DBL characteristics in the ME and EE projects

DBL charact.	ME1	T1		ME2	T2		EE1	T1		EE2	T2	
.	Changes	No changes	Nm/NA	Changes	No changes	Nm/NA	Changes	No changes	Nm/NA	Changes	No changes	Nm/NA
Proj. char												
O-E	X			X			X			X		
Auth.		X		X			X					X
Hands-on			X	X			X			X		
Multidisciplinary			X			X			X			X
Teachers' role												
- Technical design	X			X			X			X		
- Process	X			X			X			X		
- Self-development	X			X			X			X		
Design Elements												
Expl. Probl.	X			X			X			X		
Use iteration	X			X				X		X		
Expl. alternat.	X			X			X			X		
Func. decomp.			X	X			X				X	
Expl. graph. rep.					X		X			X		
Ref. constrain.			X			X						X
Expl. scope const.		X		X			X			X		
Validation		X		X			X					X
Examine designs			X	X				X				X
User perspect.	X					X		X				X
Build model	X			X			X				X	
Expl. eng. facts			X			X			X			X
Expl. issues meas.			X			X			X			X
Failure analysis			X	X					X			X
Reflection process	X			X				X		X		

Project characteristics: open-ended projects;; authentic projects; hands-on projects*; multidisciplinary. Teacher's role*: supervision on technical design aspects; supervision on process; supervision on self-development. *Design Elements*: Explore problem representation, Use interactive/iterative design methodology , Search the space (explore alternatives), Use functional decomposition, Explore graphic representation , Redefine constraints, Explore scope of constraints , Validate assumptions and constraints, Examine existing designs, Explore user perspective, Build normative model, Explore engineering facts, Explore issues of measurement, Conduct failure analysis, Encourage reflection on process. – *T- Teacher. Nm/NA- No mentioned/Not applicable.*

7.6.2.3 Changes and effects of project characteristics and design elements in ME and EE projects

Teachers report changes in two aspects: the *project characteristics (open-ended, authenticity* and *hands-on)* and in some *design elements (exploring problem, use iteration, exploring alternatives, build a model, reflection on process, etc.)*. Regarding the effects of *project characteristic* and *open-endedness,* teachers indicate in EE1 that students are not limited in analyzing the design context and take a broader scope to define the problem by "*selecting first a strategy to choose which DC/DC converter is the most suitable*." In some student groups, the open-ended project setup has led to think *out-of-the-box and generate creative solutions* that were not earlier used by the students: "Two groups have employed methods such as in the resonance of the circuit as well as the method of the frequency of the transformer to fine tuning it in order to reach maximal efficiency and ratio...they make use of the micro-control, load detection and they have measured all phases and the frequency part."

According to the teacher, *authenticity* in ME2 has stimulated students to analyze the problem and conduct research differently, as students look at the design of a propeller as a system of components with real-life specifications for a manufacturing company, taking into account all components (i.e., propeller, motor, battery, plane). To do so, students *represent the design problem* by exploring "the speed of the motor should produce, the maximal speed, about the burden that the motor can take without taking risks if it doesn't work it at the beginning." The fact that students look at the design as a system of components and examine how these components fit into that system requires a *hands-on approach* of "making hypothesis and calculations, selecting criteria and strategies" around, for instance, the functionality and the efficiency of the propeller. They also looked at how long the propeller could fly, which encouraged them to look at the problem from different perspectives, select criteria, and make measurements and calculations with realistic specifications. The teacher stated, "[Students] think about the efficiency of the propeller, what actually the propeller can do, what the maximal speed of the propeller is, what the maximal speed of the plane with that propeller is that supports better to understand how a propeller, the plane motor, and the battery work together. This approach has contributed to give a realistic form to the design process." According to the teacher, this was not perceived in earlier versions of this project. In EE2, however, the setup of *hands-on* activities by constructing a prototype of a robot arm in iterations has significantly modified students' design approach. One of the effects is that, "*The students make more simulations; the process is, however, guided, as it is expected to construct a simulation environment to test the model without the system so that they can easily make the choices*." The major gain from this iterative approach is not that students provide better solutions, but that, as reported by the teachers who were individually interviewed, "*They become aware of the process of solving a complex technical design problem."*

With respect to *design elements*, in ME2, as students explored the problem, they analyzed the functionality of the components, investigated the problem through predictions and calculations. As one teacher reports, “*Students look at different ways to make the motor operational. The shaft speed of the motors is determined by the voltage that brings to the motor. The battery has a voltage, but in order to bring the voltage of the battery to the motor, the shaft speed must create an adjustment, and that goes from the voltage to the motor. You can do this in two ways: through a variable in between so that the voltage goes low. Or by controlling the motor in relation to the battery….This [approach] brings about creative solutions*.”

Furthermore, in solving the problem, students build a model following a preliminary idea. In ME2, for instance, “*The impact is that students search for alternatives, looking at the theory and think how a design can be built to meet the requirements of flying 80 km/h. If you do that, then the design of the propeller follows a good approach, with high performance and how the…condition…is at the start. Then they need to think…of the plane leaf and in the model that they make. The groups that have done it properly have designed [and] adjusted the model to make it suitable for the start conditions and problems to make it work in a real situation*.”

In EE1, students build a model following a conceptual idea of the functionality of the system, i.e., the architecture of the system is not given (*open-ended*), and then they investigate the function of each component within the system, as well as the interaction among all the components. The way of building the model is different, as students “*look at the variations and integration of the components and dig into the constraints.”*

Other examples the effects of *design elements* have on students are seen in *exploring users’ perspectives, use iteration and encourage reflection on progress.* In ME1, the technical feedback received during the mid-term presentation of the 2D model serves to revise the models, fine tune them, and reconsider initial choices. For example, one teacher stated, “*Three angles are selected, although there are four in the construction: forces in the construction, pressure, and stress, and that leads us to do some calculations around pressure and stress, and we considered then the crucial points, to conclude that the construction remains solid by adding more material [and] to understand how the construction will break if three instead of four bars are used*.”

Finally, we observed that the projects do not include *redefinition of constraints, failure analysis, exploring engineering facts,* and *exploring issues of measurement,* as these are not related to the learning outcomes or project’s tasks.

The *project characteristics* and *design elements* that are not mentioned also are not part of the learning outcomes of the project, and therefore, no changes took place. One of the goals of this project is to introduce students to the DBL method while applying simple mechanic principles in a 3D construction.

The four pilots reveal that *open-ended* and *authenticity* nurture the *hands-on* process of looking for alternatives by scoping design solutions and testing them. Common to all projects are the limitations in iterations in the solving design process. Furthermore, making this engineering process more explicit encourages the use of engineering design activities in solving design problems.

7.6.2.4 Student observations and interviews

Table 7 and 8 provide an overview of the ME and EE analysis of student observations in DBL group activities and on student interviews. Each group consisted of eight students, and the group meetings lasted approximately one hour.

Table 7 Overview of coding of ME student observations and interviews *

Research Instrum.	Effects					Dept.	Proj.		
		ME1				ME2			
		Group 1		Group 2		Group 3		Group 4	
		M	SD	M	SD	M	SD	M	SD
Observ.	ANAPRB	2.17	1.47	1.00	.89	.50	.54	.67	1.63
	SELCRT	.67	1.21	.33	5.16	.33	5.16	2.33	2.58
	EXPSTR	4.33	1.86	4.50	2.34	3.83	1.32	3.83	1.94
	INTINF	4.17	3.18	5.50	1.97	7.00	2.89	5.33	4.54
	MAKJUDG	2.17	3.06	2.50	2.16	2.67	2.50	0.00	0.00
	MAKDEC	1.33	.81	2.00	1.26	3.00	2.19	3.67	2.94
		Group 1		Group 2		Group 3		Group 4	
Interv.	ANAPRB	.20	.44	.80	1.09	1.60	1.14	.20	.44
	SELCRT	.60	.54	.80	.83	1.60	1.51	1.60	.54
	EXPSTR	2.40	1.14	4.00	1.58	2.80	.44	3.40	.54
	INTINF	.40	.54	1.00	1.73	1.00	1.00	1.60	.89
	MAKJUDG	.00	.00	.00	.00	.20	.44	.20	.44
	MAKDEC	1.40	.89	1.20	.44	3.00	1.87	2.80	1.30

*Mean and standard deviation of frequencies

Description of coding system: ANAPRB- Analysis of problem definition (problem from different perspectives)-Gathering information; SELCRT- Select criteria/strategy for design solution; EXPSTR - Exploring different alternatives/strategies to solve (design) problem; INTINF – Interpret information (understand theory, formulas)/reflection/articulate engineering terminology; MAKJUDG - Making judgments; MAKDEC - Making decisions. S –Supervisor

The table presents means and standard deviations of the frequencies of the behaviors observed. The observations are based on the students' actions. Frequencies are the number of times the students perform an action included in our coding system. Every time a student group conducted an action we codified that action and counted in absolute terms of frequencies. As explained in section 4.2.1, a second researcher studied three video recordings of three different groups and supervisors of two projects. The researcher was first instructed on the research method and content, but also on the coding system. The researcher analysed the data and we compared the inter-raterreliability of both scores (overall Kappa 0.67) showing a good level of agreement.

ME results indicate differences in student actions in the four groups. Most of the student actions during the group meetings consist of EXPSTR, INTINF, and MAKDEC, the latter especially in ME2. One explanation could be that in ME2, the experienced supervisors emphasize asking open-ended questions, which influences students' actions to analyze the problem (scoping the problem and gathering information). Another reason may be that the setup of the design product in ME2, i.e., a propeller, requires the design of a prototype in a short time, and therefore, the analysis phase is shorter. This indicates that students' actions focus mainly on exploring alternatives and looking for options to solve design problems, making interpretations and conclusions on the findings, and finally, leading to readjustment of the design. The actions ANAPRB, SELCRT and MAKJUDG are uncommon, indicating trial-and-error behavior rather than deeply exploring the assignment prior to making sound criteria selection. (Appendix A illustrates an example of students' actions during a group meeting in the ME1 project).

With reference to the student interviews, the most common actions are EXPSTR and MAKDEC, the latter mainly in ME2. The fact that more MAKDEC are encountered in ME2 may correspond to the fact that in ME2, more guidelines have been provided for supervision and more mid-term presentations during the DBL group meetings are integrated in the project. The rest of the actions take place with lower recurrence, indicating that although these steps are perceived to some degree, students are less aware of the importance of those actions during the design problem-solving process.

From this analysis, we observe that EXPSTR, INTINF and MAKDEC are more frequently conducted during the design process. Problem-solving design steps such as ANAPRB, SELCRT and MAKJUDG are less frequent, demonstrating missing steps in students' patterns in problem solving.

Table 8 Overview of coding of EE students' observations and students' interviews*

Res. Instr.	Effects					Dept.	Proj.		
			EE1				EE2		
		Group 1		Group 2		Group 3		Group 4	
		M	SD	M	SD	M	SD	M	SD
Observ.	ANAPRB	3.00	2.00	3.75	7.5	.25	.50	.25	.50
	SELCRT	2.25	.98	2.00	.81	1.00	.81	.75	1.50
	EXPSTR	7.00	3. 16	4.00	1.41	4.25	2.06	1.50	.57
	INTINF	3.25	2.21	3.00	3.34	4.25	2.06	2.00	1.82
	MAKJUDG	1.50	1.73	.75	1.50	1.50	1.29	1.00	1.41
	MAKDEC	.75	.95	0.00	0.00	3.50	1.91	3.00	2.16
		Group 1		Group 2		Group 3		Group 4	
Interv.	ANAPRB	1.00	1.00	1.40	1.14	1.20	0.83	.80	.44
	SELCRT	0.00	0.00	.80	1.1	1.20	0.83	1.00	.70
	EXPSTR	3.60	1.51	3.60	2.40	3.40	0.89	2.20	.44
	INTINF	1.40	1.14	2.60	2.07	2.80	1.64	1.40	.54
	MAKJUDG	.20	.44	.60	.89	.80	.83	.80	.83
	MAKDEC	1.60	2.51	2.40	1.67	.60	.54	1.00	.70

*Mean and standard deviation of frequencies

Description of coding system: ANAPRB- Analysis of problem definition (problem from different perspectives)-Gathering information; SELCRT- Select criteria/strategy for design solution; EXPSTR - Exploring different alternatives/strategies to solve (design) problem; INTINF – Interpret information (understand theory, formulas)/reflection/articulate engineering terminology ; MAKJUDG - Making judgments; MAKDEC - Making decisions. S –Supervisor

Regarding the EE observations, results show there are commonalities among the four student groups. The most common student actions are EXPSTR, INFINT, and MAKDEC, the later in EE2. With respect to MAKDEC, the setup of the EE2 project, consisting of frequent feedback on technical aspects, enhanced student actions in making decisions following conclusions from experiment results. Furthermore, the fact that students have used rubrics to self-monitor this process has influenced the students in this respect. ANAPRB and SELCTR are more common in the EE1 project. The reasons are varied. First of all, EE1 supervisors are master students tasked with monitoring students and providing feedback via a rubric instrument. In EE2, however, supervisors are second-year bachelor students from the same group who take on a chairman role, and consequently, the task of monitoring the group. Secondly, the role of the supervisor in EE1 is to guide the analysis process in a brainstorming session. In EE2, general brainstorming sessions were held for all students with no individual support per group by a supervisor. The fact that EE1 is longer than EE2 may have played a role in that EE1 students had more time to analyze the problem. As in Mechanical Engineering projects, SELCRT and MAKJUDG are also less commonly observed. With respect to the interviews, EXPRST and INTINF are generally common. Students perceive these actions as steps in the design process. Surprisingly, the recurrence of MAKDEC in the students' perceptions is not as high as expected due to the supervision instruments developed for this purpose, especially in EE2. ANAPRB, SELCRT and MAKJUDG are still encountered less frequently, mimicking the general patterns we saw in ME where students still use a trial-and-error approach to solve design problems. Crosschecking student observations and interviews, we notice that EXSPTR, INFINT and MAKDEC are common student patterns in the design process. ANAPRB, SELCRT and MAKJUDG are less common. This indicates that although supervisors foster a design solution, students continue to use a less effective problem solving strategy. The project setup with the integration of project characteristics and design elements, together with the teacher and supervisor actions, may have contributed to a solution approach aimed at exploring the problem, searching for alternatives, and consequently, building and testing the model. However, as indicated previously, iterations in the design process are still limited, showing that open-ended projects, both at the freshman and second-year bachelor levels, should be approached carefully. This is confirmed by the low scores seen in student perceptions recorded during the interviews.

7.7 Conclusions

Regarding our first research question *What are the effects of the professionalization program on teachers and supervisors' opinions and behavior?*, we conclude that the ME and EE teacher and supervisor actions are in line with the DBL supervision framework to a much greater extent than before. The professionalization program has, therefore, stimulated teachers and the supervisors to change their behavior according to our DBL model from the literature.

Analysis of our observations revealed that ME teachers' supervision is now more explicitly geared to supervise the technical design, as well as the design process itself, through mid-term presentations or plans. In contrast, teacher actions during the weekly meetings remain unchanged. This is likely due to the fact that the objectives and setup of these meetings has not been changed.

Supervisor actions more frequently demonstrate appropriate DBL characteristics than in our previous study and cover a broader range of DBL actions. Factors that may have influenced changes are the frequency of questions supporting students' reflection that result in EXPSTR, INTINF and MAKDEC, as perceived in our student observations. We presume also that presentations during the group meetings provide more opportunities for feedback on presentation skills and technical process, as well as an opportunity to model design problem solving thinking.

In addition, we perceived that supervisors make use of supervision and feedback tools developed by the teachers. We confirm, therefore, that supervision now focuses on the process and not just the product, and on student development. Furthermore, feedback is more objective and transparent, less intuitive and more structured, and consistent with stated learning outcomes. Finally, the results of the survey confirm that students' perceptions of the teachers and supervisors have moved more in line with the DBL framework we presented.

Regarding the EE teachers, we observed similar teacher actions as in our previous study. However, as mentioned during the teacher interviews, supervision is now consistent and aligned to the learning outcomes and design tasks of the project, and questions addressed during supervision meetings are consistent with modeling the design process for the students.

With respect to the supervisors, we notice that DBL actions are widely used with a higher level of recurrence than in the previous study. The students' perceptions of the teachers' role are not remarkably changed in comparison with previous years.

With reference to our second research question *Does the redesign of the projects lead to changes in the project implementation?*, there were indeed changes, but they were not the same in all projects, nor to the same extent, which appears mainly due to the differences in the setup with respect to *project characteristics* (*open-ended, authenticity, hands-on*), and *design elements* (*exploring problems, exploring alternatives, building and testing designs*).

With respect to our third research question *What are the effects on students' opinions and behaviors?*, we crosschecked the findings of student observations and interviews. We observed there are effects on students' approaches in solving design problems. Effects vary, however, between projects.

With respect to the EE projects, EE1 teachers concluded the changes regarding *openendedness, authenticity* and *hands-on* promote activities such as e*xploring problem* *definition* approach towards a design solution by *exploring alternatives* of how the components of a system work as a whole. As a result, students think *out-of-the-box* on the use of different methods. Concerning EE2, the *hands-on* setup of the project explicitly implies iterations in the prototype construction process by regular feedback moments to monitor design choices.

Comparing these results with the student observations according to our coding system, we see that the project setup indeed gears students towards making decisions (MAKDEC), exploring strategies (EXPSTR), and interpreting findings (INTINF).
Although it is difficult to identify exactly which DBL characteristics caused these changes, we feel confident in mentioning from our exploration that mainly *open-endedness, authenticity* and *hands-on* characteristics engage students in *design elements* such as *exploring a design problem, searching for alternatives,* and making design choices *to build the model*. For some projects, it is mainly *open-endedness* that has promoted the design elements and the divergent process of thinking. For other projects, it is *authenticity* that infers a searching progression of experiencing, learning from results, and making adjustments.

