International Journal of Engineering Education Vol. 29, No. 2, pp. 491–503, 2013
Printed in Great Britain

0949-149X/91 $3.00+0.00

Empirical Validation of Characteristics of Design-Based Learning in Higher Education*

SONIA M. GÓMEZ PUENTE, MICHIEL VAN EIJCK and WIM JOCHEMS
Eindhoven University of Technology (TU/e), Postbus 513, 5600 MB Eindhoven, The Netherlands. E-mail: s.m.gomez.puente@tue.nl

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; design thinking; engineering education; instructional design

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 [1]. Contemporary trends and instructional design practices in engineering education advocate situated learning tasks in scenarios [2] 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 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 [3–4]. 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 [5–6]. In this educational approach, teams of students engage in multidisciplinary engineering assignments and integrate and apply knowledge to generate solutions, artifacts, and systems [7].

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 [3]. 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 [5–8]. Engineering design emphasizes, however, the systematic and intelligent process of meeting the users' needs in creating, evaluating, and specifying devices or systems [6]. 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 [9].

Considerable research has been conducted on newly coined approaches to DBL-like models, such as Learning by Design or Design-based Science [10–11]. 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 [12]. 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

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* Accepted 8 November 2012.

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 [13]. 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 [8, 14]. 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 [8, 14]. 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.

2. Background

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 [15]. Approaches such as Learning by Design [10] and Design-based Science [11] 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) [16]. Accordingly, DBL inherited from PBL the idea of students who develop inquiry skills and integrate theoretical knowledge by solving ill-defined problems [17]. 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 [13].

Despite the research conducted into design methods and engineering design processes [5, 6, 18–21], 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 [3], 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.) [22], 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

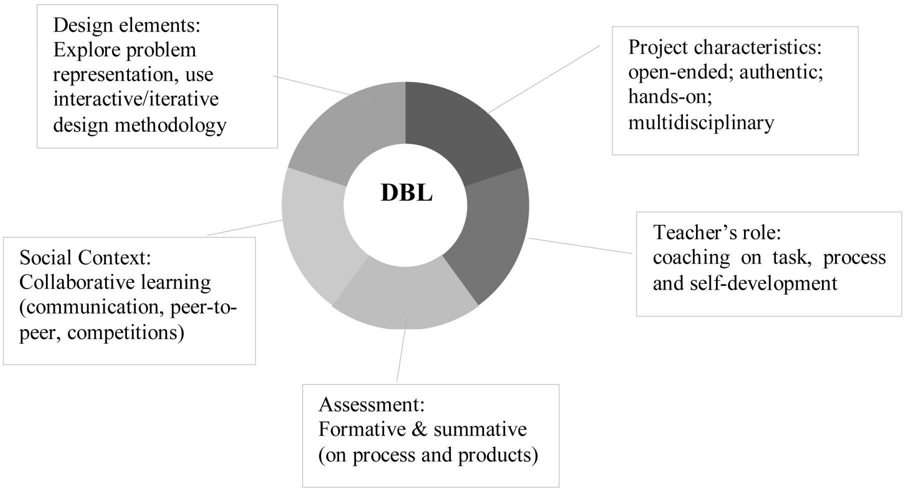

Fig. 1. Overview of DBL dimensions and the characteristics.

to define DBL within the context of higher education [8, 14].

2.2 Characteristics of DBL in higher education

In our prior research, we reviewed the literature on DBL-like projects in higher education [8, 14]. 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 [8]. Studies reporting on workplace engineering practices [16–17] 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 [24–25]. 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 [26]. 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 [27]. 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 [26–28].

With respect to design activities, we have adopted as a design framework a classification of fifteen design elements [9] 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 [14]. 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 [29] and to boost self-directness [30].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 [31]. In DBL projects, the teacher may play the role of consultant and challenge the student team with questions and scaffolding processes [27, 32] by providing benchmark lecture-by-demand [33] or by asking guiding questions [26] and stimulating discussion to use domain terminology [34] 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 [35] and encouraging self-reflection [36–37] on their own design practices through 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 [36–38] 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 [39–40]. 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. [26–41]. 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 [31]. Other examples in the literature included presenting situational contexts in which students communicated ideas and presented plans to users or customers [42]. By holding competitions and presentations, students practice engineering domain language and increase their motivation as they practice in social scenarios [43].

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.

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. Method and design of the study

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 [7]. 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 [44], 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 [45–46]. 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 [47] 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.

4.2 Survey

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 of these 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.

4.2.2 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.

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 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 contributions 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., 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)."

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

4.3 Review of teaching materials

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 [42], 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 [38].

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 [49].

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 [46].

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.

4.3.3 Member check technique

To improve the accuracy and validity of our analysis, we conducted a member check interview [47] 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.

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 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)
	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 at fully developed 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, project proposal, Gantt chart, prototype Online 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, but prototype is different

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.

5. Results

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.

Table 4. Cronbach's alpha for each dimension

Dimensions	*a*
Project characteristics	0.78
Social context	0.35
Teachers' role	0.83
Assessment	0.29
Design elements	0.80

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.

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.

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

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	0.41	Student	3.3	0.46
	EE	3.2	0.53	Teacher	3.7	0.64
	BE	3.6	0.51			
	ID	4.2	0.40			
Social context	ME	3.4	0.63	Student	3.3	0.72
	EE	3.7	0.54	Teacher	3.5	0.59
	BE	3.1	0.77			
	ID	3.7	0.44			
Teacher	ME	3.1	0.79	Student	3.1	0.69
	EE	3.5	0.38	Teacher	3.9	0.54
	BE	3.7	0.68			
	ID	4.2	0.35			
Assessment	ME	3.6	0.52	Student	3.6	0.55
	EE	3.8	0.53	Teacher	3.9	0.52
	BE	3.6	0.54			
	ID	4.1	0.52			
Design elements	ME	3.5	0.43	Student	3.4	0.44
	EE	3.6	0.39	Teacher	3.8	0.49
	BE	3.5	0.49			
	ID	4.1	0.51			

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 and the assessment of the supervisors.

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

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

	DBL dimensions				
Department/Project	**Project characteristics**	**Social context**	**Teacher's role**	**Assessment**	**Design elements**
ME					
Project 1	O, H	P	Cp	S	1, 2, 5, 8, 11, 12, 13, 14
Project 2	O, H	P	Cp	S	1, 5, 8, 11, 13
Project 3	H	C, P	Cp	S	1, 5, 8, 11, 13, 15
EE					
Project 1	H	P	Ct, Cp	F, S	5, 8, 11, 13
Project 2	H, A	P	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).

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.

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 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's 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.

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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Sonia M. Gómez Puente is a Ph.D. candidate at the Eindhoven School of Education and Educational Advisor and Teacher Trainer at TEACH, the Department of Education and Training at the Eindhoven University of Technology. She specializes in the professionalization of university teachers. Her key areas of expertise include: research and innovation in engineering education; curriculum development and instructional design; competencies development; active teaching methods; supervising students in project groups; and design-based learning (DBL).

Michiel van Eijck is Associate Professor at the Eindhoven School of Education at the Eindhoven University of Technology. His research focuses on issues of authenticity and diversity in science and technology education in regards to the socio-cultural dynamics of science and technology.

Wim Jochems is Full Professor of Educational Innovation at the Eindhoven School of Education at the Eindhoven University of Technology, the Netherlands. His research focuses on the innovation of science and technology education. He is particularly interested in the role of science teachers in implementing educational innovations.