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A comparative study of teachers' perceptions of design-based learning

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Abstract

Design-based learning (DBL) is an instructional approach in which students gather and process theoretical knowledge while working in the design of artifacts, systems and innovative solutions in project settings. In the context of secondary education, DBL has been used as an educational form to teach sciences. However, there is little investigated empirically about the characteristics of design-based learning in higher education, and more specifically, in engineering study programs. The aim of this study is to examine whether the characteristics of design-based learning theorized along five dimensions, e.g. projects' characteristics, social context, teachers' role, assessment, and design elements are present in engineering education programs in international universities. For our comparative study we have selected different engineering study programs in three technical universities in The Netherlands, Portugal and in Brazil. We have conducted a quantitative survey to gather the teachers' perceptions on the DBL five dimensions. Results show that the DBL dimensions are identified at the engineering programs of the three technical international universities. Conclusions of this comparative study of design-based learning practices in higher engineering education are representative and may be of interest for other technical universities.

Keywords: design-based learning, engineering education, authentic projects

1 Introduction

Over the last 10 years, problem-based and project-based learning approaches have gained acceptance in engineering degree programs. More than a decade ago, project-based learning started to become a response to the challenges that engineering education was facing, like globalization, pace of technological change and industry requiring lifelong learning professionals, who are able to work in teams (Schachterle and Vinther 1996). Engineering programs started to include different forms of project and problem approaches to learning. One of the most noticeable reasons to make a shift to this kind of approaches is the increasing demand for professional skills for engineering graduates (Walther and Radcliffe 2007; Vest 2008).

The vision of the engineer of the future is to work collaboratively in multidisciplinary teams of technical experts to develop design solutions to society problems and communicate with stakeholders (National Academy of Engineering of the National Academies, 2005). Contemporary trends and instructional design practices in engineering education advocate situated learning tasks in scenarios (Brown *et al.*, 1989). In these authentic scenarios students learn to perform as engineers to communicate, plan and organize information and process it to solve ill-defined problems. The character of engineering assignments is to work on open-ended and hands-on experiences approaching problems from multiple perspectives to provide innovative solutions in no one-single correct answer assignments (Dym and Little, 2009; Lawson and Dorst, 2009). Design-based learning is a vehicle to engage students in engineering multidisciplinary assignments in which student teams integrate and generate knowledge in the design of solutions, artifacts, and systems (Wijnen, 2000). Engineering educational tasks are carried out in open-ended projects in which the teacher facilitates and scaffolds the reasoning and inquiry process from novice to expert development working in a social and collaborative settings. Starting from these underpinnings, we define DBL as: the project characteristics, the role of the teacher, the assessment methods, the social context and design elements (Gómez *et al*, published online). Having in mind these five dimensions, we have explored the state-of-the-art empirical literature on DBL or DBL-like educational projects in higher engineering education.

In the coming sections we provide a description of the study conducted. Section two presents the theoretical framework around DBL characteristics. Next, we introduce the research questions for our study. Following, we present the method used to gather the perceptions of the teachers and students at the different engineering departments on the five design-based learning characteristics. We report consequently about the results and findings of the quantitative research. Finally, we elaborate our conclusions based on the results and summarize the implications for instructional design of design-based learning environments.

2 Theoretical framework

Design-based learning (DBL) is an educational approach which centers around the processes of inquiry and reasoning towards generating innovative artifacts, systems and solutions. The pedagogy and didactical insights of DBL are built up on problem-based learning (PBL) (Barrows 1985), where the problems represent design assignments. Evidences to consider DBL a promising instructional method to enhance the learning of the natural sciences in secondary education are to be found in approaches such as Learning by Design (LBD) and Design-based Science (DBS). These approaches are used in secondary science education and present positive results in enhancing reasoning and team work skills. In the context of higher engineering education, it is little known of the characteristics of DBL. We identify four dimensions relevant for organizing the characteristics of DBL in higher engineering education: the project characteristics, the role of the teacher, the assessment methods, the social context and the design elements.