7.8 Discussion

The results of the research into four design projects we have conducted within two engineering departments have shed light onto the effects DBL characteristics have on students in solving engineering design problems. Our hypothesis was that integration of the DBL characteristics from our theoretical framework in the projects would foster students' ability to solve design problems in gathering and applying knowledge to design artifacts and systems by experimenting and evaluating in learning cycles. We assumed that the redesigned of the projects including the DBL characteristics would enhance students' problem-solving process in line with our DBL framework. Although the projects show certain differences in the effects on students, we can certainly indicate from this exploration that open-endedness and authenticity stimulate a hands-on approach and broadens the design scope. This discovery process nurtures focusing on the exploration of the problem, searching for alternatives, and building a product in a system component approach.

This study has some limitations. Although all projects illustrate relevant results as a consequence of the integration of the DBL characteristics, we cannot make a wide-ranging estimation of exactly which of the DBL characteristics create these effects on students, as this exploration has been made with a limited number of groups and projects. Furthermore, it is still difficult to come to a conclusion as to how DBL works the best, as the context of each project is different, having its own context and complexity level. Furthermore, the scope of the research changed to the first year at the mechanical engineering department, according to management decisions. Therefore, strict comparisons between previous and current studies cannot be made.

The results of this study indicate that the *project characteristics* and the *design elements* are the dimensions of our DBL theoretical framework that are suitable vehicles for the pedagogy of teaching students to solve design problems. It therefore becomes important to investigate further how the DBL characteristics can be applied to support student learning to handle complex and authentic technical engineering design problems.

Likewise, we see substantial changes in teacher and supervisor development as a result of the professionalization program. However, we identify areas for further improvement. One of those is the use of feedback instruments to support student self-development. Although supervision was also geared to encourage self-development, we were not able to determine whether the role of the teacher has influenced students' development in that direction. First of all, our research questions were not designed to investigate this aspect in this study. Secondly, the use of rubrics and guideline sheets may not be the only instruments to monitor and measure student development. Therefore, it becomes essential to investigate other supervision methods available to teachers that may help them carefully monitor the quality of the design alternatives explored by students, as it has become evident from this study that teachers have little information on these steps. That this process brings better design solutions is not the question of our research, nor was it a part of the teachers' intentions to learn. Finally, organizational changes in the weekly meetings in the form of presentations of technical progress could foster modeling reasoning thinking.

7.9 References

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Appendix A: Example of students' actions during a group meeting in the ME1 project

Time	Design situation – conceptual design of 2D
	… S: sloping bars can take more weight and can be also longer
4:17	T: Why would you like to have it sloping? S: because diagonal is stronger than straight bars
4:26	T: And what happens with the forces? S: We need to think how to use the forces, because pressure forces are stronger than tensile forces…we need to use as much as possible tensile bars and less pressure bars…
6:42	T: you have to know what forces are pressure and which ones are tensile…you can see already the difference [in the drawings on the board] if you look at straight top or down S: there are now to many pressure bars…diagonal at the end…bars close to the hanging points are stronger because the pressure bars hang right in the middle of the construction [the design is adjusted according to conclusions]…what is stronger? An angle or a diagonal line? The diagonal lines are used…we have three design ideas [one with a straight arm, another with diagonal arm, and the "L form"], we need to make calculations…whether we use to much material…
14:47	T: Can you already say something about the form you need to have? Where are the most fragile points?
16:20	T:What happens with the bars in the construction? S: These are pressure bars…
16:44	T:What happens with the three corners in the inside part of the construction?...how does it lead to that position? …
17:22	T:If you have one force which pulls back the bars, what happens? S: It pulls indeed …
17:42	T:What happens with the other beams? S: These are pulled down…and it becomes pressure forces
17:47	T: What do you do with horizontal bars? S: It is better to place bars in sloping position but they will more likely break…we want is to construct a crane that goes down but that is connected in sloping...and less material as possible…short beams are less break sensitive …
20:47	T:You want the bars as shorter as possible and effective…to see what is the best construction you need to see the material that you are going to use by making calculations… S: designs 1, 3 and 4 keeping in mind sloping position and that everything that is straight can also turn in a sloping position…you need to give arguments on how we are going to set the bars inwards…three angles are stronger…or a traverse and then all of them crossed...
31:05	T: What is the added value of calculating middle bars? S: …we don't want middle bars, they do not bend, they break, we may think of welding them or screw them
33:25	T: You need to make conclusions based on judgments… S: if you set a cross bar then you realize the meaning of why force makes pressure and the other is a tensile force…
34:16	T: So, if you set a cross in a square is that better of are there other possibilities…taking out one bar… S: we can take one out…
35:19	T: I hear a lot of possibilities…cross and angels S: We take three possibilities and make calculations…three fixation points, three tensile bars to fix because this is stronger
41:13	T: I would look at all forces and the three fixation points…no all make sense and are useful…think good of tensile and pressure forces . . .

Description: S-Student; T-Tutor.

Chapter 8

...knowledge resides in the questions that can be asked and the answers that can be provided...

Aristotle[15]

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[15] Adapted from Aristotle, *Posterior Analytics*, J. Barnes (transl.), (1994). 2nd ed., New York, N.Y.: Oxford University Press. In Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D., Leifer, D.J. (2005) Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, *94*(1), 103–120.

Chapter 8

Conclusions and discussion

8.1 Introduction

The investigation presented was triggered by a number of interests. A central goal was to investigate an educational approach introduced at the Eindhoven University of Technology (TU/e) in 1997. As an active learning method, DBL was incorporated into the curricula to allow students to work in groups collaboratively on multidisciplinary assignments. The aim was to enable them as creative professionals to integrate knowledge and skills in solving design problems (Wijnen, 2000). DBL was meant to serve as an approach to gather and apply knowledge, and the profile of DBL was thus described in terms of features, i.e., professionalization, activation, co-operation, creativity, integration, multidisciplinary (Wijnen, 2000). The underlying motivation to initiate this study was the fact that design-based learning as an educational concept is a promising approach to teach science through design assignments, yet it has barely been investigated in the context of higher education, and in particular, in engineering study programs. The relevance of this investigation lies in developing DBL both from a theoretical point of view and as a practical method of teaching in the higher education classroom. It becomes relevant, as well, for the TU/e to better define the DBL framework in order to ensure the quality of this model for engineering education. The purpose of our study also was to come up with practical recommendations for the improvement of design-based learning.

We initiated this dissertation with the overall drive of defining design-based learning theoretically and identifying the characteristics of this educational concept. Furthermore, based on our definition, we tested our model in the form of a case study involving four engineering disciplines at the Eindhoven University of Technology. In addition, we examined teachers' and supervisors' actions in coaching DBL groups. Consequently, we conducted an intervention via a professionalization program wherein teachers redesigned the projects and supervisors learned to implement this approach. Finally, we studied the effects of this educational approach on teachers and students.

In this chapter, we provide an overview of the main findings gained in each of the empirical studies we conducted. Next, we analyze the methodological considerations, including the quality of the research instrument. In addition, we reflect upon the DBL theoretical framework in retrospect and consider the implications for practice and for further research.

8.2 Main findings

The main research questions guiding the studies in this investigation were as follows:

- What are the design-based learning characteristics in international higher technical education universities and how are they operationalized in engineering projects?
- How should we design a suitable DBL model to operationalize these DBL characteristics?
- What are the effects of this DBL model on teachers and students?

We carried out six studies to investigate design-based learning characteristics and the effects of this educational approach. The first two research studies (Chapter 2 and 3) focused on exploring the literature on design-based learning and PBL-alike engineering projects in order to construct a theoretical framework built upon practices. Next, we tested our DBL framework (Chapter 4) in four engineering departments at the Eindhoven University of Technology: mechanical engineering, electrical engineering, industrial design, and built environment. The aim was to gain an overview of teachers' and students' perceptions on DBL characteristics and examine whether the characteristics are integrated into the projects. Furthermore, in another study, we explored teacher and supervisor actions in supervising students in DBL groups (Chapter 5). Based on the results, we conducted an intervention for teacher and supervisor professionalization (Chapter 6) in order to embed the DBL characteristics into the teaching methodology and apply them during the project implementation phase. We selected the mechanical engineering and the electrical engineering department for our professionalization program implementation. Our final study covers the effects of DBL as an educational approach on teachers, supervisors and students (Chapter 7).

In what follows, we present the findings per study, and we summarize the main general results and our conclusions (Chapter 8). We also reflect on the methodological constraints, consider the implications for practice, and provide suggestions for further research.

8.2.1 Design-based learning as an educational approach for technical education

We initiated this research by searching out characteristics of design-based learning as an educational approach within the existing literature. DBL originally was introduced to give form to an educational concept and to respond to educational developments encouraging a learner-centred curriculum to enhance the acquisition of applicable skills required in complex activities (Wijnen, 2000). Despite some evidence in high school classroom practices (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Doppelt, 2009), we found little in the literature regarding this concept within the engineering education context. We devoted two studies to defining the theoretical framework of DBL. In Chapter 2, we explored which of the design activities carried out in the professional engineering work setting are also taught in the engineering education context.

In Chapter 3, we studied which core educational aspects are relevant in conducting design-based learning.

One of our first inquiries in this research study was to find out what problem solving activities in engineering design tasks are commonly employed by engineers in real life while solving complex multidisciplinary design problems. Furthermore, we were also interested in knowing whether these activities are part of students' projects in educational study programs. We adopted the classification developed by Mehalik & Schunn (2003), containing fifteen commonly used design activities in the context of software engineering (Chapter 2). To investigate DBL characteristics, we formulated the following research questions: *Which design elements of the professional practice of engineering design are common in DBL and which are not? In what respect is DBL either domain-specific or generic? In what respect does DBL account for developing the expertise of learners? Which elements of the professional practice of engineering design are common to DBL in authentic settings?*

To narrow the focus of our investigation, we first selected peer-reviewed scientific journals representing engineering disciplines such as mechanical engineering, electrical engineering, computer science, chemical engineering, biomedical engineering, and applied physics, among others. These journals publish empirical research articles in the field of PBL and design-alike engineering projects. We identified fifty articles from which we could ascertain these common design activities from real-life settings are also integrated and employed in educational settings to teach students how to solve complex engineering assignments (Jonassen & Rohrer-Murphy, 1999; Jonassen, Strobel, & Lee, 2006). The results of this first study demonstrate differences in design elements between professional work places and educational settings, and between domains, levels of expertise, and authenticity. We observed, for instance, that some design elements, such as *use interactive/iterative design methodology, search the space, use functional decomposition*, are used infrequently in education settings. Other elements, such as *explore user perspective, and encourage reflection on process*, are reported more frequently in authentic industry projects than in educational settings within the university. These findings suggested a set of activities that could be used in the context of DBL educational projects to prepare students for professional practices by narrowing the gap between education experience and real-life engineering settings. At the same time, these results opened up suitable opportunities for the educational staff to operationalize design activities in order to learn particular engineering skills (Gómez Puente, van Eijck, & Jochems, 2011).

Although these initial findings shed light on defining DBL as a suitable approach for educational projects, we pursued efforts to find out which characteristics are relevant in DBL educational environments (Chapter 3). One of our first premises was that designing is an intrinsic activity in engineering and that engineering problems are open-ended, complex tasks involving searching the unknown and progressively gathering knowledge (Cross, 1990; Dym, Agogino, Eris, Frey, & Leifer, 2005; Lawson & Dorst, 2009). These tasks resemble authentic engineering contexts of real-life problems and play an important role in constructing DBL project environments. Furthermore, following the literature on facilitating learning, we see how the teacher can scaffold the thinking process to experiment and test using various solution directions (Hmelo, Holton, & Kolodner, 2000; Hmelo-Silver, Duncan, & Chinn, 2007; Ramaekers, 2011). We also were interested in activities pertaining to the social context that boost collaboration and communication (Tien, Roth, & Kampmeier, 2002; Topping, 1996). In addition, assessment methods include feedback as a central component of formative assessment to increase motivation, and ultimately, to support achievement in individual learning of design processes and products (Black & Wiliam, 1998, 2009; Gijbels, van de Watering, & Dochy, 2005; Shute, 2008; Hattie & Timperley, 2007; Yorke, 2003).

In this study, we explored the following research questions: *What project features are characteristic in design-based learning projects? What are the methods teachers use to support students in design-based learning? What assessment methods stimulate learning in design-based learning? What are the salient features of the social context of design-based learning?* We reviewed the fifty peer empirically based articles to define the DBL dimensions and characteristics with examples. In doing so, we followed a two-fold approach: 1) a preliminary classification, including items pertinent to the alignment between teaching and learning and the interaction among them (Biggs, 2003), for instance, curriculum, objectives, teachers, project features, assessment, etc; and 2) an in-depth analysis focusing only on the project characteristics, the role of the teacher, the assessment, and the social context, as we believe these are the crucial aspects in constructing DBL environments. We consider these educational aspects relevant in defining DBL, as these are core pedagogical elements in giving form and context to the projects, as well as in supervising and assessing students in social collaborative groups.

The result of this study was a classification of characteristics for each DBL dimension (Gómez Puente, van Eijck, & Jochems, 2013a). Consequently, based on the findings of both studies, we defined design-based learning as an educational approach to help students learn to gather and apply knowledge in solving design problems. In this process, students investigate, estimate, generate ideas, and build and test solutions while learning from each experiences (Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Adams, Cardella, Turns, & Saleem, 2007; Dym & Little, 2009; Dym, Agogino, Eris, Frey, & Leifer, 2005). These are common characteristics of design projects in higher technical and engineering education that we found consistently in the literature.

With respect to project characteristics, projects are *open-ended, authentic, hands-on*, and *multidisciplinary* (Behrens, Atorf, Schwann, Neumann, Schnitzler, & Balle, 2010; Chang, Yeh, Pan, Liao, & Chang, 2008; Kimmel & Deck, 2005; Ringwood, Monaghan, & Malaco, 2005; Zhan & Porter, 2010; Etkina, Murthy, & Zou, 2006; Etkina, Karelina, Ruibal-Villasenor, Rosengrant, Jordan, & Hmelo-Silver, 2007; Geber, Mckenna, Hirsch, & Yarnoff, 2010; McKenna, Colgate, Carr, & Olson, 2006; Kundu & Fowler, 2009; Nonclercq, Vander Biest, De Cuyper, Leroy, López, & Robert, 2010).

The role of the teacher lies in *supervising* students *on technical aspects, the process and the progress,* as well as on *self-development.* Furthermore, the teacher’s role is to facilitate the process of thinking in order to arrive at solutions and innovations. In this inquiry process, the teacher scaffolds students by modelling the inquiry and cognitive process and by performing engineering roles, encouraging reflection, and supporting articulation of domain terminology (Chang, Yeh, Pan, Liao, & Chang, 2008; Cheville, McGovern, & Bull, 2005; Denayer, Thaels, Vander Sloten, & Gobin, 2003; Etkina, Murthy, & Zou, 2006; Etkina, Karelina, Ruibal-Villasenor, Rosengrant, Jordan, & Hmelo-Silver, 2010; Geber, Mckenna, Hirsch, & Yarnoff, 2010; Hirsch, Shwom, Yarnoff, Anderson, Kelso, & Olson, 2001; Roberts, 2001; van Til, Tracey, Sengupta, & Fliedner, 2009; Clyde & Crane, 2003). With regard to assessment, this is conducted both individually and in groups on both processes and products. Concerning the assessment instruments, examples from empirical articles show that individual formative feedback enhances learning in DBL (Baley, 2006; Behrens, Atorf, Schwann, Neumann, Schnitzler, & Balle, 2010; Chang, Yeh, Pan, Liao, & Chang, 2008; Cheville, McGovern, & Bull, 2005; Lee, Su, Lin, Chang, & Lin, 2010; Maase, 2008; Mese, 2006; Stiver, 2010). Among the assessment strategies to be highlighted are individual contribution to project work, portfolios, assignments, and oral presentations. Project work is also assessed by prototypes, team reports, and demonstrations with industry involvement, and by peer-to-peer activities (Denayer, Thaels, Vander Sloten, & Gobin, 2003; Cheville, McGovern, & Bull, 2005; Chang, Yeh, Pan, Liao, & Chang, 2008; Shyr, 2010; Roberts, 2001).

Finally, social context consists of *collaborative learning activities*, including *peer-to-peer* and *communication activities*. An optimal implementation of DBL includes holding activities in the context of peer collaboration in which students work in teams performing professional roles (Behrens, Atorf, Schwann, Neumann, Schnitzler, & Balle, 2010; McKenna, Colgate, Carr, & Olson, 2006). Design elements consist of common design activities conducted by engineers in the work place (Mehalik & Schunn, 2006). Some of these activities include *exploring problem representation, using interactive/iterative design methodology, searching the space (explore alternatives), using functional decomposition, exploring graphic representation, redefining constraints,* and *validating assumptions and constraints,* among others.

Having built a theoretical framework for our DBL model, our next step in researching DBL was to deploy this model in a case within the context of engineering study programs in a technical university.

