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REVIEW

# Exploring students' engineering designs through open-ended assignments

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**ABSTRACT**

This paper aims at presenting the experience of the Power Conversion project in teaching students to design a proof-of-principle contactless energy transfer system for the charging of electrical vehicles. The Power Conversion is a second-year electrical engineering (EE) project in which students are to gather and apply EE knowledge to design and test a system. This system is to work with power level and operates independent from an electricity grid. The instructional method used in this project is design-based learning (DBL). As an educational approach, DBL is to support students to gather and apply knowledge in *open-ended* assignments. The set-up of the project has gone through different modifications and iterations in three consecutive years regarding the organisation and supervision of the students. We have analysed the students' design products in the past three academic years in order to evaluate whether the project set-up and supervision have influenced students' designs. Results indicate that the *open-ended* character of the project has a positive influence on the designs especially regarding the criteria on efficiency, Maximum Power Point Tracking algorithm and power tracking.

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Design-based learning; engineering education; active learning; systems design

## 1. Introduction

The Power Conversion project has gone through different transitions along the past three academic years to accommodate curriculum demands to project outcomes. The Power Conversion is a second-year electrical engineering (EE) bachelor project taught at the Eindhoven University of Technology (TU/e), the Netherlands. The project aims to teach students to work in teams and to design and operate a generation, distribution and contactless power transfer system for electrical cars. The instructional design approach used to teach students to gather and apply knowledge is design-based learning (DBL). We have monitored the implementation of this project in three consecutive academic years and analysed the students' design products. The purpose of this study is to evaluate whether the instructional design and project set-up together with the supervision method have influenced students' designs and products according to the different modifications of the project.

DBL has been the educational method for over the past 17 years at the Eindhoven University of Technology (TU/e) in the Netherlands (Wijnen 2000). In its initial conceptual form by which it was defined, DBL was meant to be an educational approach specific for technical studies. It was therefore described as

> a concept of technical university education, in which students work co-operatively and actively on multidisciplinary design tasks, with the purpose of gaining qualifications as creative professionals capable of integrating all relevant aspects of education, in order to analyze existing technical systems, to assess their quality, functionality and

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cost price and with the purpose of designing new products and systems with increased performance. (Wijnen 2000, 5)

In order to give form to this approach, DBL was defined the following six features: professionalisation, activation, co-operation, creativity, integration, and multidisciplinary (Wijnen 2000). The motivation to introduce DBL at the TU/e technical study programmes was based on a number of considerations. A first initiative focused on the need to improve the quality of education and adapt it to respond to the demands of the industry and society to innovate technical systems. Furthermore, it was necessary to increase the attractiveness of studies for new students. In order to achieve that goal, the curricula of the study programmes were upgraded towards a more competence orientation and to pay attention to skills development.

In a recent investigation (Gómez Puente, van Eijck, and Jochems 2013), a theoretical framework was drawn following a literature review of more than 50 engineering education projects. The theoretical framework defines the characteristics of the design engineering projects in five categories, for example, project characteristics, the role of the teacher, the assessment, the social context, and the design elements included in the design projects. Regarding the characteristics of the projects, these are open-ended, authentic, hands-on and multidisciplinary. The role of the teacher is defined as to the one who facilitates the learning process by coaching on the task, the process and on the self-development of the students. Regarding assessment this is to assess students both formative and summative on content and process. The social context is grounded in collaborative learning principles imbedded in peer-to-peer communication teamwork and design elements. Finally, the design elements follow the classification of design activities implemented in the industry to design artefacts and systems (Mehalik and Schunn 2006).

## 2. Active learning approaches in engineering education

DBL can be considered an active learning method as it shares basic principles with this approach. Active learning is commonly defined as an educational method that engages students in the learning process. The educational considerations lies on the involvement of the students in meaningful learning activities (Prince 2004; Bell and Kahrhoff 2006) in order to promote:

- learning stimulated by inquiry, that is, driven by questions or problems;
- a process of seeking knowledge and new understanding;
- a learning-centred approach in which the role of the teacher is to act as a facilitator;
- a move to self-directed learning. By doing so, students take increasing responsibility for their learning while developing skills in self-reflection; and
- an active approach to teaching and learning.

Active learning is deeply rooted in constructivist theories (Case and Light 2011), learner-centred (Fowler, Armarego, and Allen 2001) and collaborative learning (Mills and Treagust 2003). Following these educational principles, learning takes place in a group-based process. The instructional methods promote that students solve problems interacting with each other, practicing interpersonal skills, and regular self-assessment of team functioning (Prince and Felder 2006). Furthermore, numerous studies have demonstrated the added value of active learning methods that supports students gaining content knowledge, reaching conceptual understanding, increasing problem-solving ability, and developing metacognitive skills, communication and teamwork skills, (Thomas 2000; Case and Light 2011). Problem-based learning and project-based learning (PBL) are the most common active learning methods in engineering education (Thomas 2000).