To find out the characteristics of our dimensions, we have conducted a literature review in fifty empirical studies in the context of higher engineering education (Gómez *et al.,* published online). The selection of the articles we followed a criteria: all fifty 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 selection was based on a series of key terms in relation to higher engineering educational approaches and related to DBL practices, such as Problem-Based Learning, Project-Based Learning, Design Education, Scenario Assignments or Case-Based Studies; and finally, the time span of the publications, which was limited to 2000-2010. The result of the selection of articles based on the four criteria has constituted our database of 50 articles representing the literature on DBL.

With regards to the characteristics of the projects the articles referred to assignments conducted in open-ended (Behrens *et al.* 2010; Chinowsky *et al.* 2006; Roberts 2001; Hirsch *et al.* 2001; Denayer *et al.* 2003; Wood *et al.* 2005; Mese 2006; Maase 2008; Nonclercq *et al.* 2010), authentic (Linge *et al.* 2006; Mckenna *et al.* 2006; Massey *et al.* 2006), hands-on (Wood *et al.* 2005; Lee *et al.* 2010), real-life (Macías-Guarasa *et al.* 2006; Mckenna et al. 2006; van Til et al. 2009), and multidisciplinary (Macías-Guarasa *et al.* 2006; Nonclercq *et al.* 2010; Selfridge *et al.* 2007; Kundu and Fowler 2009; Shyr 2009) design projects.

Regarding the role of the teacher, examples referred to coaching and supervision of the students in which the teacher scaffolds the process as stepping stones for the students in solution generation, or by asking questions during different project implementation phases and in inquiring and troubleshooting (Chang et al. 2008; Etkina et al. 2006; Roberts 2001; van Til 2009).

Concerning assessment we find in the literature examples of individual assessment, formative feedback tool to monitor progress (Baley 2006; Behrens *et al.* 2010; Chang *et al.* 2008; Cheville *et al.* 2005; Lee *et al.* 2010; Masse 2008; Mese 2006; Stiver 2010) but also summative assessment of products and processes. Other examples include self- but also peer-to-peer assessment are oftentimes used assessment methods to enhance both individual and group progress (Cheville et al. 2005, Chang et al. 2008, Shyr 2009).

With regards to the social context a **number of studies emphasize the link of student's presentations within** industry stakeholders to develop technical and engineering domain terminology (Denayer et al. 2003; Linge and Parsons 2006; Massey et al. 2006; Mckenna *et al.* 2006; Shyr 2009). Other examples of the social context are communication by having students play roles as, for instance, engineers and customers (Martínez Monés *et al.* 2005; Nonclercq *et al.* 2010); peer-to-peer activities (Behrens *et al.* 2010; Mckenna *et al.* 2006; Cheville *et al.* 2005; and Wood *et al.* 2005; Zhan *et al.* 2010) or motivation by holding competitions (Kundu and Fowler 2009; Massey *et al.* 2006; Nonclercq et al. 2010; Roberts 2001;Wood et al. 2005).

In terms of design elements we have adopted the classification of Mehalik and Schunn (2006). This classification includes design activities which take place in the field of software engineering and working environments and may be helpful to identify whether and how design elements common to professional engineering design play a role in DBL in higher engineering education.

3 Research questions

Our interest in this comparative study is to explore whether the design-based learning characteristics are also **identified by the teachers'** in their educational and project-related practices. To further study empirically the characteristics of design-based learning the researchers have formulated two research questions:

1. What are the perceptions of the teachers at the engineering departments on the five DBL dimensions?
2. Are these dimensions also identified by other engineering departments in other countries?

4 Method and design of the study

To carry out this study we have selected three technical universities around the world, e.g. Eindhoven University of Technology (TU/e) in The Netherlands, University of Minho in Portugal, and Pontifical Catholic University of Sao Paulo (PUC/SP), in Brazil. These technical universities have used problem-based/project-based and design-based learning as instructional approaches in engineering study programs. We take the experience of these universities as a case study to find out whether the DBL characteristics are recognized and what the teachers' perceptions are on DBL features.