8.2.2 Design-based learning application in engineering projects

We tested the DBL model from our literature review (Chapter 4) in four engineering departments at the Eindhoven University of Technology: mechanical engineering, electrical engineering, industrial design, and built environment. We identified two research questions: *To what extent do the perceptions of teachers and students in different engineering departments identify the presence of DBL characteristics in the projects assigned?* and, *To what extent are DBL characteristics encountered in the projects assigned across the different engineering departments?*

We conducted a quantitative survey and collected second-year bachelor students', teachers' and supervisors' perceptions of the DBL dimensions identified (Gómez Puente, van Eijck, & Jochems, 2013b). We developed a Likert-type, five-point scale questionnaire to gather these perceptions. To determine whether there are significant differences in perceptions between departments, as well as between teachers, and supervisors and students, we conducted an ANOVA and a post-hoc analysis. The analysis of the results revealed the average of mean scores of the four departments varies just above the average, 3, on the Likert scale. There are differences in the means between the department of Industrial Design (ID) and the other three departments with respect to characteristics, such as the project characteristics, the teacher's role, the assessment, and the design elements.The results suggest that the teachers and students in the ID department perceive the projects to have more of the DBL characteristics and practices reported in the empirical literature as compared to the other three. Results of the ANOVA confirm significant differences among all departments in the project characteristics, the role of the teacher, and the design elements. Results reveal significant differences between ID and the rest of the departments regarding project characteristics and design elements. With respect to the teacher's role, significant differences are encountered between ID, Mechanical Engineering (ME) and Electrical Engineering (EE). Regarding the teachers' and students' perceptions, the mean scores of the five DBL characteristics reveal differences in the perceptions of teachers (3.9) and students (3.1) with respect to the teacher's role. No major statistically significant differences are encountered, however, in the teachers' and students' perceptions with regards to project characteristics, social context, assessment, or design elements.

The findings indicate the DBL characteristics we derived from theory were also found in the projects we examined. However, we found considerable differences between the departments. ID contains DBL characteristics more frequently and more explicitly and strongly resembles the current trends in engineering design practices that we found in contemporary literature on the subject. With respect to the other departments, we identified significant differences regarding project characteristics, the role of the teacher, and design elements. However, we are cautious about making further statements in relation to the dimensions of assessment and social context, as these two variables were less reliably measured. Referring to perceptions, we see significant disparities among teachers and students. We also find significant differences in some aspects of project characteristics, the role of the teacher, and the design elements. These differences are seen mainly in the ME and EE departments when compared with the practices in Built Environment (BE) and ID.

In addition, we also reviewed DBL project documents following a protocol we developed, including the DBL dimensions and their characteristics. The results indicated that the ID and the BE projects more commonly embraced the DBL practices regarding the project characteristics, the design elements and the teacher's role. Although ME and EE projects also contain these characteristics, there were still some differences, mainly with respect to the teacher's role and project characteristics.

The results of this study revealed that the DBL characteristics are more frequently perceived by the ID and BE teachers and supervisors, as well as their students, and also more in the ID and BE projects than in ME and EE projects. This does not necessarily mean that projects in other departments perform low. Our interest at this stage was to focus on the results that bring about opportunities for improvement. In this regard, we centred our intervention in this research study on the mechanical engineering and the electrical engineering departments.

Bearing in mind that not all DBL dimensions could be fully investigated, we selected the project characteristics, the design elements and the teacher's role for in-depth study, according to the following arguments. First, these dimensions were reliably measurable. Second, grounded on our definition of DBL as an educational approach to gather and apply knowledge to solve authentic and complex design tasks resembling engineering activities, the emphasis on the project characteristics and the design elements become essential in DBL projects. Finally, as the role of the teacher was a less-perceived factor in our analysis of results in these two departments, and keeping in mind that the teacher's role has a prominent place in the literature on facilitating learning and scaffolding thinking processes, we selected the teacher's role as a key element to be further investigated.

Based on the need for insight into supervising practices, we studied the teachers' and supervisors' behaviors in DBL projects at two departments, mechanical engineering and electrical engineering.

8.2.3 The supervision of DBL groups

We conducted a qualitative study using interviews with teachers, and interviews and observations of supervisors in each of these two departments to examine how supervision and facilitation actions are applied and whether these correspond to the DBL framework we found in the literature (Chapter 5). In this particular study, we explored the following research question: *To what extent do teachers' and supervisors' actions in facilitating and supervising students in our case represent the DBL characteristics found in the literature?*

A structured interview protocol and observation instruments were developed based on our definition of teachers' roles outlined in the previous empirical and literature studies. Two observers were assigned to verify the data: one present in person during the observation period and one to validate the findings by use of a videotape of the sessions. The sample (N=16) consisted of teachers and supervisors between the two engineering study programs. We selected teachers from freshman and second-year bachelor DBL projects responsible for student supervision and assessment in these two departments. The student supervisors consisted of teachers, master and Ph.D. students, and technical staff. Participants were selected randomly from the small pool of candidates available within these departments.

Results showed there were differences between the two departments with respect to supervision actions. These differences are more visible regarding the ME teachers' and supervisors' actions pursuant to our DBL framework. Furthermore, facilitation of the learning process and modelling thinking by, for instance, asking open-ended questions, stimulating reflection upon technical design, encouraging articulating engineering terminology, or stimulating students to analyze the problem from different perspectives, were not encountered. Teachers' actions within the EE department represent, more frequently, the actions described in our literature review on design-based learning practices. There were more midterm presentations to foster the proper setting to formulate questions. However, we observed that supervisors' actions were limited to monitoring progress of the process and team performance. Furthermore, we identified that the feedback and assessment tools were not consistent with the learning outcomes.

Following the results of this study, we conducted a professionalization program to redesign the DBL projects at the two departments, mechanical engineering and electrical engineering.

8.2.4 The redesign of the DBL projects

The aim of the professionalization program for the teachers and supervisors was to redesign the DBL projects according to our DBL theoretical framework (Chapter 6) in close cooperation with the teachers involved. In this study, we preliminarily defined our research questions as follows: *To what extent have the Mechanical Engineering and Electrical Engineering teachers applied the DBL theoretical framework in the redesign of the projects as a result of our professionalization program using the Experiential Learning Cycle as an educational method?* and *Are there improvements in the redesigned projects compared to the projects of our previous study?*

Prior to designing our program, we searched the literature on teacher professionalization. The result underlies interventions situated in the context of engaging teachers in inquiring and researching their own practices and in reflecting on their own concrete classroom situations, together with colleagues (Schön, 1983; van Veen, Zwart, Meirink, & Verloop, 2010; McAlpine, Weston, Beauchamp, Wiseman, & Beauchamp, 1999; Healey, 2000; Hoekstra, Brekelmans, Beijaard, & Korthagen, 2009). Activities such as observation, feedback, communicating results and discussions focusing on improving students' results were found to be effective implementations to professionalize the teaching staff. Likewise, other examples of interventions include those involving teachers in the analysis and formative evaluation of their own educational experiments and practices used iteratively to develop education (van den Akker, 1999; Cobb, Confrey, diSedda, Leherer, & Schauble, 2003).

We selected the Experiential Learning Cycle (ELC) by Kolb (1984) as a constructivist learning model to work with teachers during the professionalization sessions. We selected this model as it represents the principles of the literature on professionalization of teaching staff to work on the improvement of classroom practices in cooperation with the teachers. Furthermore, it is also based on experiencing insights and situations, reflecting upon own practices (Schön, 1983), and understanding the new DBL insights and applying new ideas in the redesign of DBL projects. The iterative character of this model reproduces the engineering design approach of developing products and systems following a process of analysis, reflection and communication on a prototype and application and testing in a new context. We employed this model to expose teachers to best practices in situated design scenarios representing realistic engineering design activities. We presented examples from the literature in which engineering scenarios are situated in real-world and complex tasks. This approach allows teachers to review practices and redesign DBL projects (Gómez Puente, van Eijck, & Jochems, submitted to journal).

We conclude from this study that the four redesigned DBL projects comprehensively embraced the DBL characteristics from our theoretical framework. We observed, however, limitations with regard to project characteristics, e.g., *open-ended* and *multidisciplinary*. The limitations concerning *open-ended* have to do with the year and complexity level of the project. With respect to *multidisciplinary*, embedding the projects in a broader scope of searching and other contexts creates conflicts with the curriculum and learning outcomes of the projects and courses. The same conclusion can be drawn from the moderate use of design elements, as these are aligned to the learning outcomes.

8.2.5 Teachers', supervisors' and students' perceptions

This section presents the main results of our explorative study of design-based learning in two departments over four projects (Chapter 7). In this study, we investigated the following research questions: *What are the effects of the professionalization program on teachers' and supervisors' opinions and behaviors? Does the redesign of the projects lead to changes in the project implementation?* and *What are the effects on students' opinions and behaviors in the projects as a result?*

Comparing results from our previous study, we observe that ME student's perceptions show higher mean scores over all dimensions. The ANOVA confirms significant differences regarding three DBL characteristics: project characteristics *($p < .01$)*; the role of the teacher *($p < .03$);* and the design elements ($p < .03$)*.* Remarkably, the scores of the teachers' role are substantially higher than in our former study. Students' perceptions of the teacher's role in the previous study averaged 2.8, while in this study, the mean score is 3.3. This finding suggests that the professionalization program has had an effect on the *teachers' role* as perceived by students. With respect to *project characteristics* and *design elements*, we observe that students' perceptions are also higher than in the previous study. Surprisingly, teachers' perceptions in this regard are slightly lower.

The EE results of the ANOVA indicated significant differences regarding the teachers' role *(p = .00).* However, *project characteristics (p < .18),* and *design elements* (*p < .41),* do not show significant differences. Students' perceptions regarding the *teachers' role* are slightly higher than in the previous study (M 3.3 vs. 3.5, respectively), as well as *project characteristics* (M 3.6. vs. 3.3) were slightly lower. With respect to *design elements*, there is little variation (M 3.6 vs. 3.5). Teachers' perceptions, however, are higher across all dimensions except *design elements*, which had the same result as in our previous study. Although teacher behavior has changed as a consequence of the professionalization program, this is not reflected by the students' own perceptions.

Our interpretations regarding the respondents' perceptions on the DBL dimensions are that there is an improvement in students' scores in both departments regarding the project characteristics and design elements, and in particular, the teachers' role. Although these changes are more remarkable in ME than in EE, it suggests that the intervention in the form of a professionalization program has caused some positive effects in changing teachers' and supervisors' behavior.

Surprisingly, although the teachers' perceptions in EE are considerably higher than in the previous study, ME teachers' perceptions are the same or slightly lower than before. Unfortunately, we cannot find a clear answer for this result. Our conjecture, however, is that the research instrument is sensitive to the context and specific to the project situation, and although teachers recognize these characteristics as representative of engineering design activities, not all are included in their projects, as some are not relevant for the learning outcomes or content to be taught.

8.2.6 Project characteristics

To analyze the effects of the DBL characteristics in the redesigned projects, we interviewed the teachers. We observed the changes and effects in students' approach in gathering and applying knowledge in solving design problems. The interviews with the EE teachers indicate that open-ended activities have encouraged a more hands-on approach of active experimentation, as students scope the problem from different perspectives in a different manner. Dealing with incomplete information, with ill-defined and ambiguous problems, is expected to promote a search for options.

We see similar findings in the effects caused by *authenticity.* As one ME teacher reports, having students focus on a system in which all components are encountered has influenced students' approach as they analyze and define the problem in a broader scope and define the problem from a system perspective. In the teachers' views, students examine the problem by representing how engineers think and operate in designing a product, providing a solution, experimenting, and making decisions to optimize the product. These are some changes indicated by the teachers that are different as compared to the previous project set up.

With respect to *design elements*, the activities in the project, such as *explore problem representation, explore alternatives, and build a model*, are conducted more explicitly as the students research the design problem in a broader scope with different or fewer specifications. Alternatives are researched to give form to an ambiguous artifact, and the product is built as a result of different try-outs and improvements.

In conclusion, this exploration indicates that the project characteristics (e.g., *open-ended, authenticity, and hands-on*), together with some *design elements*, stimulate translating the requirements or specifications by looking for alternatives, building and analyzing the properties of a model, and testing and evaluating the design to refine and optimize it.

There is a common pattern in ME and EE students' actions in gathering and applying knowledge in solving design problems, according to students' perceptions. The most frequent actions are *exploring alternatives to solve problems* (EXPSTR), *interpreting information* (INTINF), and *making decisions leading to adjustments and iterations in the design* (MAKDEC). We find the same effect in the student interviews at both departments. That MAKDEC is mainly found in the second of the two projects in both departments may be due to the fact that the results were discussed with management and with the DBL teacher teams, and that the recommendations to make the design process more iterative have encouraged teachers to slightly adjust some activities in the setup of the projects. Consequently, teachers put more emphasis on activities such as mid-term presentations, requesting more frequent presentation of midterm findings. In these presentations, students explain the reasoning behind the selection of design choices and indicate future steps based on analysis of results of experiments, calculations, etc. These may have encouraged short iterations in both departments.

8.2.7 Professionalization of teachers

We also analysed the effects of the professionalization program on the teachers and supervisors. Based on our observations, we conclude that the ME and EE teachers' and supervisors' actions are in line with the DBL supervision framework to a much greater extent than before. The professionalization program has, therefore, stimulated teachers and supervisors to change their behavior in line with our DBL model. ME teachers' supervision is now more explicitly geared to supervise the technical design, as well as the design process itself, through mid-term presentations. In contrast, teacher actions during the weekly meetings remain unchanged. This is likely due to the fact that the objectives and setup of these meetings have not been modified.

Supervisor actions more frequently demonstrated appropriate DBL characteristics than in our previous study and cover a broader range of DBL actions. Furthermore, there were also significant changes in the second mechanical engineering project when compared to the first. We believe the main factors driving this change are the presentations during the group meetings that provide more opportunities for feedback on presentation skills and technical process, and the frequency of questions supporting students' reflection, which result in an increase of EXPSTR, INTINF and MAKDEC, as perceived in our student observations.

In addition, we observed that supervisors make more use of supervision and feedback tools developed by the teachers. We conclude, therefore, that supervision now focuses on the process, not just on the product, and on student development. Feedback is now more objective and transparent, less intuitive and more structured, and consistent with stated learning outcomes. These findings are associated with the results of the survey confirming that student perceptions of the teachers and supervisors aligned more with the DBL framework we presented.

Regarding EE teachers, we observed similar teacher actions as in our previous study. However, as mentioned during the teacher interviews, supervision is now more consistent and aligned to the learning outcomes and design tasks of the project, and questions addressed during supervision meetings are consistent with modeling the design process for the students. With respect to the supervisors, we noticed that DBL actions are widely used with a higher level of recurrence than in the previous study. The students' perceptions of the teacher's role are not remarkably changed.

8.2.8 Final remarks on the results of the research

Design-based learning is a promising and suitable educational approach for engineering education in learning to gather and apply knowledge in problem-solving design assignments. However, no precise statements can be made about which specific DBL characteristics caused the changes we observed, as the DBL features are integrated in different ways in the projects, and each project has its own nature, context, and level of complexity. Furthermore, our research study has been conducted with different cohorts of students. Despite the differences, we still observe that the students' approach to solving design problems is consistent in the projects. In the same line, we observed that *design activities* motivate students to carry out the assignments, searching different perspectives in problem exploration and alternatives. These aspects, along with the fact that supervision and feedback has been intensified, seem to bring about positive signs in teaching students the process of gathering and applying knowledge in solving design problems. The characteristic *multidisciplinary*, however, has not been included. This shows that providing a broader context to the problem is still limited to the learning outcomes and aims of the study program.

8.3 Methodological considerations

In the following section, we summarize the research methodology used in this study and reflect upon some methodological considerations, i.e., the reliability of our instruments and sampling.

8.3.1 The quality of the research instruments

We have used different methods, both quantitative and qualitative, to investigate DBL characteristics. We employed Likert-type questionnaires, analysis of project documents, member check, interviews and observations. To investigate the DBL dimensions and characteristics on teacher, supervisor and student perceptions, we employed a five-point Likert-type questionnaire to collect quantitative data on the DBL dimensions and characteristics. We selected this type of questionnaire because it enabled us to collect quantitative data in a standardized fashion. Several qualitative methods also were used: protocol analysis for the review of project documents, member check, interviews and observations. To revise and analyze the teachers' DBL projects in the different departments, we developed a protocol that included items from the DBL dimensions and characteristics. We analyzed the project documents of four different departments using the same theoretical framework used in the quantitative survey (the project characteristics, the social context, the teacher's role, the assessment, and the design elements).

To improve accuracy and verify our analysis, we conducted a *member check* interview with all teachers responsible for the projects. The purpose of this *member check* interview was to gain feedback from our respondents on the interpretations of our analysis and check the authenticity of the work.

Direct observations of teachers, supervisors and students in supervision activities were collected in order to study participants' behaviors during DBL supervising meetings with students. We then conducted semi-structured interviews with teachers, supervisors and students. We used an *interview guide* with a list of questions and specific topics that focused on the DBL characteristics from the literature with the objective of gathering information on how participants have experienced these DBL characteristics.

Finally, to codify the students' observations and interviews, we adopted a coding system comprising a classification of problem-solving activities in design projects. This classification corresponds to common steps encountered in the literature on solving engineering design problems. The selection of a mix of methods allows triangulation. Our considerations were based on our desire to contribute to the quality of the research.

The questionnaire including items of the five DBL dimensions consisted of a Likert-type five-point questionnaire that included N=40 items. The reliability of the instrument in our first study showed a Cronbach's alpha of 0.919 for the overall instrument. Cronbach's alphas, per dimension, indicate a high level of reliability in three dimensions, namely project characteristics, design elements, and the teacher's role. Regarding assessment and the social context, results indicate a lower level of reliability. This may be due to the formulation of questions. Other explanations include the possibility that questions were perceived differently due to the differences in DBL models among departments, or the low number of items included in these two dimensions. The correlations between the five dimensions are substantial, ranging from 0.33 to 0.68, suggesting that the five characteristics are associated.