Within this framework of active learning methods, DBL arises as an educational approach by which students gather and apply knowledge while designing creative and innovative practical solutions (Doppelt 2009; Gómez Puente, van Eijck, and Jochems 2014a, 2014b). In doing so, DBL projects are embedded in the curricula in order to support students to achieve academic outcomes and industry expectations. Within the current engineering education curricula demands, DBL projects encourage students to develop and practice twenty-first century skills, as students are involved in assignments in which they address hands-on, problem solving, collaborative teamwork and innovative creative designs representing the real-world (Dym et al. 2005; Atman et al. 2007; Sheppard et al. 2008; Lawson and Dorst, 2009; Froyd, Wankat, and Smith 2012).

## 3. The theoretical framework of design-based learning

DBL is an educational approach that has been mostly used in the context of secondary education to teach science curriculum (Apedoe et al. 2008). Grounded in activating methods such as learning by design (Kolodner 2002) and design-based science (Fortus et al. 2004), DBL has served to help students acquire problem-solving and analytical skills common to science classes while they work on design assignments.

In the context of higher education; however, DBL is imbedded in the educational principles of problem-based learning (PBL) as a way to develop inquiry skills and integrate theoretical knowledge by solving ill-defined problems (De Graaff and Kolmos 2003). Problem-based learning as a learner-centred approach 'empowers students to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem' (Savery 2015, 5). DBL shares with PBL educational insights. One of those is that as the starting point for the DBL design assignments are ill-defined and open-ended often interdisciplinary problems.

Distinctive elements of the DBL approach emphasise the project planning process embedded in engineering assignments, in which students are provided with specifications for a desired end product (Savery 2015, 5). In addition, it enhances applying knowledge of the specific engineering domain through student involvement in the design activities of artefacts, systems, or solutions. The added value of this approach is that by integrating design into science education, DBL provides the perfect vehicle for students to actively investigate and construct innovative design solutions while working in dynamic learning environments (Mehalik and Schunn 2006; Mehalik, Doppelt, and Schunn 2008). Furthermore, in this type of assignments, the teachers play a role as instructors or coaches rather than as tutors as it is common in problem-based assignments.

There is extensive literature in different engineering disciplines illustrating the educational added value of design-oriented and project-based on students' gains and more specifically in the field of EE (Guzelgoz and Arslan 2009; Hosseinzadeh and Reza Hesamzadeh 2012; Aliakbarian et al. 2014; Zhang, Thorp Hansen, and Andersen 2015). These practices highlight the application of PBL to courses including educational principles of starting with an ill-structured problem or assignment, in which students collaboratively work, for instance, on modelling power systems, implementing various power converter applications, or on how to tackle manpower requirements of a dynamic and ever-changing telecommunications and electromagnetics industry demands. In these design projects, learning is integrated from a range of disciplines as subjects which are relevant to solve societal and technological problems. In order to teach students the necessary skills, the power conversion design project has readjusted the instructional design approach from the structured type of assignment to a more ill-defined and open-ended design project. This DBL project focuses on having students to gather and apply knowledge in the design of a contactless energy transfer system for the charging of electrical vehicles. The DBL approach lies on inquiry and reasoning design tasks in which students select and evaluate product criteria, explore different alternatives and generate strategies to produce a system or prototype, and based on arguments and sound interpretation of results create a new iteration in the design. Interesting effects are shown in students' designs as a consequence of the changes in the educational approach.

### 3.1. Research question

Although DBL has been implemented over the past 18 years at the TU/e little research has been done about the effects of the DBL features on the students. Likewise, supervision methods to monitor both students' content development and process have been modified along the years.

We have monitored the Power Conversion project in a sequence of years. Our interest in studying and following this project in three consecutive years was to understand how DBL characteristics such as *open-ended* works in students' design projects. Furthermore, we also wanted to investigate whether new approaches in supervision of students, that is, rubrics, has also had an impact on students' actions.