4.1 Research setting

DBL was introduced in 1997 at the Eindhoven University of Technology. This model was adopted from the PBL model from Maastricht University (Gijselaers 1996) and from the Aalborg University model of problem-oriented, project-based learning (Kolmos 2002). DBL had been developed as the university's central educational concept and was built upon discussions with directors of studies from the different departments (Wijnen 2000) and from the inspiration of good practices in from the project work model of Aalborg and Roskilde universities in Denmark (Perrenet and Pleijers 2000). 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 *et al.* 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 2000). DBL has been implemented for over the past 10 years but it is a concept that still needs further development.

At the University of Minho, most of the engineering degree programmes adapted to the Bologna requirements have included interdisciplinary projects. The first degree programme to do this, was the Integrated Master´s Degree in Industrial Engineering and Management. PLE was started in 2004/2005 with the first edition of an interdisciplinary first year project in which students worked according to an adapted version of the project-led engineering education method of Powell and Weenk (2003). Four courses of the second semester of the first year were transformed into one project that students had to work on during the whole semester. In the following years, the project took place at the first semester of the first year. The shift from traditional teacher-centred learning to a project approach was made for several reasons. A project approach to learning, in the first place, is student-centred and engages the learners in their learning process. It also means a shift away from fragmented disciplinary teaching and learning and creates a context for interdisciplinary learning experiences. Another motive for a change to project-based learning was the closer contact with the professional reality of the future engineers. Students, especially those who just started their degree, and are mainly involved in basic science courses, get a more balanced idea about the problems that engineers work on. The development of professional skills like leadership, working in groups, presentation and communication is another important reason for the implementation of project-based learning. The motives at the other degree programmes are similar, although the model may be different.

The Biomedical Engineering program at PUC-SP began in 2009, fully implemented on Problem Based Learning (PBL) strategy. In the program's project the curriculum organization is no longer by subjects but pass to prioritize a multi-disciplinary organization in modules, allowing inter and transdisciplinarity. The program structure includes five different thematic areas, including activities for biomedical engineers, as suggested by the Brazilian Society of Biomedical Engineering (SBEB 2007), being treated in a progressive manner, complementary and integrated over the duration of the program (five years). The thematic areas are structured around core modules and associated modules, including theoretical and practical contents related to each thematic areas and complementary contents such as communication skills and expression, administration, law, entrepreneurship, bioethics, inclusion and social responsibility and sustainability. The problems that are presented along each thematic area give priority to the technical, ethical and humanist aspects, the most important situations, of higher prevalence and with greater potential for intervention. A challenge faced in the implementation of the process relates to assessment methods. The continuous assessment tools are used and reviewed by the program coordinator and discussed with the program's collegiate so that their interpretations can be used to improve the program and overcome the challenges that stand constantly in this methodology. The aim of such assessments and analyses is to allow continued discussion on all aspects that guide the new curriculum and allow its frequent rethinking. The measurement of the results of the management is done at various levels of evaluation, including the evaluations of the students, contents, format and organization of the program. Another level covers the evaluation of the program's project implementation and the evaluation of the program coordinator besides the support that the dean of the faculty offers.

4.2 Survey

For the purpose of this study we have selected different departments in the three universities. At Eindhoven University of Technology we have included four engineering departments, e.g. Mechanical Engineering (ME), Electrical Engineering (EE), Architecture, Building and Planning (Arch.), and Industrial Design (ID). The rationale behind was to collect the perceptions and the practices of two creative-type of engineering undergraduate studies, e.g. Industrial Design and Architecture Building and Planning, and two technical-oriented studies, Mechanical Engineering and Electrical Engineering.

At the University of Minho we selected the following departments Biomedical Eng., Mechanical Eng., Electrical Eng., Polymers, Maths., Production, Chemistry and Information Systems.

The engineering study program from PUC/SP is Biomedical Engineering (EngBio) department.