We also compared the results on the questionnaire of our previous study with those of the study following the professionalization intervention. Prior to conducting the research, we narrowed the questionnaire and focused only on three dimensions: project characteristics, design elements and the teacher's role. The questionnaire contained N=33 items. Reasons for selecting these three dimensions are the reliabilities found in the previous study and our interest in exploring specific DBL dimensions and characteristics in the projects. The reliability of this instrument is 0.789 overall. With respect to the second study, the Cronbach's alphas are considerably higher in design elements and teacher's role, while lower in project characteristics. These results imply that our research instrument is sensitive to the group and study year. Correlations in our second study among the three dimensions range from 0.37 to 0.49, suggesting the three characteristics are associated. Based on these results, we can conclude the quality of our instrument is satisfactory and allows us to gain an overview of DBL dimensions and realize differences among departments, teachers, supervisors, and students.

We tested our observation and interview instruments to improve the accuracy of this tool. We compared the results of the observations recorded by the first researcher with that of an independent second researcher to verify the consistency of the findings and interpretations. Analysis showed that out of the 20 actions identified by both researchers, fifteen were the same and five were different, indicating concurrency of 75%. The final version of the observation instrument consequently was adjusted.

With respect to the analysis of projects that were redesigned during the professionalization program, we verified the findings of our analysis of the redesign of the projects with those of a second researcher with experience in research methodologies, knowledge about activating approaches in engineering education , expertise in project education, and familiar with the DBL characteristics used in this study. We selected a sample of one project from each department. The inter-rater-reliability (Gwert, 2012) between the two researchers appeared to be moderate to good. Cohen's Kappa for the ME project is .70 (good), and for the EE project is .54 (moderate). The major discrepancies among the two researchers are in the interpretation of open-endedness. This might be caused by the fact that the project description and materials to be analyzed may not be sufficiently illustrative of the open-ended character of the assignment.

To verify the findings of our observations on students in the final phase of this study, a second researcher reviewed three video recordings of three different groups and three different supervisors from two different projects, using our coding system. An analysis of the two researchers' coding results showed an overall overlap of 69%. The inter-rater level of agreement between the two researchers in coding student actions showed Cohen's Kappa's of .65 for the first observation, .70 for the second, and .50 for the third observation (Gwert, 2012). The overall Kappa score was 0.67, indicating a “good” level of agreement.

We therefore conclude that the combination of instruments used in this study allows us to conclude that the results are accurate and offer a sufficient level of reliability.

8.3.2 Sampling and generalizability

This study has a limited numbers of informants, i.e., teachers, tutors, project leaders responsible for student supervision, and students. In addition, the sample was taken from four departments of one university of technology, and the DBL model was redesigned and tested in only two departments. In total N=98 respondents from all four departments (N=46 second-year students, and N=52 second-year teachers and supervisors) participated in our first study. The study of second-year bachelor DBL project documents included three projects per department and two in those that did not have more projects. The number of projects studied assured a representation of DBL practices in each department and an appropriate approach to analyze the DBL projects. The study on supervision practices at the mechanical engineering and electrical engineering departments included N=16 teachers and supervisors.

In our second study N= 291 respondents from two departments (N=168 students and N=28 teachers and supervisors from two ME first-year projects; and N=72 EE students and N=23 teachers and supervisors from two EE second-year projects) took part. The students were observed four times group-wise per project.

Had we limited ourselves to using just questionnaires for data gathering, we would have been able to handle larger samples within our limited time frame. However, in order to get a deeper understanding of DBL, questionnaires were not sufficient. The combination with other research methods, i.e., quantitative survey, analysis of projects, member check interviews, observations, and interviews with different key respondents, allowed us to more deeply analyze findings from different perspectives. However, our choice implied limited sampling sizes. Nevertheless, the differences in the perceptions between teachers and students, as well as the differences encountered in the instructional materials of the students’ project activities, are likely representative of other DBL-based engineering study programs, or at least applicable to them. The differences are plausible when comparing the study programs of our research, and in particular, those regarding ID and Built Environment. Despite the fact that the results in this study are promising, the generalizability of the results is also limited, although it can serve as a learning experience and is interesting for its replicability and adaptation in the context of engineering disciplines in other technical universities.

8.4 DBL theoretical framework in retrospect

An important driver in this study was to make use of theories and theoretical principles to model design-based learning as an educational concept. These theories are grounded in educational notions on active learning methods, such as learning by design (LBD) (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003), and design-based science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). Furthermore, *situated learning* (as a theory that posits that learning is unintentional and situated within an authentic activity or context) and *cognitive apprenticeship* (learning-through-guided-experience on cognitive and metacognitive skills by which students learn the problem-solving processes that experts use to handle complex tasks) have also supported the construction of the DBL theoretical framework. In the following section, we reflect upon these major educational pillars that have been prominent in giving form to our work.

8.4.1 Design-based learning as an instructional approach for engineering education

Design-based learning has been used in secondary education with the purpose of learning relevant concepts in the context of science (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008). It is grounded in similar educational approaches, such as learning by design (LBD) (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003), and design-based science (DBS) (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). In the context of higher education, it shares educational principles similar to PBL as a learner-centered active method (Kolmos, De Graaff, & Du, 2009). Despite slight differences between these approaches, they are all rooted in active learning methods to foster inquiry and critical thinking. Following these educational approaches and according to our definition of the DBL theoretical framework on the one hand, and the description of its characteristics from our research within educational engineering practices on the other, we employed these educational theories to develop DBL activities for projects. These activities were meant to encourage students to gather information and apply knowledge by conducting explorations, generating data and evaluating the success of the design choices.

8.4.2 Situated learning and the concept of authenticity

A core concept in our research has been *authenticity*. Following educational theories on situated learning (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Roth, 1995; Roth, van Eijck, Reis, & Hsu, 2008) we borrowed examples from educational practices in international technical universities from our literature review (Denayer, Thaels, Vander Sloten, & Gobin, 2003; Macías-Guarasa, Montero, San Segundo, Araujo, & Nieto-Taladriz, 2006; Massey, Ramesh, & Khatri, 2006; McKenna, Colgate, Carr, & Olson, 2006; Van Til, Tracey, Sengupta, & Fliedner, 2009; Nonclercq, Vander Biest, De Cuyper, Leroy, López, & Robert, 2010). We used these examples as ‘good practices’ on *authenticity* to redesign the DBL projects. Therefore, situated learning and authenticity are represented in the redesign of the DBL projects in two ways. In the first place, we adopted the taxonomy of design elements (Mehalik & Schunn, 2006) carried out by engineers in engineering companies. This authentic character of the design elements involved in the DBL activities in the projects nurtures the process of preparing students for everyday professional challenges. Secondly, the project scenarios represented real-life design tasks encountered by engineers constructing artifacts while navigating through open, ambiguous situations. In these scenarios, students learn to solve problems by gathering knowledge in an experimentation loop.

8.4.3 Cognitive apprenticeship and the notion of scaffolding

The role of the teacher in DBL is exemplified in cognitive apprenticeship. This role is to facilitate the learning process of novices by experts through modeling, coaching, scaffolding, stimulating reflection, articulation, and exploration (Collins, Brown, & Newman, 1989; Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007; Hmelo, Holton, & Kolodner, 2000; Hmelo-Silver, Duncan, & Chinn, 2007). To adapt these teacher actions into educational contexts, the teacher’s role is to model and scaffold engineering thinking such that students can observe, enact, and practice these actions. We integrated cognitive apprenticeship theory and transformed the examples from our literature review in DBL teachers’ actions and supervision activities. In order to do so, we:

- included strategies such as prompting open-ended questions to model and scaffold engineering thinking;
- facilitated the exploration of the design problem from different perspectives;
- stimulated critical reflection on the design process;
- promoted articulation on the design choices; and,
- designed feedback tools to coach students.

8.5 Implications for educational practice

The results of this study provide guidelines and recommendations to teachers and supervisors for the design and implementation of DBL. The study also provides suggestions for the set-up of DBL assignments, together with interventions to adjust curriculum requirements.

The first recommendation refers to the (re-)design of projects. *Authenticity* has proved to have effects on students' approach to solving design problems. Students search multiple routes to develop, for instance, an electrical system, and they learn to perform complex tasks situated in real-life engineering contexts. The journey of discovering the unknown implies an open space of analysis in the design process. Students solve problems in a broader perspective and synthesize the findings by fine-tuning the model after each loop of experimentation, evaluation, and optimization. The practical application in hands-on activities has encouraged frequent trials and oftentimes short iterations to modify the model.

DBL, therefore, should include assignments with open-ended and ill-structured tasks in which students handle incomplete information and investigate the unknown. In this journey, students define the scope and context of the problem, explore multiple solution methods, select the criteria, redefine constraints and anticipate problems in order to develop new products and systems.

Following the rationale of integrating situated learning in DBL, the inclusion of *design elements* will support students in learning to operate as professionals by conducting design activities that resemble complex engineering tasks. In this venue, it will be important that learning to solve complex design tasks is made explicit to the students. By doing so, students will be aware of and will be encouraged to go through the common problem-solving steps for complex tasks.

The concept of *multidisciplinary* requires special attention. We concluded in this study that no single project includes multidisciplinary features. Taking the concept of multidisciplinary in the strictest meaning possible, no integration of disciplines has been encountered, even after redesign. This corresponds to different facts. First, the teacher professionalization and the project redesign did not aim at constructing and designing the projects from scratch, as this would have required fundamental changes at the curricular level and a lot of time and coordination with other departments. Additionally, it would have been beyond the scope of this study. Secondly, all the projects are performed within the boundaries of the department and are linked to or even embedded in existing courses. However, our definition of *multidisciplinary* also includes a broader concept of approaching the projects in a social, economic or environmental context, framing project activities in wider explorations of the design problem to meet users' or society's needs. In order to make the concept of *multidisciplinary* more explicit in the curriculum, more attention should be paid to societal implications (e.g., socio-economic, environmental, health, etc.). This can be implemented by including research or alike assignments on aspects to meet specific society or users' needs.

One of the premises we implied in this study was that teachers' actions would facilitate students' learning and scaffold thinking in solving complex design tasks. As a consequence of our intervention, we observed an increase in both teachers' and supervisors' actions towards facilitating the learning process. Our second recommendation regarding teachers' roles is that student supervision should include strategies to scaffold thinking. Our results indicate that supervising actions encourage exploring the problem from different perspectives, stimulating the interpretation of results of experiments, and finally, synthesizing the information to make decisions. However, to enhance and facilitate the learning process, it becomes important that supervisors emphasize other aspects of the design process, such as analyzing the problem, selecting criteria and making judgments. Preparing teachers and supervisors for this task should include regular feedback moments and facilitation should also include strategies to stimulate learning and scaffold reasoning during the DBL group meetings. Examples from the DBL literature for supervision and facilitation could include, like *providing feedback on evolving efforts (e.g., coaching on progress in technical design, design process, data collection, and testing methods), supporting students in reflecting on and explicating rationales for technical design, argument formulation, and decision making*, among others.

Finally, our last recommendation concerns the professionalization program for teachers. The instructional model employed during the professionalization of teachers, the experiential learning cycle (ELC) by Kolb (1984), appeared to be suitable to stimulate teachers to readjust and redesign their practices. The iterative character of this model reproduces the engineering design approach of developing products and systems following a process of analysis, reflection and communication on a prototype, and finally, application and testing in a new context. This approach allows teachers to review practices and redesign DBL projects. Therefore, we recommend applying this model as a vehicle for intervention in the professionalization of teachers.

8.6 Implications for further research

This research has served to explore design-based learning as an educational approach for engineering study programs. The DBL framework has been coherently generated from an exhaustive literature research based on DBL and PBL-alike practices. The five dimensions framing DBL are core factors of success in supporting students to gather and apply knowledge in the design process and design assignments. Given the promising results of this research and the fact that research on DBL is still scarce, DBL as an approach for engineering education still opens up venues in different directions for further investigation. Further, as our research only covers engineering programs of one university of technology, it is clear that evidence gathered at other universities is needed to provide a more solid base.

One of the results in this study that brings about interesting aspects for further research is that the supervisors' actions have influenced the students' approach to solving design problems. These effects are more frequently encountered in exploring strategies of design options, interpreting information gathered during the calculations, experiments or try-outs, and to certain extent, to make short iterations and some adjustments in the design. It would be interesting to investigate empirically how supervision actions affect students' gains at the knowledge level.

In this regard, another interesting venue for research is the continuous dilemma of supervising students in open-ended projects and facilitating the learning process while stimulating self-development. Researching how supervision stimulates self-development in open-ended assignments will shed light on teachers' and supervisors' roles and will help alleviate the friction between teaching, which is directive, and learning actions in open-ended projects. Therefore, researching supervision strategies and feedback instruments will be an interesting vehicle to improve supervision.

We also have studied how the project characteristics and design elements have influenced students' approach in solving design problems. One of the results from this research is that *multidisciplinary*, in the meaning of involving aspects in the DBL projects that represent societal, economic, environmental or alike needs, have not been included in the projects. The relevance of including the societal context in the project setting is pertinent to DBL. It is of interest to investigate what effects *multidisciplinary* can have on students' approach to solving design problems and in gathering and applying knowledge in designing models.

We noted that not all *design elements* have been included in the projects, mainly due to the curriculum requirements. Some of the *design elements* that have been introduced in the projects, such as *searching alternatives* or *build a model*, have had positive results. The continuation of this research will focus on looking into the effects of the other *design elements* on students' DBL project implementations.

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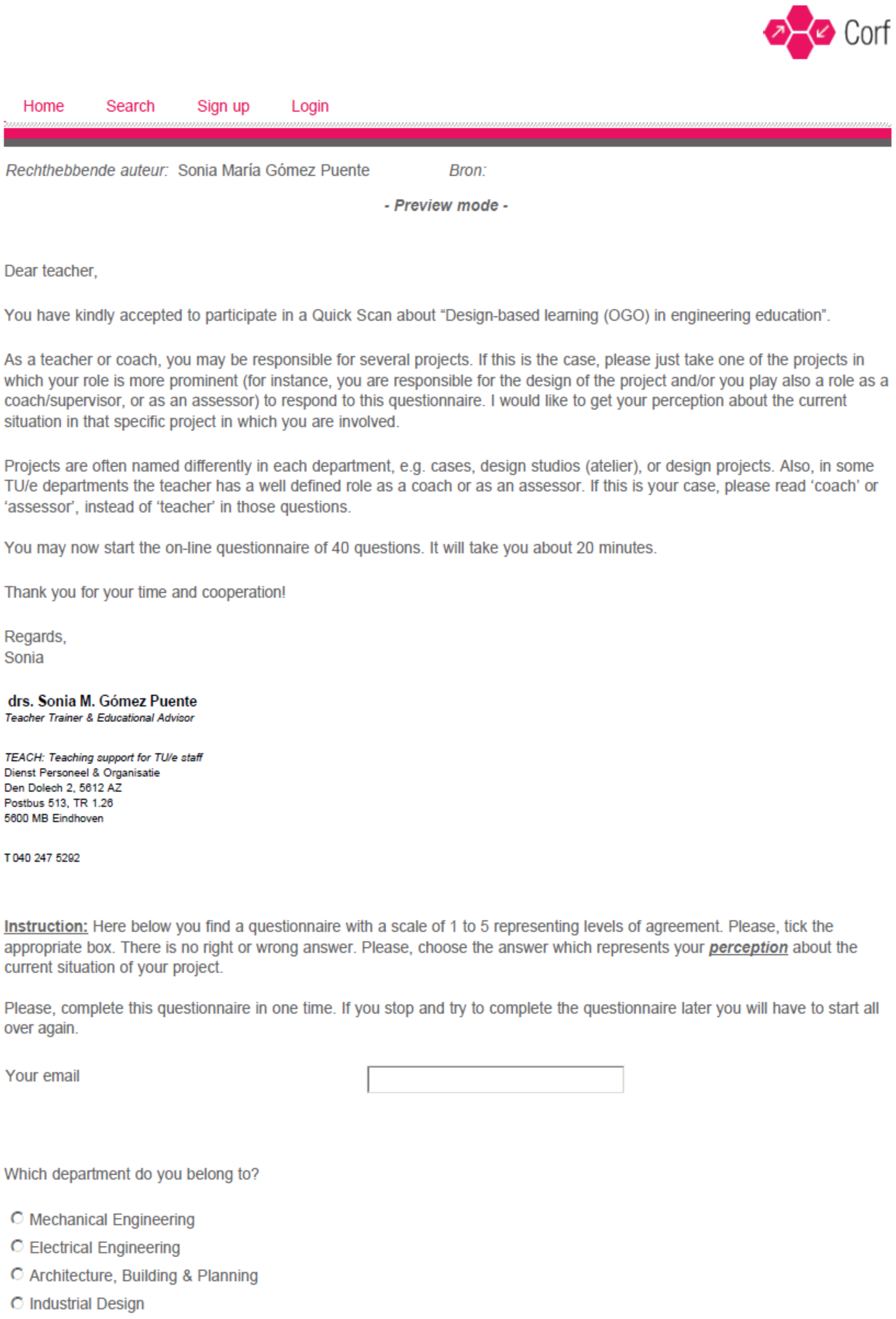
Appendices

Appendix 1. Likert-scale questionnaire with five dimensions



Rechthebbende auteur: Sonia María Gómez Puente *Bron:*

- Preview mode -

Dear teacher,

You have kindly accepted to participate in a Quick Scan about "Design-based learning (OGO) in engineering education".

As a teacher or coach, you may be responsible for several projects. If this is the case, please just take one of the projects in which your role is more prominent (for instance, you are responsible for the design of the project and/or you play also a role as a coach/supervisor, or as an assessor) to respond to this questionnaire. I would like to get your perception about the current situation in that specific project in which you are involved.