### 3.2. Research methodology

The methodology we have followed to study whether *open-ended* type of project characteristics and supervision have had effects on students consists of the following approach:

- Development of quality criteria for product's design, that is, the transferred power (W) of the system, the efficiency, the implementation of a maximum power point tracking algorithm (MPPT), and the load detection. The criteria are used to monitor the process by the teachers who are the experts in each specialisation and by the project leaders. This criteria have been used along the three consecutive years to monitor and evaluate the quality of the students' products against efficiency in the design generated. The criteria are linked to the learning outcomes of the project and the assessment form, that is, constructive alignment (Biggs 2003).
- Regarding the monitoring of students' progress, we fine-tuned the supervision methods and developed rubrics as a supervision, feedback and assessment instrument. The criteria are both based on both content, that is, understanding own specialisation, understanding overall system, research skills, quality of technical work; and progress, such as motivation, communication, and planning.

We collected the information on quality of designs by registering the students groups' product performance during the final demonstrations according to the criteria. Tables 4–8 provide a broad overview of the group's performance in the three consecutive academic years. In Table 1, we provide an overview of the population for these studies.

Regarding the students' performance, we collected the data by registering students' scores according to the criteria in the rubrics (see Figure 6).

Regarding the population, the number of students is different per year as the students' registration in the power conversion course varies. The target group therefore consists of second-year students, both male and female. The number of students is given in Table 1.

## 4. Power conversion: a design-based learning project

In the project, a proof-of-principle contactless energy transfer system for the charging of electrical vehicles is designed, tested, and demonstrated. The system is scaled with respect to power level and operates independent from the electricity grid. The input of the system is a direct current

**Table 1.** Overview of number of students distributed in the three consecutive years.

| Year | Number of students |
|---|---|
| 2011/2012 | $N = 37$ |
| 2012/2013 | $N = 50$ |
| 2013/2014 | $N = 50$ |

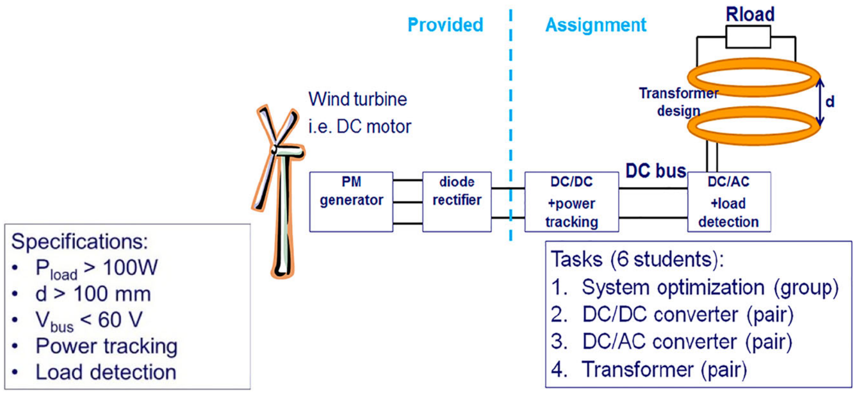


**Figure 1.** Organisation of the project with specifications.

(DC) motor which represents the wind turbine. It can be operated in two modes: speed controlled and wind turbine operation. The DC motor drives a brushless permanent magnet generator (Huebner Giessen DSG P 71.07-8). The output of the generator is rectified by a diode rectifier bridge and, consequently, the generator behaves as a variable DC voltage source. The output power from the diode rectifier has to be transferred without any contact to a load resistor which represents the battery of an electric car. The battery management system and battery charging circuits have been omitted in the project for simplicity. The specification of the contactless energy transfer systems which is given to the students is shown in Figure 1.

In this project, students are to act as professional engineers in teams and design iteratively a contactless power delivery system by modelling and constructing electric circuits with preliminary defined component values with the possibility of using as well certain assumptions. The rationale behind is to have students to validate the model and initial assumptions by measurements and simulations.

According to the DBL, instructional approach in engineering design projects, engineering students are to gather and apply knowledge while working on the design of artefacts, systems and innovative solutions in project settings. The characteristics of the projects (i.e. open-ended, authenticity, hands-on, and multidisciplinary), the design elements (Mehalik and Schunn 2006), and the role of the teacher as a coach and facilitator, are key components within the DBL educational approach that foster students' design problem-solving process (Gómez Puente, van Eijck and Jochems 2014a).

The main purpose within this design-based learning project is to stimulate students to go through a process of design in order to learn concepts and apply knowledge to generate new ideas (Kolodner 2002; Apedoe et al. 2008). Design-based learning, as an educational approach, is used in the Power Conversion project to teach how local sustainable energy sources and smart grids work in order to not supply the grid at a fixed voltage level and frequency. The basic principle is to understand how power converters are integrated to (inter) connect and stabilise the grid.

The Power Conversion project is a second-year EE bachelor project. The EE students investigate a power conversion and distribution system as applied to electric vehicle chargers in a DBL project. This project is integrated within the course Electro-mechanics. This course introduces the main principles of electro-mechanical energy conversion. It discusses the governing laws and the steady-state characteristics of the three most important classes of electrical machines:

- governing laws and magnetic circuits,
- DC-machines,
- induction machines, and
- synchronous machines.