4.2.1 Sampling

At the Eindhoven University of Technology we have selected the second year of the undergraduate program for this study because it was part of a larger doctoral dissertation research. Reasons for the selection of the second year both teachers and students were that first year students are less familiar with the educational context of engineering design assignments in teams at undergraduate level; and that projects in capstone courses are carried out sometimes individually in some departments. Subsequently, we selected a population of second year teachers and students who are already familiar with the pedagogical concept of design-based learning and who have already gained some experience in previous teamwork projects. Likewise, we approached teachers who have designed, coached and assessed students in second year projects. For the **purpose of this comparative study, we will only focus on teachers' perceptions.** The data presented in this **study represents only the teachers' perceptions. Data related to students'** perceptions have been consequently removed. Table 1 presents the sample size of teachers per department who participated in the survey in the TU/e.

Table 1 Sample size of teachers per department who participated in the survey in the TU/e

Population Teachers	Frequency
ME	12
EE	11
Arch.	11
ID	18
	Total 52

At the University of Minho and PUC/SP we have selected all teachers from all integrated master´s degree because our interest was to gather information on whether the DBL characteristics are recognized in engineering studies. We are also aware that the application of the DBL dimensions, and more specifically, project characteristics, could be sometimes limited due to the scope of some projects in some disciplines. Table 2 and Table 3 summarizes the sampling at these universities. The questionnaire used at the Eindhoven University of Technology has been readjusted and more items were added (N=48) for the purpose of this study at the University of Minho and PUC/SP.

Table 2. Sample size of teachers per department who participated in the survey at University of Minho

Population Teachers	Frequency
Mechanical Eng.	5
Electrical Eng.	2
Polymers	3
Maths	2
Production	6
Chemistry	1
Information Systems	2
	Total 21

Table 3. Sample size of teachers per department who participated in the survey at PUC/SP

Population Teachers	Frequency
Biomedical Eng.	7
	Total 7

4.2.2 Instruments

The instrument consisted of a structured Likert-type questionnaire with a 1 to 5 scale containing N=40 items. This questionnaire was designed to collect perceptions on the disagreement or agreement on statements related to the five dimensions and their characteristics of design-based learning encountered in the empirical studies. This questionnaire was developed in the framework of a doctoral dissertation research to gather the perceptions of teachers and students about DBL.

Prior to sending it to the selected target group, the questionnaire was validated with two teachers, two tutors and two students. We adjusted the questions according to their suggestions for improvement. The list of items was constructed from a literature review of 50 empirical studies on engineering education (Gómez et al., 2011) in which we identified the five dimensions and characteristics of design-based learning which are part of our DBL theoretical framework (Gómez *et al.,* published online). Reliability test of the questionnaire instrument applied in the research study at the Eindhoven University of Technology (Gómez et al; to be submitted shortly to journal) showed that two dimensions, e.g. assessment and social context, are unreliable, due to a low number of items regarding these two dimensions in the questionnaire. The correlations between the five dimensions, however, are substantial ranging from .33 to .68 (Pearson correlation) suggesting that the five characteristics are connected.

Table 4. Reliability per scale according to teachers/tutors' and students' perceptions and example of items*

Dimensions	α	k	Example of questionnaire items
Project charac.	.78	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 analyse results, to apply newly-gained knowledge, to try-out)"
Social context	.35	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	.83	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	.29	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	.80	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)"

*The results and examples of questions in this questionnaire are developed in the framework of Ph.D. research.

Results of the reliability test lead the research team at Minho University and PUC/SP university to further adjust the instrument. We have therefore added four more items in the dimensions assessment and in the social context (N=48).

Table 5. Reliability results test show that all dimensions are reliable in the survey conducted in these two universities

Dimensions	α
Project characteristics	.64
Social Context	.74
Teacher's role	.80
Assessment	.76
Design elements	.88

5 Results

5.1 Results and findings of the survey

Results of the Eindhoven University of Technology reveal that the average of mean scores of the four departments varies just above of the average 3 in the Likert scale. There are differences in the means between all departments and Industrial Design in characteristics such as projects' characteristics, the teacher's role, the assessment, and the design elements. The results suggest that Industrial Design projects are closer to the design-based learning characteristics and practices of the state-of-the-art literature.