Projects are often named differently in each department, e.g. cases, design studios (atelier), or design projects. Also, in some TU/e departments the teacher has a well defined role as a coach or as an assessor. If this is your case, please read 'coach' or 'assessor', instead of 'teacher' in those questions.

You may now start the on-line questionnaire of 40 questions. It will take you about 20 minutes.

Thank you for your time and cooperation!

Regards,
Sonia

drs. Sonia M. Gómez Puente
Teacher Trainer & Educational Advisor

TEACH: Teaching support for TU/e staff
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T 040 247 5292

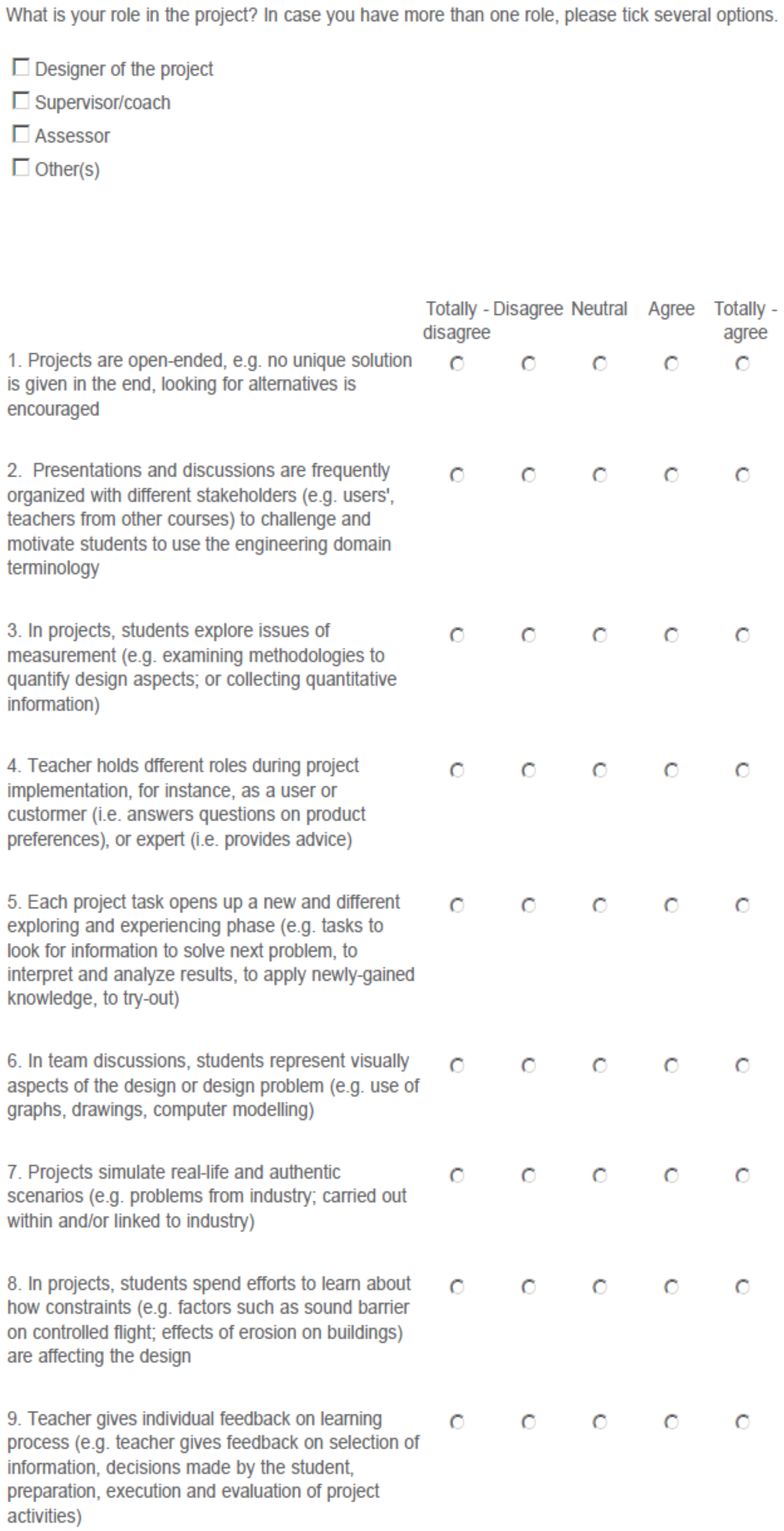
Instruction: Here below you find a questionnaire with a scale of 1 to 5 representing levels of agreement. Please, tick the appropriate box. There is no right or wrong answer. Please, choose the answer which represents your ***perception*** about the current situation of your project.

Please, complete this questionnaire in one time. If you stop and try to complete the questionnaire later you will have to start all over again.

Your email ☐

Which department do you belong to?

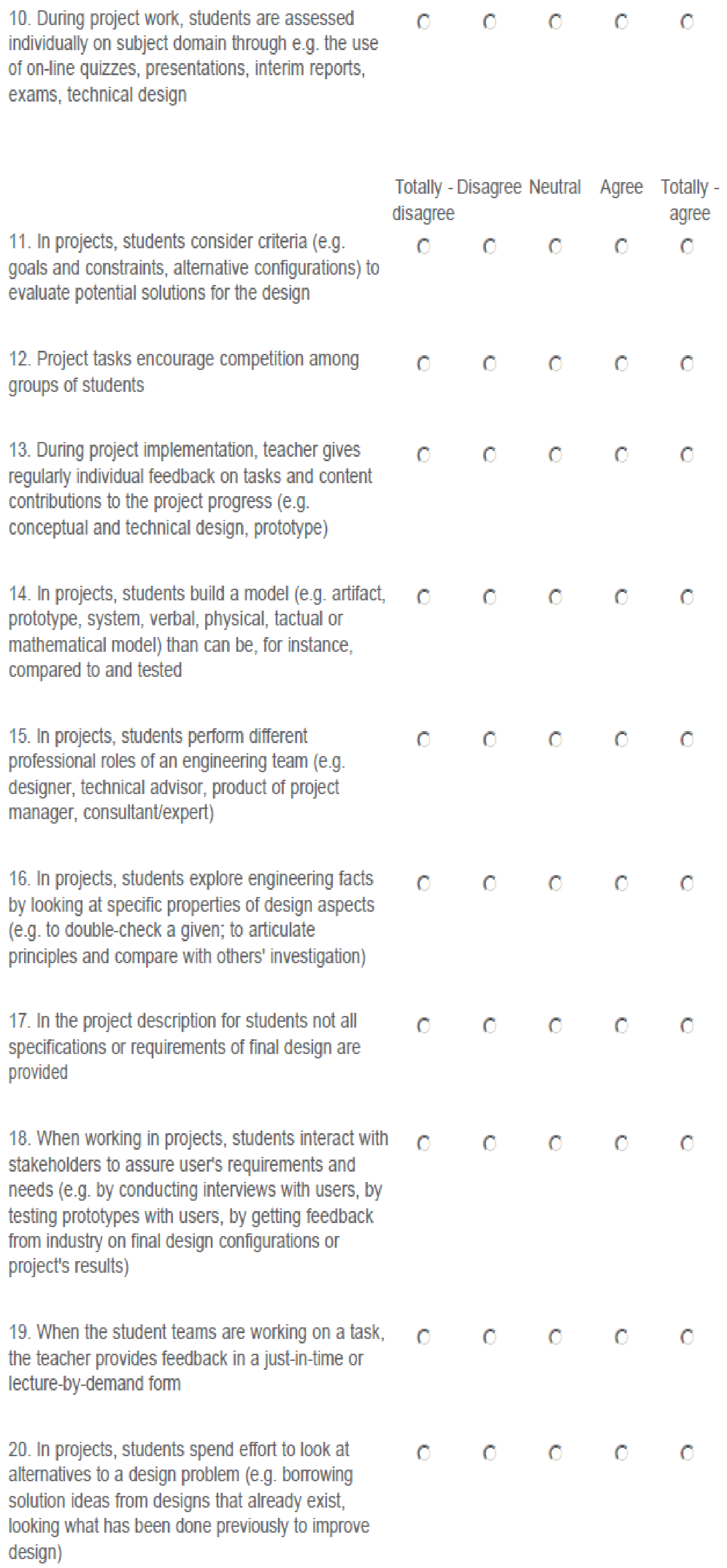
- ○ Mechanical Engineering
- ○ Electrical Engineering
- ○ Architecture, Building & Planning
- ○ Industrial Design



What is your role in the project? In case you have more than one role, please tick several options.

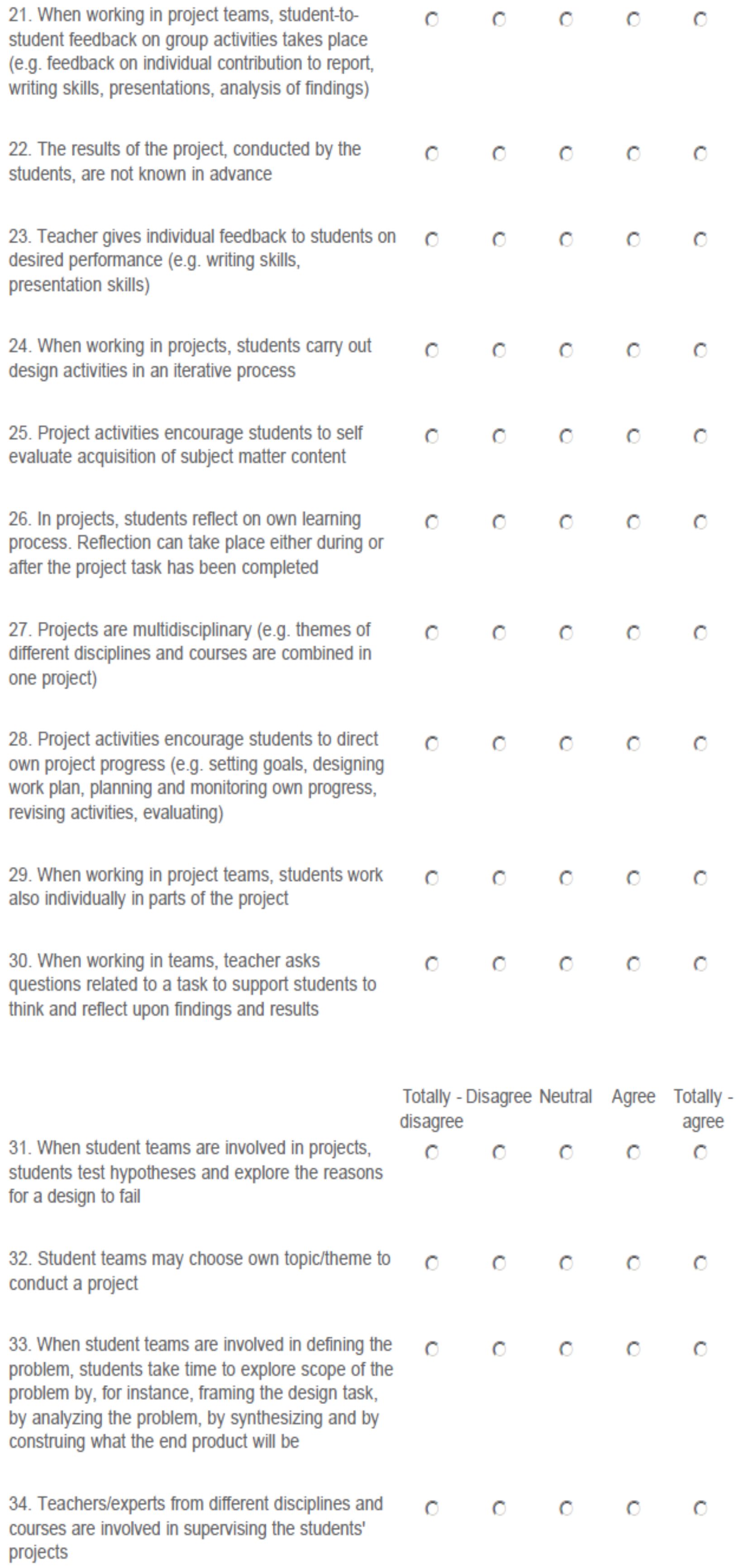
☐ Designer of the project
☐ Supervisor/coach
☐ Assessor
☐ Other(s)

	Totally - disagree	Disagree	Neutral	Agree	Totally - agree
1. Projects are open-ended, e.g. no unique solution is given in the end, looking for alternatives is encouraged	○	○	○	○	○
2. Presentations and discussions are frequently organized with different stakeholders (e.g. users', teachers from other courses) to challenge and motivate students to use the engineering domain terminology	○	○	○	○	○
3. In projects, students explore issues of measurement (e.g. examining methodologies to quantify design aspects; or collecting quantitative information)	○	○	○	○	○
4. Teacher holds dfferent roles during project implementation, for instance, as a user or custormer (i.e. answers questions on product preferences), or expert (i.e. provides advice)	○	○	○	○	○
5. Each project task opens up a new and different exploring and experiencing phase (e.g. tasks to look for information to solve next problem, to interpret and analyze results, to apply newly-gained knowledge, to try-out)	○	○	○	○	○
6. In team discussions, students represent visually aspects of the design or design problem (e.g. use of graphs, drawings, computer modelling)	○	○	○	○	○
7. Projects simulate real-life and authentic scenarios (e.g. problems from industry; carried out within and/or linked to industry)	○	○	○	○	○
8. In projects, students spend efforts to learn about how constraints (e.g. factors such as sound barrier on controlled flight; effects of erosion on buildings) are affecting the design	○	○	○	○	○
9. Teacher gives individual feedback on learning process (e.g. teacher gives feedback on selection of information, decisions made by the student, preparation, execution and evaluation of project activities)	○	○	○	○	○

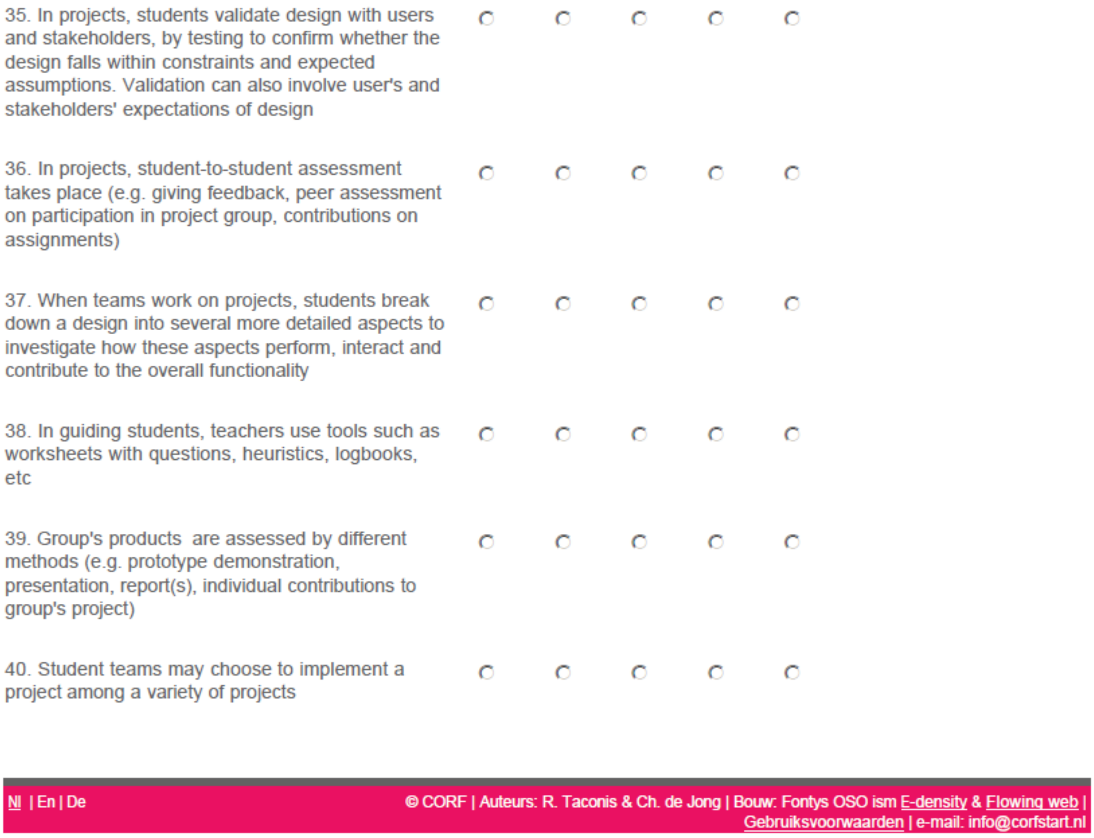


10. During project work, students are assessed individually on subject domain through e.g. the use of on-line quizzes, presentations, interim reports, exams, technical design ○ ○ ○ ○ ○

	Totally - disagree	Disagree	Neutral	Agree	Totally - agree
11. In projects, students consider criteria (e.g. goals and constraints, alternative configurations) to evaluate potential solutions for the design	○	○	○	○	○
12. Project tasks encourage competition among groups of students	○	○	○	○	○
13. During project implementation, teacher gives regularly individual feedback on tasks and content contributions to the project progress (e.g. conceptual and technical design, prototype)	○	○	○	○	○
14. In projects, students build a model (e.g. artifact, prototype, system, verbal, physical, tactual or mathematical model) than can be, for instance, compared to and tested	○	○	○	○	○
15. In projects, students perform different professional roles of an engineering team (e.g. designer, technical advisor, product of project manager, consultant/expert)	○	○	○	○	○
16. In projects, students explore engineering facts by looking at specific properties of design aspects (e.g. to double-check a given; to articulate principles and compare with others' investigation)	○	○	○	○	○
17. In the project description for students not all specifications or requirements of final design are provided	○	○	○	○	○
18. When working in projects, students interact with stakeholders to assure user's requirements and needs (e.g. by conducting interviews with users, by testing prototypes with users, by getting feedback from industry on final design configurations or project's results)	○	○	○	○	○
19. When the student teams are working on a task, the teacher provides feedback in a just-in-time or lecture-by-demand form	○	○	○	○	○
20. In projects, students spend effort to look at alternatives to a design problem (e.g. borrowing solution ideas from designs that already exist, looking what has been done previously to improve design)	○	○	○	○	○