### 4.1. Structure of the course and project approach

The course consists of a limited number of lectures, instructions and lab work, and the design project. Lectures are devoted to present the theory on magnetic equivalent circuits, energy and force, DC-machine construction, DC motor circuit model, field winding arrangements, armature reaction, transformer model of induction machines, synchronous machine construction, rotor field and electromotive force (EMF), isolated and grid connected synchronous machines. In addition, students apply the theoretical insights provided in the lectures in the instructions. Furthermore, during the lab assignments, students carry out measurements on coupled machine sets and analyse torque, speed, and power flows. The practical application of the theory in producing prototype designs, systems, and models, remains in the design project part of this courses.

The Power Conversion design project focuses on having students to analyse a DC machine and a PM synchronous so that they can apply this in the design while operating with speed and torque control motor-generator sets. The *open-ended* character of the project requires students to calculate losses in the different parts of the machine sets (windings, bearings, and iron). The project set-up therefore is to stimulate critically thinking as the students need to make choices for the further simulation of machines in the SimPowerSystems toolbox of Matlab. Finally, this approach encourages the teams to compare theoretical and measurement results. In order to produce a design and integrate the key content elements of the project, students work active in teams following the DBL approach.

Students, divided in teams of up to 8 students, carry out a brainstorming session at the beginning of the project in order to make a more definition on the design project. In addition, the division of tasks among the team members is made upon which students choose an engineering role, such as metal-oxide semiconductor field effect transistor (MOSFET) designer, and electrical engineer technical expert. Within each role, students perform the design tasks by searching concepts in the literature, conducting calculations, doing tests in the labs and finally, based on results, generating iteratively a new design and prototype. Meanwhile, students present interim results through demonstrations, group presentations and reports upon which they received formative feedback from the teachers who are the experts in the different content fields involved in the project. The role of the project leaders is to supervise the progress weekly basis and provide feedback on the students' planning, general set-up of the prototypes and team work performance. We provide in Figure 2, a general overview of the students' design phases and the project approach.

The *Magnetic equivalent circuits* part of the project requires students to apply all governing laws and rules and describe the relations among electrical, magnetic and mechanical quantities. In addition, they use engineering language related to electrical machine in order to explain and define the related quantities (such as magnetomotive force, EMF, flux linkage, apparent and incremental inductance, leakage, fringing, stacking factor, saturation, Flux density-Field strength (BH-) curve, and − i diagram). Part of this component in the design project is to have students to analyse magnetic circuits with and without nonlinear magnetic materials, and to use the electrical quantity inductance to link magnetic field variables to an electric circuit. In order to do so, students need to calculate the electromagnetic force using magnetic energy and magnetic co-energy.

Within the design is to investigate how *DC machines*. The students need to research the properties of the different parts of a DC machine and indicate them in a cross-section. However, it is also important that students derive an expression for the EMF in the armature as function of the construction of a DC machine, as well as for the electromagnetic torque as function of the construction of a DC machine. In doing so, students learn to classify a DC machine depending on the connection of the field winding (separately excited, shunt excited, and series excited machines); and, the equivalent circuits of the different types of DC machines. Moreover, the design project includes to determine expressions for the electromagnetic torque and speed. Prior to this, students are to analyse the DC machine with the equivalent circuit and the power flow, and explain different speed control methods for DC machines.

