Developing engineering solutions through design-based learning projects: an electrical engineering example

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1. INTRODUCTION

Design-based learning was introduced in 1997 at the Eindhoven University of Technology (the Netherlands) with *the ultimate goal is to educate engineers who are able to provide society with new and better technical systems and products* [1]. DBL was integrated into the engineering programs to have students gather and apply theoretical knowledge. DBL is grounded in the educational principles of Problem-Based Learning (PBL).

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According to previous research studies [2-3], we defined DBL dimensions as project characteristics, design elements, the teacher's role, assessment and social context. These five dimensions are critical in the implementation of design-based learning to facilitate students' learning process. As a pedagogy, DBL has not received attention comprehensively in engineering disciplines and the benefits of this approach to teach students to gather domain knowledge and apply it iteratively in the design process are still to be investigated.

In this paper, we provide a general framework of the theoretical insights of DBL. Next, we present shortly the results of previous studies regarding teachers' and students' perceptions on DBL, the analysis of the projects, and on teachers' and supervisors' actions in supervising DBL groups. Following, we provide a snapshot of the set-up of the professionalization sessions with DBL teachers to redesign the projects. Subsequently, we present the educational method, the Experiential Learning Cycle (ELC), that we use for the professional development program. Finally, we present the results of the redesign of a DBL project in the context of electrical engineering domain.

2. THEORETICAL FRAMEWORK OF DESIGN-BASED LEARNING

Design processes are intrinsically linked to engineering practices and to the inquiry nature of proposing solutions to users' and industry problems. This design process implies acquiring gradually about the nature of the design problem and the best routes to take towards a design product [4-5]. Each step of the design process opens up a new experiential situation looking at the problem from different perspectives, selecting alternatives and experimenting with the results and testing in iterations to propose solutions to ill-defined multidisciplinary design problems.

To facilitate the learning process we focus on a theoretical framework consisting of five dimensions: the project characteristics, the design elements, the role of the teacher, assessment and the social context.

2.1. Project characteristics

Studies reporting about workplace engineering practices highlight that solving design problems 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 [6-7]. Projects are therefore authentic, multidisciplinary and open-ended design assignments in which students apply hands-on skills in conducting research on system features, redesigning iteratively the functionality of the system or product, and testing the prototype [8-9-10].

2.2. The design activities

We have adopted taxonomy of fifteen design elements drawn on empirical results of a meta-analysis [11]. This taxonomy is based on the most frequent design activities applied in software engineering design tasks in industry contexts. Some of these design elements include for example: explore graphic representation, use interactive/iterative design methodology, validate assumptions and constraints, explore user perspective, explore engineering facts, explore issues of measurement, and conduct failure analysis.

2.3. The role of the teacher

The teacher, as a tutor or instructor, has a prominent role in facilitating the learning process, but also in coaching students on technical designs, process and self-development. The teacher guides the students and scaffolds the process by asking questions or by stimulating students to explore alternatives and reflect upon the process. In addition, the teacher plays an authentic role acting as a client, providing formative feedback on students' learning processes on their own design practices through iterative prototyping by testing viability of plans and communicating ideas [12-13].

2.4. The assessment method

There are some evidences referring to formative feedback which, as an assessment tool, becomes a feasible vehicle to increase motivation and ultimately, to support achievement also in individual learning. Examples of formative and summative assessment encountered in the literature are rubrics, reports, presentations and demonstrations, quizzes, prototypes and systems, etc. [14-15]

2.5. The social context

Drawing on empirical studies on collaborative learning environments, students work actively communicating and reflecting with their peers, but also presenting technical design to panels of experts and industry stakeholders. In addition, competitions are encountered as examples of motivating collaborative activities in the projects [16-17].

3. QUANTITATIVE AND QUALITATIVE STUDY ON DBL

We conducted a quantitative and qualitative study in a previous research in four engineering departments, e.g. Mechanical Engineering (ME), Electrical Engineering (EE), Built Environment (BE), and Industrial Design (ID) [18]. The purpose was to gather the teachers' and students' perceptions on the five DBL characteristics. In addition, we conducted a qualitative study to analyze three DBL second year bachelor project in each of these departments.

3.1. Research method

We designed a 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 comprised items from our literature review on DBL. We tested first the questionnaire with two teachers, two tutors, and two students and we adjusted the questions following the feedback.

In addition, we reviewed the DBL projects at these departments following a protocol consisting of characteristics of DBL projects from the literature. The objective was to gain an overview on whether the projects meet the DBL characteristics from the international literature review. To review the projects we collected project descriptions students receive from teachers, mid-term and final reports, examples of peer-review assessment forms, students' presentations, posters, etc. By reviewing different materials we aimed at ensuring a valid database construction for our analysis.