21. When working in project teams, student-to-student feedback on group activities takes place (e.g. feedback on individual contribution to report, writing skills, presentations, analysis of findings)	○	○	○	○	○
22. The results of the project, conducted by the students, are not known in advance	○	○	○	○	○
23. Teacher gives individual feedback to students on desired performance (e.g. writing skills, presentation skills)	○	○	○	○	○
24. When working in projects, students carry out design activities in an iterative process	○	○	○	○	○
25. Project activities encourage students to self evaluate acquisition of subject matter content	○	○	○	○	○
26. In projects, students reflect on own learning process. Reflection can take place either during or after the project task has been completed	○	○	○	○	○
27. Projects are multidisciplinary (e.g. themes of different disciplines and courses are combined in one project)	○	○	○	○	○
28. Project activities encourage students to direct own project progress (e.g. setting goals, designing work plan, planning and monitoring own progress, revising activities, evaluating)	○	○	○	○	○
29. When working in project teams, students work also individually in parts of the project	○	○	○	○	○
30. When working in teams, teacher asks questions related to a task to support students to think and reflect upon findings and results	○	○	○	○	○
	Totally - disagree	Disagree	Neutral	Agree	Totally - agree
31. When student teams are involved in projects, students test hypotheses and explore the reasons for a design to fail	○	○	○	○	○
32. Student teams may choose own topic/theme to conduct a project	○	○	○	○	○
33. When student teams are involved in defining the problem, students take time to explore scope of the problem by, for instance, framing the design task, by analyzing the problem, by synthesizing and by construing what the end product will be	○	○	○	○	○
34. Teachers/experts from different disciplines and courses are involved in supervising the students' projects	○	○	○	○	○



35. In projects, students validate design with users and stakeholders, by testing to confirm whether the design falls within constraints and expected assumptions. Validation can also involve user's and stakeholders' expectations of design	○	○	○	○	○
36. In projects, student-to-student assessment takes place (e.g. giving feedback, peer assessment on participation in project group, contributions on assignments)	○	○	○	○	○
37. When teams work on projects, students break down a design into several more detailed aspects to investigate how these aspects perform, interact and contribute to the overall functionality	○	○	○	○	○
38. In guiding students, teachers use tools such as worksheets with questions, heuristics, logbooks, etc	○	○	○	○	○
39. Group's products are assessed by different methods (e.g. prototype demonstration, presentation, report(s), individual contributions to group's project)	○	○	○	○	○
40. Student teams may choose to implement a project among a variety of projects	○	○	○	○	○

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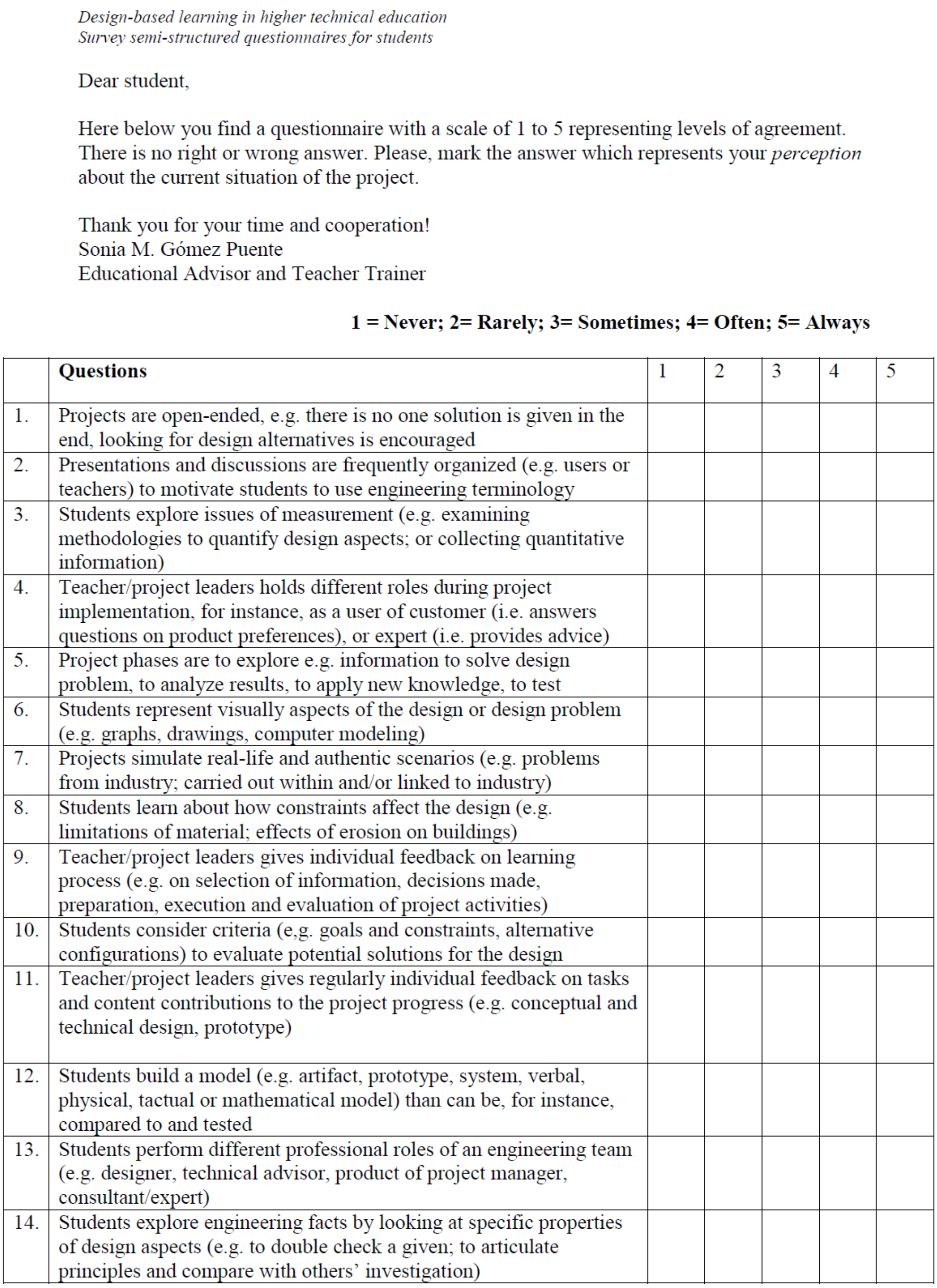
Appendix 2. Likert-scale questionnaire with only three dimensions



Design-based learning in higher technical education
Survey semi-structured questionnaires for students

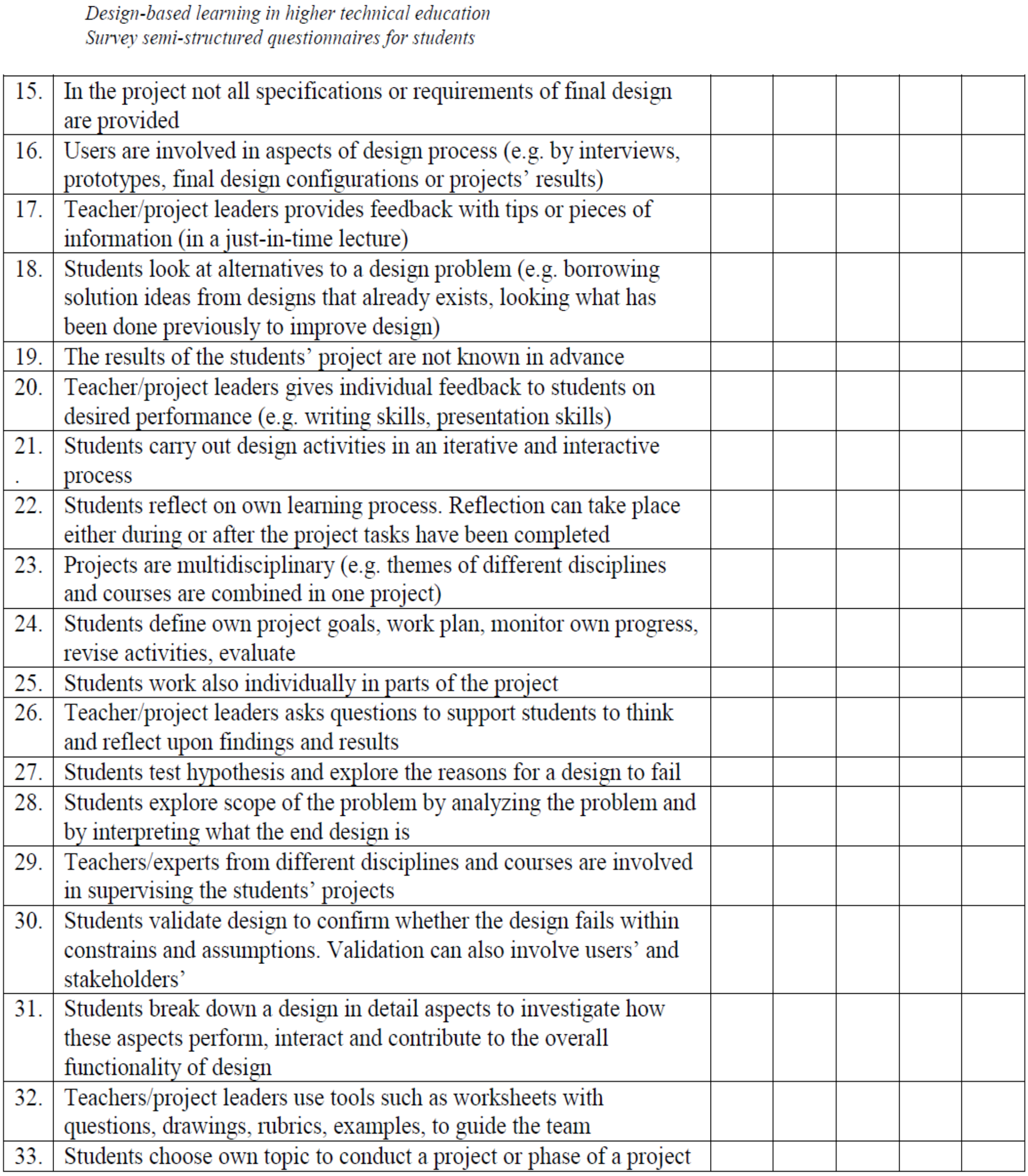
Dear student,

Here below you find a questionnaire with a scale of 1 to 5 representing levels of agreement. There is no right or wrong answer. Please, mark the answer which represents your *perception* about the current situation of the project.

Thank you for your time and cooperation!
Sonia M. Gómez Puente
Educational Advisor and Teacher Trainer

1 = Never; 2= Rarely; 3= Sometimes; 4= Often; 5= Always

	Questions	1	2	3	4	5
1.	Projects are open-ended, e.g. there is no one solution is given in the end, looking for design alternatives is encouraged					
2.	Presentations and discussions are frequently organized (e.g. users or teachers) to motivate students to use engineering terminology					
3.	Students explore issues of measurement (e.g. examining methodologies to quantify design aspects; or collecting quantitative information)					
4.	Teacher/project leaders holds different roles during project implementation, for instance, as a user of customer (i.e. answers questions on product preferences), or expert (i.e. provides advice)					
5.	Project phases are to explore e.g. information to solve design problem, to analyze results, to apply new knowledge, to test					
6.	Students represent visually aspects of the design or design problem (e.g. graphs, drawings, computer modeling)					
7.	Projects simulate real-life and authentic scenarios (e.g. problems from industry; carried out within and/or linked to industry)					
8.	Students learn about how constraints affect the design (e.g. limitations of material; effects of erosion on buildings)					
9.	Teacher/project leaders gives individual feedback on learning process (e.g. on selection of information, decisions made, preparation, execution and evaluation of project activities)					
10.	Students consider criteria (e.g. goals and constraints, alternative configurations) to evaluate potential solutions for the design					
11.	Teacher/project leaders gives regularly individual feedback on tasks and content contributions to the project progress (e.g. conceptual and technical design, prototype)					
12.	Students build a model (e.g. artifact, prototype, system, verbal, physical, tactual or mathematical model) than can be, for instance, compared to and tested					
13.	Students perform different professional roles of an engineering team (e.g. designer, technical advisor, product of project manager, consultant/expert)					
14.	Students explore engineering facts by looking at specific properties of design aspects (e.g. to double check a given; to articulate principles and compare with others' investigation)					



Design-based learning in higher technical education
Survey semi-structured questionnaires for students

15.	In the project not all specifications or requirements of final design are provided					
16.	Users are involved in aspects of design process (e.g. by interviews, prototypes, final design configurations or projects' results)					
17.	Teacher/project leaders provides feedback with tips or pieces of information (in a just-in-time lecture)					
18.	Students look at alternatives to a design problem (e.g. borrowing solution ideas from designs that already exists, looking what has been done previously to improve design)					
19.	The results of the students' project are not known in advance					
20.	Teacher/project leaders gives individual feedback to students on desired performance (e.g. writing skills, presentation skills)					
21. .	Students carry out design activities in an iterative and interactive process					
22.	Students reflect on own learning process. Reflection can take place either during or after the project tasks have been completed					
23.	Projects are multidisciplinary (e.g. themes of different disciplines and courses are combined in one project)					
24.	Students define own project goals, work plan, monitor own progress, revise activities, evaluate					
25.	Students work also individually in parts of the project					
26.	Teacher/project leaders asks questions to support students to think and reflect upon findings and results					
27.	Students test hypothesis and explore the reasons for a design to fail					
28.	Students explore scope of the problem by analyzing the problem and by interpreting what the end design is					
29.	Teachers/experts from different disciplines and courses are involved in supervising the students' projects					
30.	Students validate design to confirm whether the design fails within constrains and assumptions. Validation can also involve users' and stakeholders'					
31.	Students break down a design in detail aspects to investigate how these aspects perform, interact and contribute to the overall functionality of design					
32.	Teachers/project leaders use tools such as worksheets with questions, drawings, rubrics, examples, to guide the team					
33.	Students choose own topic to conduct a project or phase of a project					

Appendix 3. Coding scheme used in protocol analysis of project documents

Dimension	Characteristics	Implementation	Classification			
			++	+	-	--
Project features	❖ Open-ended	➢ No unique solution is encouraged, search for alternatives, more than one possible design solution approach is stimulated				
		➢ Ill-defined: project is vaguely formulated; product specifications and/or customer requirements are not given or are intentionally unstructured, results are not known in advance; students cope with incomplete or imprecise information				
		➢ Some aspects of the design project are to be defined by learners (e.g. definition of own problem, end product, own specifications or product criteria); Students determine own procedures to design solution (e.g. procedures for data collection, troubleshooting, testing plan); make decisions based on selection of alternatives				
	❖ Authentic -real-life design problems	➢ Students approach customer, company, user, to find out information about product specifications and requirements; to get feedback and assessment on product design				
		➢ Students play different engineer roles (designer, project manager, technical expert)				
		➢ Customer's, user's, company experts can be represented by teachers or tutors				
		➢ Design assignments are embedded in professional practical scenarios representing industry problems				

Dimension	**Characteristics**	**Implementation**	**Classification**			
			++	+	-	--
		➢ Teachers from different disciplines and expertise are involved in designing, supervising and evaluating projects				
Teachers' role	❖ Coaching on technical aspects	➢ Feedback on process: work plan and intermediate deliverables (e.g. reports, analysis of prototype, choices for design, etc) ➢				
	❖	➢ Teacher/tutor acts as an expert, customer and gives information on specifications upon request (tailor-made support)				
	❖ Coaching on progress/process	➢ on planning of own activities (steps to approach information, plan, implement and evaluate design tasks and activities)				
	➢ Coaching on self-development	➢ Team work, presentation skills, etc				
		➢ Feedback on self-development and reflection based on competence development; individual growth subject matter contribution				
Assessment	➢ Formative assessment	➢ Students are (formative) assessed on content through multiple-choice or on-line quizzes; interim reports; etc				
		➢ Individual assessment based on e.g. individual contribution to projects; individual tasks assigned to projects (on both technical as well as process contribution on technical design); individual reflection reports				
		➢ Process assessment: on project mgt. (e.g. workplan design proposal, plan and organization of activities, suggestions of solutions for customer)				
	➢ Summative assessment	➢ Summative assessment on product: (technical design, suitable solutions for customer) presentations, reports, demonstrations, etc				

Dimension	Characteristics	Implementation	Classification			
			++	+	-	--
Social context	➢ Peer-to-peer	➢ Provide feedback to each other on products, plans, research methods, etc.				
	➢ Communication skills (written, presentation skills)	➢ Students present intermediate and final results to stakeholders (e.g. users, company, customers)				
		➢ Discussions, debates and presentations are frequently organized to get feedback on each other contribution, on prototype concept or design				
	❖ Competition (motivation)	➢ Demonstrations of end project results are done with company stakeholders (e.g. technical functionality, 'sell' solution)				

Design Stages	(N=50)
Explore problem representation	78
Use interactive/iterative design methodology	28
Search the space (explore alternatives)	40
Use functional decomposition	28
Explore graphic representation	78
Redefine constraints	18
Explore scope of constraints	26
Validate assumptions and constraints	86
Examine existing designs	6
Explore user perspective	26
Build normative model	96
Explore engineering facts	28
Explore issues of measurement	56
Conduct failure analysis	6
Encourage reflection on process	16

Appendix 4. Observation instrument for observation of supervisors' actions

Observations: Teachers' interventions and actions during coaching and supervision of students **Teacher/tutor…**	**Observations**
1. formulates questions (e.g. open-ended questions)	
2. acts as an expert, customer and gives information on specifications upon request	
3. provides feedback on progress on presentation skills, team work, etc	
4. reviews progress on plans, proposals, etc.	
5. provides feedback on their evolving efforts (coaching on progress in technical designs design process, data collection, testing methods)	
6. supports students in reflecting on and explicating rationale for technical design, argument formulation, and decision making	
7. supports students in case of difficulties (e.g. *just-in-time teaching)*	
8. uses methods/tools (worksheets, drawings, examples, etc.) to guide the team	
9. encourages students to articulate engineering terminology during regular meetings and presentations	
10. encourages students to explore alternatives for problem solving, problem representation by looking at problems from different perspectives	
11. encourages students to learn from each other students' plans, knowledge application in problem solving experiments	
12. observes students during implementation of activities	
13. This action is not coded in this protocol. This action is not clear.	