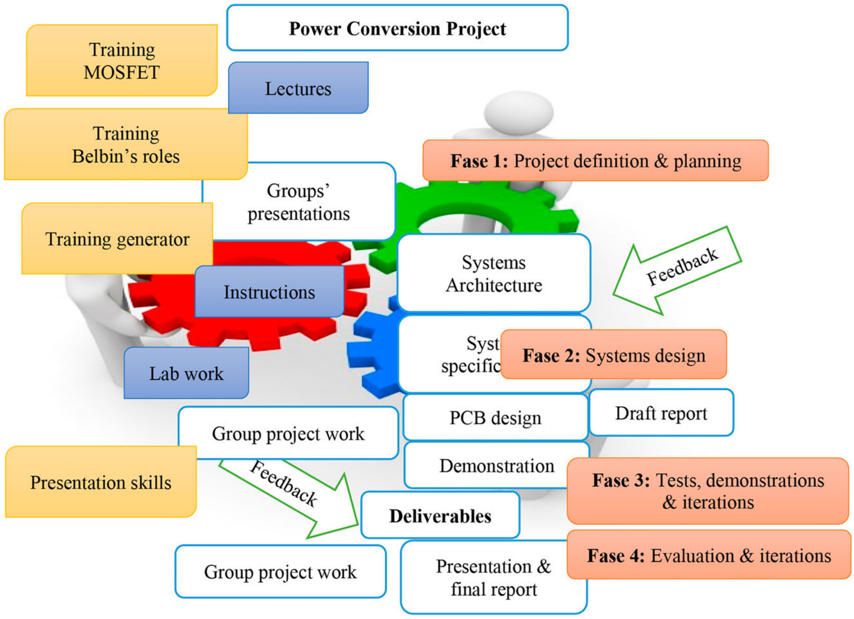


**Figure 2.** Students' design phases and project approach.

Regarding the *Induction machines* element of this design project, a key aspect is to learn how the different parts of an induction machine and indicate them in a cross-section. Students classify an induction machine based on the physical construction of the stator and rotor, and explain methods to reduce harmonics in the stator field of an induction machine. In this sense, the knowledge learned in courses is now applied to derive the equations of the rotating stator field and its speed of the fields inside an induction machine based on the quantity slip. They also derive the parameters of the per-phase equivalent scheme of a three-phase induction machine based on a no-load and a blocked rotor test. In addition, students analyse the active power flow in an induction machine and evaluate the torque-speed characteristic in an induction machine and its special characteristics. Finally, they compare and describe speed control methods for induction machines.

The *Synchronous machines element* of the project includes the application of the different parts of a synchronous machine. Within this part, students work in a classification of synchronous machines based on the physical construction of the stator and rotor. Prior to this step, students are to draw and analyse the phasor diagram of a three-phase synchronous machine; evaluate the torque-speed characteristic in a synchronous machine. In order to do that students are to derive the per-phase equivalent scheme of a three-phase synchronous machine and determine expressions for the electromagnetic torque and speed (cylindrical rotor only).

### *4.2. Modifications in the educational set-up of the Power Conversion project*

The Power Conversion project consisted of an assignment in which students were asked to design a system by analysing firstly a contactless power delivery system. To carry out this assignment, students were provided with the systems architecture as shown in Figure 1. The overall goal is to analyse the power flow and interactions of the given subsystems. As part of the assignment is to determine the specification of the total system, specifying each subsystem, integrating the subsystems and demonstrate them.

The set-up of the project has been improved and readjusted along the years to serve the purposes of the curriculum. As a result of the different set-ups and integration of project characteristics and the transformation of the teacher's role, we expected also to observe effects on students' designs and final products. For the purpose of this study, we focus on the effects of *open-ended* and supervision on students' products. In the following section, we describe, from an educational and instructional point of view, the differences in the phases this project has gone and the effects on students' designs.

*First pilot*: During the first version of this project (2011/2012), the assignment was well defined to certain extent. Only general specifications were given; however, the architecture of the solution was also provided. Despite the fact that the students had the design framed in a given architecture, the results and final product was still *open-ended* as no unique solution was given or indicated and, very little intermediate deliverables were requested to the students. Regarding other DBL characteristics of the project, such as *authenticity*, the Power Conversion project was a practical (but-scaled) real-life problem resembling an industrial setting. However, no client or user was embedded in this scenario. Furthermore, the *hands-on* elements of the project, for example, modelling, designing, prototyping, and testing, were part of the students' activities. In this project, only one iteration was encouraged. The project duration consisted only of a period 84 hours in 14 weeks for project execution. As instruction and study material, the students had access to lecture notes with background information along with additional time for four practical technical assignments to trains skills and improve knowledge. In terms of *multidisciplinary*, there are no elements from other disciplines although the assignment requires students to combine aspects of magnetics, power electronics, electro-mechanics, power systems micro-electronics, and control.

After evaluating the project both with students' questionnaires (response: 5/37) and teachers' feedback meetings, the main conclusions were that students' satisfaction was especially on coaching and on facilities. However, there were remarks regarding improvements necessary on pre-knowledge, documentation and skills. In contrast, teachers' evaluation considered that the role of the expert was still unclear for the students, and that little system knowledge was gained. Finally, regarding the supervision, it was found out that the project leaders had no (real) responsibilities.

*Second pilot*: Following this evaluation and first experiences with DBL, later adjustments were included in 2012/2013 structure of the project. Some of the new elements were that the design of the system needs to comprise additionally the decomposition of the total system in subsystems and to determine the functionality and interactions of each system. Moreover, it was requested from the students to review the design process, and to give an advice to the client. The major changes in this regard were that the project was *open-ended* as shown in Figure 3.