4. FINDINGS

Our findings indicate that there are significant 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, showing the DBL model at the Industrial Design program the DBL characteristics from our framework. We are cautious, however, in making further statements about these differences in relation to the dimensions of *assessment* and *social context*, since these two dimensions were less reliable.

Results of the analysis of the projects indicate that not all DBL dimensions are embedded in the projects throughout all departments according to our framework. We find differences in some aspects of project characteristics, the role of the teacher, the design elements and assessment. These differences are encountered mainly in Mechanical Engineering and Electrical Engineering when compared to the practices in Built Environment and Industrial Design. Finally, with regard to 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.

5. RESEARCH ON TEACHERS' ROLES IN SUPERVISING STUDENTS

In another research study, we interviewed teachers and supervisors, and conducted observations on supervisors' actions in supervising DBL students and in facilitating learning processes. We conducted the interviews and observations at the ME and EE departments as it was concluded from previous research studies that there was a need for intervention. In order to observe the supervisors we developed a framework of actions from our literature review. In addition, we constructed a list of items for the interview to further understand how facilitation and supervision of students take place in the groups.

Our first conclusion is that the supervision actions of the ME teachers and tutors do not represent comprehensibly the actions described in the literature on design-based learning. Furthermore, although *formulates questions* is a common practice among teachers and tutors, these questions do not always aim at, for instance, having students to articulate a design, or to encourage search for alternatives.

The teachers' actions at the EE department represent more frequently the actions described in the literature on design-based learning practices, although these take place at a moderate or low level. Results indicate as well differences in supervising actions in the two second-year DBL projects due to the set-up of intermediate formative feedback moments.

6. THE PROFESSIONAL DEVELOPMENT OF DBL TEACHERS

Following the findings of our previous research studies, we conducted an intervention aiming at the professionalization of the DBL teachers at the ME and EE departments. The purpose was to work together with the teachers in the redesign of the DBL projects. We employed the Experiential Learning Cycle (ELC) (Kolb 1984) as educational method during the professionalization program (*Fig. 1*)

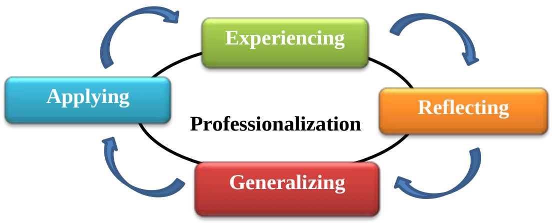

Fig. 1. Adapted from The Experiential Learning Cycle, David Kolb (1984)

Our intervention focused on a professionalization trajectory consisting of a series of meetings with 6 teachers from the ME and 7 teachers from the EE departments. In addition, we also trained the supervisors at the two departments. The participants were exposed to DBL examples from the literature. For the purpose of this paper, we provide in *Table 1.* only one example of the redesign of a project, the EE 'Power conversion' project.

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Table 1. Examples of redesign EE project 'Power conversion'

DBL dimens.	DBL charact.	Examples DBL charact. integrated in 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.
	Hands-on	Students work in 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 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	Supervision on: - Technical design; - Process; - Self-development	Teacher acts as the client, and domain teachers are the experts. Supervision on: - on technical design: reports; demonstrations; presentations; - process: progress of planning; regular short presentations within the group; - self-development: regular feedback with rubrics
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 the individual student performance
	Summative	- Demonstration (15% of final grade); - Final reports (40% of final grade); - Grade: motivation each student to the responsible lecturer at the end project (15% of final grade); - Peer-review: 15% of final grade.
Social context	Competitions Presentations Peer-to-peer	Competitions: After final demonstration a prize is awarded to best team on: performance's demonstration, functionality of designed system, the accuracy of final specification, etc.; Presentations with (fictitious) industry representative, i.e. (fictitious) client.

7.RESULTS OF THE PROFESSIONALIZATION PROGRAM

7.1.Verification of results

A second researcher verified our analysis of the redesign of the projects. Results of the inter-reliable agreement [19] indicate moderate to good level of agreement (Cohen's Kappa). Regarding the ME project the level of agreement is .70 (good), and in the EE project is .54 (moderate).

7.2. Results of analysis of the redesign of the projects

Results show that the projects comprise in general the DBL characteristics from the theoretical framework. Furthermore, there are similarities among projects and departments regarding *project characteristics*, such as *authenticity, hands-on,* and*, multidisciplinary; the design elements*, *assessment*, and the *social context*. The differences encountered between the projects and the departments, however, are to be found mainly in *project characteristics*, and more specifically, in the degree of *open-endedness*. Furthermore, differences are also encountered, in a moderate manner, in *the role of the teacher*.

7.3.Conclusions

The degree of *open-endedness* differs between projects and departments. Open-ended is linked to the educational purposes, namely, to the learning lines, the learning outcomes of the projects within the bachelor years and the nature of the curriculum. Further, multidisciplinary and authenticity still remain a challenge.

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