Summary

In engineering education, the context of solving engineering design problems calls for situated learning environments that support students in acquiring and applying disciplinary knowledge to solve authentic assignments. Design-based learning is an educational approach to gather and apply disciplinary knowledge while constructing artifacts, designing systems, and creating innovative solutions.

Learning to manage the complexity of professional practices implies discovering the nature of open-ended and ill-defined multidisciplinary tasks in realistic scenarios. Solving engineering design problems requires going through learning cycles of proposing, experimenting, and optimizing the products. In these assignments, students carry out authentic design problems as they are exposed to engineering activities such as exploring the problem, using an iterative approach, using functional decomposition, exploring engineering measurements, or validating constraints, proper of professional engineering practices. In learning to perform as engineers, the role of the teacher is pivotal in this process. The teacher's main role is to supervise students on technical aspects progress and processes, and students' self-development. Supervising in DBL scenarios implies facilitating the process of gaining domain-specific knowledge by scaffolding thinking and modelling the inquiry process of solving problems, encouraging reflection and articulation, and asking questions to stimulate critical thinking. In doing so, formative feedback with the use of rubrics and frequent presentations on prototypes and demonstrations facilitate learning. Furthermore, assessment in DBL includes monitoring the process using formative and summative supervisory instruments such as oral questioning, weekly presentations and individual assignments within group work, and self- and peer assessment, among other assessment methods. Finally, the social context consists of group activities that stimulate communication and collaboration, such as providing feedback on one another's assignments.

Following an investigation on design-based learning, we found that DBL has been widely used in secondary education to teach the sciences. Originally, DBL finds its roots in active learning approaches, such as Design-based Science (DBS) and Learning by Design (LbD). In higher education, DBL holds similar educational principles as Problem-based Learning (PBL) and like approaches. However, despite the fact that DBL has been employed as a method to teach students science concepts, we have found few examples in higher education suitable to apply in engineering education settings. In this regard, the need to investigate DBL empirically as an educational approach for technical education becomes of paramount importance.

This dissertation reports the effects of the DBL theoretical framework on teachers, supervisors and students. Design-based learning has been introduced to support students in acquiring and using the disciplinary knowledge learned in the lectures. The major results in this study are that DBL project characteristics, such as *open-ended, authenticity* and *hands-on,* stimulate students to take a broader scope in exploring the problem in order to gather

and apply knowledge during the process of solving engineering design issues. The design elements from our study, in particular, *explore problem representation*, *search for alternatives* and *build the model*, have been identified as activities that students carry out differently. In addition, observations and interviews on students' actions show that in gathering and applying knowledge in the process of solving engineering problems, the most common actions are exploring alternatives, interpreting information, and to a lesser extent, making decisions that lead to, although limited, iterations. Furthermore, teachers and supervisors who were involved in the professionalization program have applied DBL actions from our theoretical framework in the supervision of students.

The central research questions guiding the studies in this investigation were as follows:

- What are the design-based learning characteristics in international higher technical education universities and how are they operationalized in engineering projects?
- How should we design a suitable DBL model to operationalize these DBL characteristics?
- What are the effects of this DBL model on teachers and students?

Setting up the rationale for this investigation

We devoted six research studies to investigating the above-mentioned questions. In the introduction to this manuscript (Chapter 1), we presented an overview of the rationale for this exploration. We reflected upon the historical context of design-based learning and set this educational approach at the center of current trends in engineering education. Furthermore, we investigated the foundations of DBL as an educational approach to teach science concepts in high school, and consequently, we zoomed into the problem statement, as DBL has not been widely researched in the context of higher education.

For each study, we developed specific questions that we investigated empirically. In the coming section, we briefly describe the content and inquiries explored in each of the studies. Finally, we reflect upon the importance and relevance of this study for the field of engineering education, as we intended to develop a concept for technical education. In this regard, the relevance for educational practice is emphasized, as this research is a practical-oriented investigation aimed at supporting faculty staff, managers of education, and ultimately, educational practitioners to rethink their practices by exposing teachers to different approaches to design and implement DBL. We concentrate, therefore, on investigating DBL practices in real-life student group settings.

Developing the theoretical framework for design-based learning

We devoted two literature reviews to develop the theoretical framework of DBL (Chapter 2 and Chapter 3). We first selected a number of international and peer-reviewed journals in the field of engineering education drawn from ERIC and ICO databases (Chapter 2). Moreover, we collected 50 articles following a search on DBL-like terms. In addition, we borrowed the taxonomy of Mehalik and Schunn (2006) on activities constituting the most frequent design elements taking place in professional engineering work settings. Likewise, we adopted this classification to analyze how educational practices are carried out in international universities and whether these practices make use of these elements to teach students to gather and apply knowledge in solving complex engineering tasks. The results indicated there are differences in design elements between professional work places and educational settings, as well as between domains, levels of expertise, and authenticity. The outcomes of this study pointed out activities that can be used in the context of educational engineering projects.

In addition, we zoomed in our classification of 50 articles to study which characteristics are relevant in DBL environments (Chapter 3). In doing so, we examined the characteristic of the projects, the role of the teacher, the assessment methods, and the social context, as these are essential educational elements that influence DBL environments. From our inquiry, we concluded DBL projects are *open-ended*, complex engineering tasks that take place in realistic scenarios. In this process, the design of solutions embeds *hands-on* activities carried out in *multidisciplinary* tasks while teams explore societal problems involving a process of scoping the problem and analyzing and testing to finally optimize the product. The teacher's role in this regard is to scaffold the thinking process by modelling reasoning, supporting reflection, stimulating articulation, and encouraging the exploration of the problem from different perspectives. In doing so, the use of formative and summative supervisory instruments supports the students' development on technical aspects, as well as the process and progress. Regarding assessment methods found in DBL environments, assessment includes feedback as a central component of formative assessment. This increases motivation and enhances achievement, as assessment focuses on individual development. The social context embeds practices that stimulate peer-to-peer collaboration and communication. We defined DBL as an educational approach that facilitates the gathering and application of knowledge while proposing, experimenting, and adjusting the products in an engineering design process.

In our third study (Chapter 4), we carried out a quantitative survey and qualitative study to investigate whether the characteristics of our DBL model drawn from the literature are employed in the engineering departments at the Eindhoven University of Technology. In order to test this model, we selected four departments: mechanical engineering (ME), electrical engineering (EE), industrial design (ID), and built environment (BE). We selected second-year teachers, supervisors and students to collect perceptions on DBL with the use of a five-point Likert scale questionnaire. The results of the ANOVA and the post-hoc analysis revealed significant differences among departments, showing the average of industrial design scores is higher in dimensions such as project characteristics, the teachers' role, and assessment and the design elements. We also qualitatively investigated the DBL characteristics present in the projects. We studied a number of second-year projects within these departments and applied a protocol including DBL characteristics from the literature. Results indicated that ID and BE projects included the characteristics of our five DBL dimensions to a greater extent than did ME and EE.

Following the results of these studies in which we identified areas for improvement, mainly in ME and EE projects, we carried out a study (Chapter 5) to examine the supervision and facilitation actions of teachers and supervisors in DBL environments following a DBL protocol garnered from our theoretical framework on supervision actions. We selected ME freshman and second-year EE bachelor teachers and supervisors (N=16) at these two departments. The analysis of supervision actions indicated there are differences in ME and EE teachers and supervisors regarding feedback moments, supervision instruments to monitor progress and process of team performance, and the actions conducted to facilitate learning. Some of these actions, such as asking-questions, stimulating reflection upon technical design, or encouraging articulating engineering terminology, among others, were more limited at the ME department.

Bearing in mind the results of these studies, we developed a professionalization program aimed at supporting teachers to redesign their current DBL practices (Chapter 6). To design the professionalization program, we searched the literature to ascertain the current practices and factors influencing teacher development. We identified interventions situated in the context of teacher practices that involve faculty staff in inquiring and researching their own practices and in reflecting on their own specific classroom situations in cooperation with colleagues. Activities such as observations, getting feedback, and evaluating results, among others, are considered to be effective undertakings to foster teacher professionalization. Borrowing these principles, we developed a professionalization program. Subsequently, we selected the freshman and second-year teachers at the ME and EE departments (N= 6, and N=7, respectively) to participate in the professionalization aspect of this study. Here, the main conclusions pointed out that although the ME and EE projects incorporated DBL characteristics to a greater extent, limitations regarding *open-ended* and *multidisciplinary* were still encountered.

We then tested the redesign of the DBL projects at the ME and EE departments (Chapter 7). We used triangulation based on a combination of research methods (i.e., quantitative survey; qualitative analysis of projects; observations; and interviews with students, teachers and supervisors) in order to research the effects of the enhanced DBL characteristics. We conducted a quantitative survey using the same five-point Likert scale questionnaire as in our previous study. We took a sample at the ME department of N=168 students and N= 28 teachers and supervisors and at the EE of N= 72 students, and N= 23 teachers and supervisors. Furthermore, we investigated changes in the projects as we examined the effects of the enhanced DBL characteristics on students, teachers, and supervisors. According to ANOVA analysis, we identified significant differences regarding the project characteristics, the teachers' role and the design elements in the ME department. Furthermore, according to students' perceptions of the teachers' roles, we found an increase in the mean of 3.3. compared to our previous study (2.8). With regards to the EE projects, ANOVA analysis showed there are significant differences regarding the teachers' roles. There are, however, not significant differences regarding the project characteristics and the design elements. In students' perceptions, there is little change, although these perceptions are slightly higher with regard to the teacher's role and project characteristics, while teachers' perceptions are higher in all dimensions except in design elements, showing the same result as in our previous study.

In this study, we also investigated students' approaches in gathering and applying knowledge by solving complex engineering design problems. In doing so, we focused on what steps students take in order to solve problems. Our exploration indicated that the most frequent steps taken by students in gathering and applying knowledge while solving engineering problems are exploring alternatives, interpreting information, and to a certain extent, making decisions that lead to short iterations. These patterns were found in both ME and EE projects.

Finally, the results of our analysis of projects indicate there are changes in students' approaches to solving design problems via exploring problem representations, exploring alternatives, building a model, and to a certain extent, reflecting on the process.

This research study reveals interesting insights. First, it solidifies the usability of the DBL theoretical framework as an educational approach in higher education that facilitates students' processes in gathering and applying knowledge. However, despite relevant findings in this research, the fact that DBL characteristics are applied differently in the projects and that the projects are also different in nature, complexity, discipline, organization and length, does not allow us to make strict conclusions about which DBL characteristics influence students' approaches in solving engineering design problems.

Implications for educational practice

From this research study, we learned a number of lessons that may be of interest for educational practitioners and technical universities in applying the DBL theoretical framework. In order to foster learning in gathering and applying disciplinary knowledge, it is essential that the context of projects represents authentic professional engineering scenarios. Students learn to perform complex tasks situated in real-life engineering contexts by exploring open-ended and ill-structured tasks to define the scope and context of the problem, explore multiple solution methods, select the criteria, redefine constraints, and anticipate problems in order to develop new products and systems.

Furthermore, the integration of *design elements* will support students in learning to operate as professionals by conducting design activities that resemble complex engineering multidisciplinary tasks and teams. The latter becomes of paramount importance to taking a broader concept of approaching the engineering design problems in a social, economic, or environmental context, and framing project activities in wider explorations of the design problem to meet users' or society's needs.

The role of the teacher in supervising students is crucial to DBL environments. Teacher actions in the supervision of students should include strategies to scaffold thinking, provide feedback on evolving efforts (e.g., coaching on progress in technical design, design process, data collection, and testing methods), support students in reflecting on and explicating rationales for technical design, argument formulation, and decision making, among others. Preparing teachers and supervisors for these tasks should embrace regular feedback moments, and facilitation should also comprise strategies to stimulate learning and scaffold reasoning during the DBL group meetings.

Implications for further research

This research has brought about interesting insights of DBL as an educational approach. However, there are still other relevant areas open for investigation in further explorations.

In supervising students in DBL groups, *the role of the teacher* is critical. Although this study reveals results on students' approaches to solving design problems (e.g., exploring strategies to prpose design options, interpreting information gathered during the calculations, experiments or try-outs, making decisions leading to iterations), it will be relevant to explore empirically how supervision actions affect students' gains.

Furthermore, facilitating learning and stimulating *open-ended* scenarios is still a complex task. Exploring supervision strategies and feedback instruments will be an interesting vehicle to improve students' support in DBL environments. Likewise, it will be interesting to investigate how *multidisciplinary* tasks, comprising societal, economic, environmental, etc., can affect students' approaches to gathering knowledge and solving problems. Finally, some of the *design elements* that have been introduced in the projects, such as *exploring problem representation*, *searching alternatives* or *building a model*, have had positive results. The continuation of this research will focus on looking into the effects of the other design elements on students.

Samenvatting

Bij het oplossen van authentieke opdrachten in technisch onderwijs, vraagt de context van het oplossen van engineering ontwerpproblemen om leeromgevingen die studenten ondersteunt bij het verwerven en toepassen van disciplinaire kennis. Ontwerpgericht onderwijs (OGO) is een werkvorm voor technisch onderwijs om disciplinaire kennis te vergaren en toe te passen in het maken van artefacten, het ontwerpen van systemen en het creëren van innovatieve oplossingen.

Leren om een weg te vinden in de complexiteit van de beroepspraktijk, betekent het ontdekken van de aard van *open-ended* en *ill-defined* multidisciplinaire taken in realistische scenario's. Het oplossen van engineering ontwerpproblemen vereist het doorlopen van de leercycli van het doen van voorstellen, experimenteren en het optimaliseren van de producten. In deze opdrachten werken studenten aan *authentieke* problemen vanuit de ingenieurspraktijk. Ze werken aan het verkennen van het probleem, het gebruikmaken van een iteratieve aanpak, en van functionele decompositie, of het verkennen metingen of valideren van beperkingen zoals in de professionele werkplek. De rol van de docent is het faciliteren en begeleiden van de studenten op technische aspecten, op de voortgang en processen, maar ook op zelfontwikkeling van de studenten. Begeleiding in OGO scenario’s impliceert ondersteuning (*scaffolding)* en van het verkrijgen van domein specifieke kennis. Deze wordt bevorderd door het modelleren van het denkproces voor het oplossen van problemen, door het stellen van vragen en daarmee kritisch denken te stimuleren. Daarbij faciliteert formatieve feedback het leren met het gebruik van rubrics, frequente presentaties over prototypes en demonstraties. Bovendien hoort bij beoordeling van OGO het bewaken van het proces door het gebruik van formatieve en summatieve begeleidingsinstrumenten, zoals onder meer mondelinge ondervraging, wekelijkse presentaties en individuele opdrachten binnen het groepswerk, s*elf*- en *peer assessment.* Tot slot, de sociale context bestaat uit groepsactiviteiten die communicatie en samenwerking bevorderen, waarin het geven van feedback op elkaars opdrachten wordt gestimuleerd.

Na een onderzoek over ontwerpgericht onderwijs ondervonden we dat OGO op grote schaal wordt gebruikt in het voortgezet onderwijs om wetenschappelijke concepten te onderwijzen. Oorspronkelijk vindt OGO zijn wortels in actieve leermethoden zoals Design-based Science (DBS), en Learning by Design (LBD). In het hoger onderwijs, volgt OGO vergelijkbare pedagogische principes als bij Problem-based learning (PBL). Echter, ondanks het feit dat OGO is gebruikt als een methode om studenten wetenschappelijke concepten te leren, hebben we in het hoger onderwijs nauwelijks geschikte voorbeelden gevonden die geschikt waren voor een technische onderwijsomgeving. In dit verband bestaat de noodzaak om OGO empirisch te onderzoeken als een werkvorm voor technisch onderwijs.

Dit proefschrift rapporteert over de effecten op leerkrachten, begeleiders en studenten van het theoretisch kader van OGO. Ontwerpgericht onderwijs is ingevoerd om studenten te ondersteunen en om de disciplinaire kennis geleerd in de colleges toe te passen. Belangrijkste resultaten in deze studie zijn dat OGO-projectkenmerken zoals *open-*

ended, authenticiteit en *hands-on* studenten stimuleren om een bredere kijk te hebben bij het verkennen van het probleem, om kennis te vergaren en om deze vervolgens toe te passen bij het oplossen van het technische ontwerpprobleem. De *ontwerpelementen* uit onze studie, in het bijzonder, het verkennen van een probleem, het zoeken naar alternatieven en het te bouwen van een model, zijn geïdentificeerd als activiteiten die de studenten met een uitgebreide aanpak op een andere wijze uitvoeren. Bovendien laten observaties en interviews over acties van studenten zien dat bij het verzamelen en toepassen van kennis in het oplossen van technische problemen, het verkennen van alternatieven, het interpreteren van informatie en tot op zekere hoogte het nemen van beslissingen die leiden tot iteraties (hoewel beperkt), de meest voorkomende acties zijn. Bovendien hebben docenten en begeleiders, die betrokken waren bij het professionaliseringsprogramma, OGO acties van ons theoretisch kader bij de begeleiding van studenten toegepast.