*Open-ended* in this context means that the architecture of the system was not given, only minimal specifications were indicated although there were more intermediate deadlines as described in Table 2. The *authenticity* element of the project comprises that the responsible teacher played the role of a client. In terms of *hands-on*, the iterative approach was strongly encouraged. No major changes were encountered on *multidisciplinary*.

*Third pilot*: The redesign of the project in 2013/2014 was initiated by a curriculum change in which the total number of hours for the project increased from 84 to 112, but the project was given in 8 weeks instead of 14 weeks. This meant that the students are to start earlier with the simulations

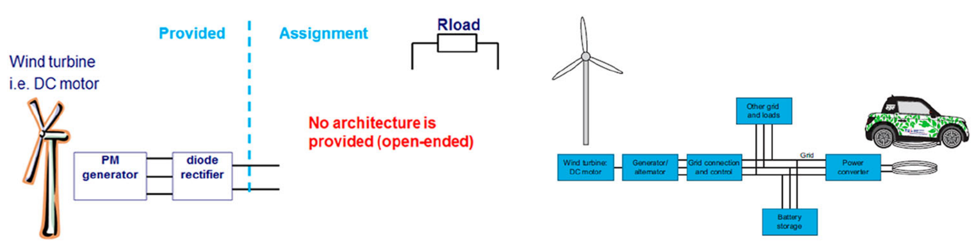


**Figure 3.** Organisation of the project without specifications.

**Table 2.** Overview of deliverables and feedback moments.

| | 2011–2012 |
|---|---|
| Week | Deliverables to structure project |
| 7 | Design review presentation |
| 7 | Individual report (+individual feedback) |
| 14 | System specification |
| 14 | System demonstration |
| 14 | Final report (+self-evaluation and feedback) |
| | 2012–2013 |
| Week | Deliverables to structure project |
| 3 | Architecture to client |
| 5 | Draft specification to client |
| 7 | Advise/pitch to client |
| 7 | Design review with experts |
| 7 | Draft report to experts (individual report) |
| 9 | PCB design to expert (if designs are successfully tested on breadboards only) |
| 13 | Final specification to client |
| 14 | Demonstration to client and experts |
| 14 | Technical report to client (group report) |
| | 2013–2014 |
| Week | Deliverables to structure project |
| 2 | Presentation architecture and planning |
| 3 | Draft spec paper |
| 4 | Design review (three presentations per group) |
| 5 | PCB design |
| 6–7 | Skills presentation |
| 7 | Final specification (presentation) |
| 8 | Demonstration |
| 8–10 | Final technical report |

and iterations of the system in order to design a suitable prototype. Although the project remained *open-ended*, the deliverables were shorter and the supervision more intensive.

## 5. The supervision method

Following Hattie and Timperley (2007), the supervision strategy in this project to support students in designing is based on providing feedback on three levels: feedback on the task, on the process (on both methodology and teamwork), and finally on the self-development of the student. This method is also supported by abundant literature on supervision and coaching of students in engineering education projects. In improving the supervision of students in design projects, we have adopted Hattie and Timperley's (2007) feedback strategy to our contexts. The supervision of students' teams in design assignments has gone therefore through different phases and iteration as a result of evaluation of the different experiences with this project.

*First pilot*: The supervision of students' groups in projects in the 2011/12 academic years consisted of providing feedback on the design by the content expert teachers through mid-term presentations, and on the required skills by the project leaders during group coaching meetings. The supervision of the group work consisted of short mid-term presentations with technical experts, in which students, in groups of six, showed the preliminary prototypes to the teachers in order to receive feedback on the product. In addition, students were weekly supervised by the tutors, who in the context of the EE department take the form of project leaders. The project leaders are master students who follow a project management course. They chair the meetings and give feedback to students on performance in the group. They did not hold however a technical role. However, the level of complexity in the design, product requirements, setup of the project and number of weeks, asked for a readjustment in the supervision systems.

*Second pilot*: In a later stage (2012/2013), the project has taken on a more authentic structure to represent a real-world industry problem. In this regard, the supervision is carried out by the content experts, the academic and technical staff, and by the project leaders who monitor the process also from a methodological point of view. Moreover, to make this project more authentic the role of the teacher turned to be that of a client requesting frequent presentations of product design. The supervision of students (eight students per group) by the content experts is twofold: first of all, the responsible teacher, in the role of the client looked at the planning and the initial development of the product. In addition to this, the technical staff, experts in different fields, for example, systems architecture, power electronic topologies, inductive components, MOSFET and drivers, and micro-controllers, monitor carefully that the design meets minimal product quality standards. The quality criteria were based on power, efficiency, MPPT, and load detention. In Table 2, we provide an overview of deliverables and feedback moments.