We have conducted an ANOVA to know whether there are significant differences between groups on the some characteristic. Results of analysis of ANOVA confirm the 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 in assessment. Subsequently, we have conducted a Post-Hoc analysis to identify the significant differences among departments. Results of the Post-Hoc analysis reveal that there are significant differences between ID and the rest of the departments regarding the project characteristics and the design elements. With regards to the teachers' role significant differences are encountered between ID and ME and EE. (Gómez et al., to be submitted shortly to journal).

Table 6. Means and standard deviation at the Eindhoven University of Technology (The Netherlands), University of Minho (Portugal) and PUC/SP (Brazil)

Dimensions TU/e (The Netherlands)	Mean	SD	Dimensions Un. Minho (Portugal)	Mean	St. Dev.	Dimensions PUC/SP (Brazil)	Mean	St. Dev.
Project charact.	* 3,6	,64	Project charact.	3.7	.44	Project charact.	3.8	4.7
Social context	3,5	,58	Social Context	4.0	.44	Social Context	3.9	.60
Teacher	*3,9	,54	Teacher's role	3.8	.37	Teacher's role	4.1	.67
Assessment	*3.9	.51	Assessment	3.9	.58	Assessment	3.9	.62
Design elements	*3,8	,48	Design elements	3.7	.46	Design elements	3.8	.70

The mean difference is significant at the .05 level

Studying results of the means and standards of University of Minho (Portugal) we perceive that the average of mean score is just above of the average 3 in the Likert scale. Results of ANOVA test conducted in Univ. of Minho and Univ. of PUC/SP (Brazil) shows no significant differences among the departments in these two universities regarding the five DBL dimensions.

6 Conclusion

The purpose of this comparative study was to investigate teacher's perceptions on the design-based learning characteristics. Furthermore, our interest focused on exploring empirically whether the design-based learning dimensions of our theoretical framework, e.g. the project characteristics, the social context, the teachers' role, the assessment, and the design elements, are identified by teachers' at technical universities all over around the world.

Our findings indicate that teachers identify the DBL dimensions. Although teachers at all departments identify the design-based learning characteristics significant differences are however encounter at the engineering departments at the Eindhoven University of Technology and more specifically in the dimensions project characteristics, the role of the teacher, and in the design elements.

Results at University of Minho and PUC/SP reveal that the DBL characteristics are recognized by the teachers at the engineering study programs at these universities.

We can conclude, therefore, that the educational design-based learning model at these universities resembles the current trends in engineering design education as found in the state-of-the-art literature. Moreover, as the data gathered in this comparative study are **drawn from teachers' perceptions we can interpret**, carefully, that the design-based learning characteristics are part of the educational practices of the engineering study programs at different technical universities, and that design activities conducted by students in project settings represent authentic engineering scenarios. We are aware that this case is a comparative study and that further research on the nature of the projects needs to be examined against the dimensions of the DBL framework. Based on the results, however, we can cautiously affirm that DBL characteristics are encountered in the PLE practices at University of Minho and the PBL practices at PUC/SP.

The perceptions of the teachers could be also representative in other engineering study programs. We imply, therefore, that the results of this case may be of interest for other technical universities and that the results of this study can serve as a mechanism to review the design projects.

It is noteworthy to mention that although the sampling of our research study was small in some universities, such as in PUC/SP (Brazil), and that the differences in the nature and character of the educational project models, this instrument has served to highlight the characteristics embedded in the projects, and to illustrate that the projects include international and state-of-the-art features.

The results in this study provide examples and opportunities for intervention for other universities to include the dimensions in the educational project activities. To prepare students for engineering practices, the instructional design of projects and the learning activities are to situate learning in contexts in which students perform engineering authentic professional tasks, including open-ended problem-solving scenarios in which students learn to inquiry and reason design solutions.

The development of instructional design of design-based learning projects requires further empirical research together with teachers. However, these interventions need to be aligned with curriculum outcomes and academic requirements.

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