De centrale onderzoeksvragen die leidend waren bij de studies in dit onderzoek waren als volgt:

- Wat zijn de kenmerken van OGO op internationale technische universiteiten en hoe worden ze geoperationaliseerd in *engineering*projecten?
- Hoe moeten we een geschikt OGO model ontwerpen om deze kenmerken te operationaliseren?
- Wat zijn de effecten van dit OGO model op docenten en studenten?

De rationale voor het opzetten voor dit onderzoek

Wij hebben zes onderzoeken gedaan, om de bovengenoemde vragen te exploreren. In de inleiding van dit manuscript (hoofdstuk 1) presenteerden we een overzicht van de beweegredenen voor deze verkenning. Daarnaast hebben we gereflecteerd over de historische context van ontwerpgericht onderwijs en deze pedagogische aanpak geplaatst binnen de huidige trends in het techniek onderwijs. Verder onderzochten we de fundamenten van OGO als een onderwijsbenadering om wetenschappelijke concepten in het voortgezet onderwijs aan te leren, en hebben we dus ingezoomd op de probleemstelling uitgaande dat OGO niet op grote schaal onderzocht is in de context van het hoger onderwijs.

Voor elk onderzoek ontwikkelden we specifieke vragen die we empirisch hebben onderzocht. In het volgende deel beschrijven we in het kort de inhoud ervan en wat er is onderzocht. Tot slot, reflecteren we over het belang en de relevantie van deze studie voor het vakgebied van het engineering onderwijs, met de bedoeling om een concept voor technisch onderwijs te ontwikkelen. In dit opzicht is de relevantie voor de onderwijspraktijk benadrukt als een praktijkgerichte onderzoek dat is gericht op het ondersteunen van docenten, onderwijsmanagers en onderwijskundigen. Het is dus bedoeld om over ze over hun ervaringen te laten reflecteren en ze hun OGO projecten te herzien. We concentreren ons daarom in het onderzoek op real-life situaties met studenten tijdens de uitvoering van OGO projecten in groepsverband.

Ontwikkeling van het theoretisch kader voor - ontwerp gebaseerd leren

Wij verrichtten twee verschillende empirische studies om het theoretische kader van OGO te onderzoeken en te ontwikkelen (hoofdstuk 2 en hoofdstuk 3). We hebben eerst een aantal tijdschriften en internationale peer-reviewed tijdschriften geselecteerd op het gebied van technisch onderwijs uit ERIC en ICO databases (hoofdstuk 2). Bovendien hebben we 50 artikelen uit een zoekopdracht op soortgelijke OGO-termen verzameld. Daarnaast hebben we de taxonomie van Mehalik en Schunn (2006) overgenomen voor de activiteiten die het meest worden toegepast in professionele engineering werkplekken. Ook hebben wij deze indeling gebruikt om te analyseren hoe de onderwijspraktijk in internationale universiteiten worden uitgevoerd en of deze onderwijspraktijken gebruik maken van ontwerpelementen om studenten te leren om kennis te vergaren en toe te passen bij het oplossen van complexe technische taken. De resultaten geven aan dat er verschillen zijn in de ontwerpelementen tussen professionele werkplekken en onderwijsinstellingen, maar er zijn ook verschillen tussen domeinen, niveaus van expertise en authenticiteit. De resultaten van deze studie wezen erop dat deze activiteiten kunnen worden toegepast in het kader van technische onderwijsprojecten.

Daarnaast hebben we bij onze indeling van de 50 artikelen ingezoomd om te onderzoeken welke kenmerken van belang zijn in OGO leeromgevingen (hoofdstuk 3). Daarbij onderzochten we de karakteristieken van de projecten, de rol van de leraar, de assessmentmethoden en de sociale context want dit zijn de essentiële didactische elementen die OGO leeromgevingen beïnvloeden. Uit ons onderzoek identificeerden we dat OGO projecten *open-ended*, complexe technische taken die plaatsvinden in *authentieke* scenario's zijn. In dit proces worden *hands-on* activiteiten ingebed in de ontwerpoplossingen, met multidisciplinaire taken, terwijl teams maatschappelijke problemen verkennen. Dit proces bevat het identificeren van het probleem, het analyseren en uitvoeren van testen, om uiteindelijk het product te optimaliseren. De rol van de leraren, in dit verband, is om het denkproces te ondersteunen (*scaffolding*) door het modelleren het redeneren, het begeleiden van reflectie en het verkennen van het probleem vanuit verschillende perspectieven. Formatieve en summatieve instrumenten worden gebruikt om de ontwikkeling van de studenten op technische aspecten te ondersteunen en studenten worden ook bij het proces en de voortgang begeleid. Ten aanzien van de assessmentmethoden in de OGO-omgevingen, is feedback bij de beoordeling een centraal onderdeel van de formatieve evaluatie. Dit wordt gedaan om de motivatie te verhogen maar het richt zich tevens op de individuele ontwikkeling. De maatschappelijke context dient als voorbeeld om peer-to -peer samenwerking en communicatie te stimuleren. Op basis van die studies definiëren we OGO als een werkvorm voor het technische onderwijs die het vergaren en het toepassen van kennis faciliteert tijdens het proces van het doen van voorstellen, het experimenteren en het aanpassen van de producten in het oplossen van technische ontwerpproblemen.

In onze derde studie (hoofdstuk 4), voerden we een kwantitatief en kwalitatief onderzoek uit naar de kenmerken van ons OGO model die we uit de literatuur hadden gehaald ook worden toegepast bij de opleidingen van de Technische Universiteit Eindhoven. Om dit model te testen, hebben we vier faculteiten, Werktuigbouwkunde (ME), Elektrotechniek (EE), Industrial design (ID), en Bouwkunde (BE) geselecteerd. We selecteerden daar tweede-jaars docenten, begeleiders en studenten voor het verzamelen van gegevens over hun beleving van OGO, met behulp van een vijf punt Likert-schaal vragenlijst. De resultaten van de ANOVA en de post-hoc analyse toonde significante verschillen aan tussen opleidingen, waaruit blijkt dat Industrial design gemiddeld hoger scoort op kenmerken als, de rol van de docenten, de beoordeling en de ontwerpelementen. We hebben ook kwalitatief de OGO kenmerken in de projecten onderzocht. Voor de studie van een aantal tweedejaars projecten van deze opleidingen hebben we een protocol met OGO kenmerken uit de literatuur toegepast. Resultaten gaven aan dat bij ID en BE projecten de kenmerken van onze vijf OGO dimensies in grotere mate worden toegepast dan bij Me en EE projecten.

Naar aanleiding van de resultaten uit onze vorige studie waarin de gebieden die voor verbetering vatbare waren, vooral projecten betrof bij ME en EE , hebben wij een studie uitgevoerd (hoofdstuk 5) naar de begeleidingsprocessen van docenten en begeleiders in OGO omgevingen aan de hand van ons theoretisch kader over begeleidingsacties. Wij hebben hiervoor eerstejaars en tweedejaars bachelor docenten en begeleiders (N = 16) van deze twee opleidingen geselecteerd. De analyse van de begeleidingsacties had aangegeven dat er verschillen zijn in de ME en EE acties van de docenten en begeleiders met betrekking tot de feedbackmomenten, de begeleidingsinstrumenten om voortgang, proces en teamprestaties te monitoren en de acties uitgevoerd om het leerproces van de studenten te faciliteren. Sommige van deze acties waren beperkter bij ME, zoals onder andere het stellen van open vragen, het stimuleren van reflectie op het technisch ontwerp en het stimuleren van correct gebruik van technische terminologie.

Rekening houdend met de resultaten van deze studies hebben we een professionaliseringsprogramma ontwikkeld gericht op de ondersteuning van de docenten om hun huidige OGO projecten (hoofdstuk 6) te herontwerpen. Om het professionaliseringsprogramma te ontwikkelen hebben we in de literatuur onderzocht wat de huidige kenmerken en factoren zijn die de professionalisering van leraren beïnvloeden. In dit onderzoek bleek dat succesvolle interventies in de onderwijsomgeving van de docent liggen en dat belangrijke aspecten voor de professionalisering de betrokkenheid van de docent bij het onderzoeken en analyseren van hun eigen werk zijn en het reflecteren op eigen specifieke onderwijssituaties in samenwerking met collega’s. Activiteiten zoals observaties, het krijgen van feedback en evaluatie van de resultaten, onder meer worden beschouwd als effectieve vormen voor het bevorderen van de professionalisering van docenten. Op basis van die principes ontwikkelden we een professionaliseringsprogramma.

Vervolgens hebben we eerstejaars en tweedejaars docenten aan de ME en EE opleidingen geselecteerd (N = 6 en N = 7 respectievelijk). In deze studie wezende belangrijkste conclusies erop dat, hoewel de ME en EE projecten in grote mate de OGO kenmerken toepassen, er beperkingen waren ten aanzien van open-ended en multidisciplinariteit.

We testten de herinrichting van de OGO -projecten bij de ME en EE faculteiten (hoofdstuk 7). We gebruikten triangulatie methode gebaseerd op een combinatie van onderzoeksmethoden, namelijk kwantitatief onderzoek, kwalitatieve analyse van de projecten, observaties en interviews met studenten, docenten en begeleiders, om de effecten van de OGO kenmerken te onderzoeken. We voerden een kwantitatief onderzoek met behulp van dezelfde vijf -punt Likert-schaal vragenlijst zoals in onze vorige studie uit. Bij de ME opleiding hebben N = 168 studenten en N = 26 docenten en begeleiders deel genomen aan deze studie, en bij de EE opleiding N = 72 studenten en N = 23 docenten en begeleiders. Verder onderzochten we acties van begeleiders en studenten tijdens de uitvoering van de projecten en onderzochten we de effecten van de OGO kenmerken bij studenten, docenten en begeleiders. Volgens de ANOVA-analyse identificeerden we in de ME opleiding significante verschillen met betrekking tot de kenmerken van het project, de rol van de docenten en de ontwerpelementen. Verder hebben we in de beleving van de studenten een verhoogde gemiddelde in 3.3 gemeten voor de rol van de docenten in vergelijking met onze vorige studie (2.8). Met betrekking tot de EE projecten, toonden de resultaten van de ANOVA-analyse aan dat er significante verschillen zijn met betrekking tot de rol van de leerkrachten. Er zijn echter geen significante verschillen in de projectkenmerken en elementen gevonden. Wat betreft de beleving van de studenten is er weinig variatie maar het is iets hoger in de rol van de docenten als in de kenmerken van het project, terwijl de beleving van docenten hoger zijn in alle dimensies, behalve in de ontwerpelementen met de hetzelfde resultaat als in onze vorige studie.

In deze studie zijn ook de benaderingen van de studenten in het verzamelen en toepassen van kennis door het oplossen van complexe technische problemen in het ontwerp onderzocht. Daarbij hebben we ons gericht op de stappen die studenten nemen om problemen op te lossen. Ons onderzoek geeft aan dat de meest voorkomende stappen die studenten nemen bij het verzamelen en toepassen van kennis bij het oplossen van technische problemen het onderzoeken van alternatieven zijn, het interpreteren en tot op zekere hoogte doen van korte iteraties. Deze patronen worden vaak gevonden in zowel ME en EE projecten.

Tenslotte, uit de resultaten van onze analyse van projecten blijkt dat er veranderingen zijn in de wijze waarop studenten problemen onderzoeken, zoeken naar en verkennen van alternatieven, modelleren en in zekere mate in de wijze waarop ze reflecteren op het proces.

Dit onderzoek over OGO kenmerken onthult interessante inzichten. Allereerst, het onderschrijft de bruikbaarheid van het OGO theoretisch kader als een werkvorm die studenten processen vergemakkelijkt bij het vergaren en toepassen van kennis. Ondanks dat er relevante bevindingen naar voren zijn gebracht door dit onderzoek kunnen we geen strikte conclusies trekken over wat nu precies de OGO kenmerken zijn die de studenten beïnvloeden bij het oplossen van technische problemen in het ontwerpproces, omdat bij het onderzoek de OGO kenmerken verschillend zijn toegepast in de projecten en omdat de projecten ook verschillend van aard, complexiteit, discipline, organisatie en de lengte zijn.

Implicaties voor de onderwijspraktijk

Uit dit onderzoek leerden we een aantal lessen die interessant kunnen zijn voor docenten, onderzoekers en andere betrokkenen in het leerproces van studenten tijdens het toepassen van het OGO theoretisch kader in technische universiteiten. Om het verzamelen en toepassen van disciplinaire kennis te bevorderen is het essentieel dat de context van de projecten authentieke professionele engineering scenario's zijn. Studenten leren complexe taken in een realistische technische omgeving uit te voeren, door het verkennen van open-ended en weinig gestructureerde taken, het definiëren van het probleem, het verkennen van verschillende oplossingsmethoden, het selecteren van de criteria, het herdefiniëren van de beperkingen en het anticiperen op problemen in het ontwikkelen van nieuwe producten en systemen.

Bovendien zal de integratie van ontwerpelementen studenten ondersteunen in het leren om te werken als een deskundige door het toepassen van ontwerpactiviteiten die complexe technische multidisciplinaire taken en teams simuleren. Dat laatste is erg belangrijk voor het plaatsen van engineering ontwerpproblemen in een bredere sociale, economische of milieukundige context, waardoor deze een grotere gelijkenis krijgen met de vraag en behoeften en werkwijze vanuit de markt en maatschappij. De rol van de docent in het begeleiden van studenten is cruciaal voor de OGO leeromgevingen. De begeleiding van studenten moet onder andere strategieën bevatten voor het ondersteunen van het denkproces, voor het geven van terugkoppeling over de ontwikkeling door de inspanningen (coachen bij de voortgang van het technisch ontwerp, het ontwerpproces, het verzamelen van gegevens en testmethoden), het ondersteunen van studenten bij het reflecteren op en het uiteenzetten van argumenten voor het technische ontwerp, het formuleren van argumenten, en bij de besluitvorming. Om docenten en begeleiders voor deze taken voor te bereiden zijn regelmatige feedback momenten nodig, en ondersteuning zou ook strategieën moeten bevatten om het leren en het ondersteund redeneren te stimuleren tijdens de DBL groepsbijeenkomsten.

Implicaties voor verder onderzoek

Dit onderzoek heeft geleid tot interessante inzichten in OGO als werkvorm. Echter, er zijn nog andere relevante gebieden die openstaan voor onderzoek in de verdere verkenningen. In het begeleiden van studenten in OGO groepen de rol van de docent is van cruciaal belang. Hoewel deze studie resultaten laat zien op gebied van de aanpak van studenten bij het oplossen van problemen in het ontwerpproces (bijv. het verkennen van strategieën van ontwerpopties, interpreteren van verzamelde informatie bij berekeningen, experimenten of try- outs informatie, het nemen van beslissingen die leiden tot iteraties), zal het nog steeds relevant zijn om de invloed van begeleiding op de studenten verder te onderzoeken.

Bovendien is het faciliteren van leren en stimuleren in *open-ended* scenario nog steeds een complexe taak. Het verkennen van begeleidingsstrategieën en van feedbackinstrumenten zal een interessant middel zijn om de ondersteuning van studenten in OGO groepen te verbeteren. Evenzo zal het interessant zijn om te verkennen hoe multidisciplinaire taken, waaronder maatschappelijke, economische, milieu aspecten, van effect zijn op de benadering van studenten bij het vergaren en het toepassen van kennis. Tot slot, zijn er een aantal van elementen geïntroduceerd in de projecten, zoals het verkennen van het probleem, het zoeken alternatieven of het bouwen van een model, die positieve resultaten hebben opgeleverd. De voortzetting van dit onderzoek zal zich richten op het kijken naar de effecten van de andere ontwerpelementen op studenten.

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Curriculum Vitae

Sonia María Gómez Puente was born on 30 October 1969 in Madrid, Spain. She completed her master's degree in 2003 in Education and Training Systems Design at University of Twente (Enschede, the Netherlands). Since 1998, she has worked as a coordinator of educational projects and as a trainer for international organizations abroad. Later, she worked as an educational consultant and trainer at MDF Training and Consultancy (Ede, the Netherlands) and served in a number of NUFFIC (the Netherlands Organization for International Cooperation in Higher Education) projects, strengthening international universities in Tanzania, Rwanda, and Guatemala. In these projects, she was mainly involved in the coordination of educational activities regarding curriculum development and in the professionalization of teachers by providing advice, coaching, and training.

Since 2008, she has been employed at the Eindhoven University of Technology (TU/e) as an educational advisor and a teacher trainer. She worked at the education and training department for the professionalization of teachers (TEACH/DPO) within the University Teaching Qualification program (Basis Kwalificatie Onderwijs, BKO). Starting in January 2014, Sonia works as an education development policy advisor and quality assurance officer at the Applied Physics department at the TU/e.

In 2010, she began her Ph.D project at Eindhoven School of Education (ESoE), Eindhoven University of Technology (the Netherlands), from which the results are presented in this dissertation.

ESoE dissertation series

Sande, R. A. W. van de (2007). *Competentiegerichtheid en scheikunde leren: over metacognitieve opvattingen, leerresultaten en leeractiviteiten*.

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Raessens, B. A. M. (2009). *De E-kubus: een analysemodel voor curricula.*

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