As mentioned earlier, the supervision process follows the DBL theoretical framework. This includes supervision on the content, the process and the self-development. Regarding the engineering process, in the academic year 2012/2013, the project leaders were trained to coach the students in design according to the engineering design process. This process includes the analysis of the design task, the study of the problem definition from different perspectives and the formulation of hypothesis; the selection of the criteria upon which to carry out research on design options and design strategy in order to develop possible solutions; the design and test of the prototype based on exploration of alternatives and considerations; the interpretation of information and analysis of findings and results; making judgements on these results within the given theory; and finally making decisions in order to redesign the prototype and initiate an iteration. The project leaders were also trained in training in project management, giving feedback, the supervision of students, review of progress meetings and in assessment. In addition, the role of the project leaders in supervising the students is to coach the students in gaining and developing research skills necessary to design models and prototypes.

In enhancing students' tasks, it is also essential that students get feedback but also forward and feed-up on the progress in designing devices and systems. The actions of the supervisors in the project 2012/2013 (both teachers and tutors) during this process was, for instance, to challenge students by asking questions; to stimulate the process of consultation and questioning to help arrive to fully develop specifications in order for the students to realise whether they need more information and improve own design; to give just-in-time teaching strategy in the form of suggestions to carry out missing tasks; to encourage the evaluation of the process and self-reflection; or just by providing feedback upon mid-term deliverables. Moreover, in giving feedback, the supervisors make use of rubrics as a tool for learning to get students acquainted with the understanding of own specialisation and content, the overall overview of how the system works and the application of the content learned in the lectures of previous courses. Rubrics are a scoring tools that lists the criteria for a piece of work. Rubrics usually contain evaluative criteria in order to assess students' performance in different levels of achievement (Martinez, Herrero, and de Pablo 2010). In Table 3, we present an example of the rubrics employed to enhance students' learning.

The supervision in this project is not a stand-alone action. During the redesign of the project activities, the scenario followed a number of transformations. In the first edition of this project, the faculty staff, the experts in the different EE fields, provided content input along the development process of the design. Later, the project was adjusted in such a way that the responsible teacher took an authentic role as he was the client from a company who in the form of intermediate contact meetings provided content input in the design process. Figure 4(a) and 4(b), we describe the modifications in relation to the role of the project leaders and the expert teachers in providing feedback and supervision. The main difference in the supervision approach in Figure 4(a) (2012/2013) and Figure 4(b) (2013/2014) is that the role of the teacher is authentic as he reviews the design products from a company and client point of view. He comments therefore on products following the specifications and expected criteria made at the beginning with the company. The teacher therefore supervises that the overall quality of the project and the process meets the agreements. The common element between the two supervision approaches is that the direct feedback is given to the students'

**Table 3.** Example of the rubric for the Power Conversion project.

| Criterion | Poor | Marginal | Average | Good | Excellent |
|---|---|---|---|---|---|
| **Understanding own specialisation** | Shows no understanding of own research topic | Shows only marginal understanding of own research topic | Has a reasonable understanding of own research topic | Shows a good understanding of both the overall system and own research topic | Has understood both the overall system and own research topic completely which has led to a good design |
| **Understanding overall system** | Shows no understanding of the overall system | Shows only marginal understanding of the overall system | Has a reasonable understanding of the overall system | Shows a good understanding of both the overall system and own research topic | Has understood both the overall system and own research topic completely which has led to a good design |
| **Research skills (use of resources)** | No resources have been used, or have been wrongly used | Only a few resources have been used (manual has been red and used) | Most resources (manual, literature research, expert) have been used, but not consistently | All resources have been used, able to ask questions and to find relative consistently | Able to solve a problem efficient by using resources (literature, experts) |
| **Dedication (motivation initiative)** | Let's others do the work and a negative attitude which affects other group members | Negative attitude towards the project team. Trends to watch others, gets involved only when necessary | Completes his/her tasks. Neutral attitude towards the project and the team | Positive attitude towards the project and the team. Gets involved in the project | Takes initiative, very involved in the project. Concerned with getting the job done |
| **Communication within the group (technical aspects about the project)** | Communication skills ineffective. Does hardly communicate with other group members | Communication skills ineffective. Does marginal communicate with other group members | Communicates with other group members about own research topic | Communicates with other group members about own research topic and total system (asks questions) | Communicates effectively with other group members about own research topic and the total system |
| **Dealing with feedback** | Feedback is not accepted by the individual at all | Feedback is accepted but ignored by the individual | Feedback is accepted by the individual and an attempt is made to account for it | Individual shows serious interest in understanding the feedback and accounting for it | Feedback is accepted by the individual and is optimally used |
| **Quality of the technical work done** | Work must be redone by other to meet standards | Work must be redone or repaired to meet standards | Quality of the work is acceptable | Work is high quality. A producer | Work is of exceptional quality |
| **Planning** | No plan is given | Only a very schematic plan is give. Planning is realistic | A schematic plan is given, with some interlinking to other activities. Plan is realistic | A detailed plan is given, interlinking to other activities. Planning seems realistic | A detailed plan is given, with interlinking to other activities. Planning seems realistic and is promising for success |

groups during the mid-term presentations and guidelines for further adjustments are also given to the groups' project leader with the overall purpose of making emphasis in the process.

With respect to the process, the project leaders followed carefully the development of the design. In this regard, the project leaders meet the group weekly basis in order to gain an overview of the design process. To monitor this process, a rubric was created with specific criteria not only on both content and methodology, but also on group dynamics. The scoring groups consisted of five degrees Poor (0–1 points), Marginal (3–5 points), Average (6 points), Good (7–8 points), and Excellent (9–10 points).

*Third pilot*: The latest modifications of the project (2013/2014), the Power Conversion assignments have followed, in principle, the same supervision style as in the previous year. However, a

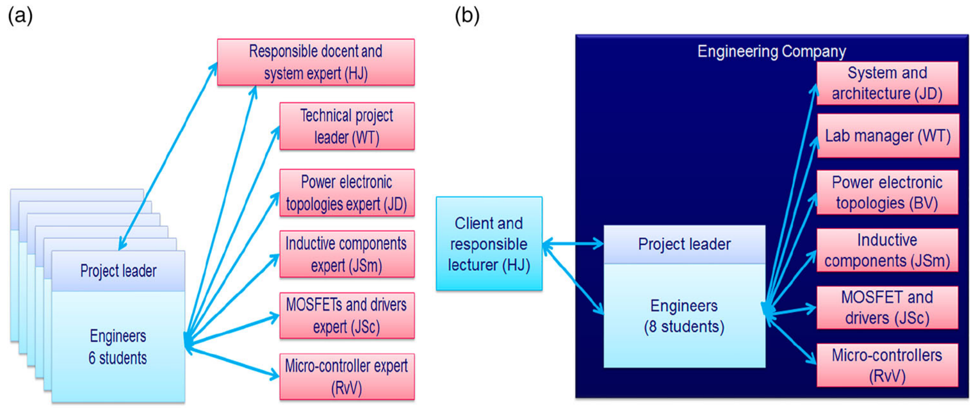


**Figure 4.** (a) Project set-up in 2012–2013. (b) Project set-up in 2013–2014.

few elements have changed as the responsible teacher has not played the role of a client and that the supervision did not include the criteria on as these were not any more part of the design process. The number of students to coach varies per year: in 2011/2012 were $N = 37$ students enrolled in this project; while in 2012/2013, and 2013/2014 were $N = 50$ students.

It is worth noting that the evolution of supervision and coaching of students in terms of forms and methods was supported by a professional development trajectory for both faculty and technical staff, and project leaders (Gómez Puente, van Eijck and Jochems 2014b). The professional development trajectory consisted of a series of training workshops in which the teachers and content experts were trained in the (re-)design of the projects following the DBL framework and methodology. The re-design of the DBL projects included as well as the development of coaching and assessment tools such as feedback sheets and rubrics. The feedback moments were also adjusted according to the outcomes of the project on the one hand. On the other hand, as the project set-up was *open-ended* and the students did not have well-defined guidelines on final product design, the feedback took place, regular basis, in the form of expert meetings. The active learning character of coaching was represented by the fact that the project leaders supported students during both the analytical and synthesis design process by asking critical questions enhancing reflection on the design.

### *5.1. Evolution of the supervision methods*

The supervision of students' teams in design assignments has gone therefore through different phases and iterations as a result of evaluation of the different experiences with this project, and summative assessment of student's design and learning process. The Power Conversion project encountered only summative assessment in the 2011/2013 set-up. Assessment was based on report (33%), peer review and grade project leader (33%), and finally, demonstration and design review (33%). Later, assessment was changed to include also formative assessment in order to meet the university regulations aiming at increasing the pass rates but also at encouraging students to be actively involved in the courses. The assessment of the DBL assignments in the later versions, i.e. 2012/2013, and 2013/2014, included formative feedback and assessment. Formative assessment consisted of a mid-term presentation to advice the client on product design along with a design review presentation with experts, mid-term feedback and assessment on individual progress report. Marks of formative assessment were also counted for the summative assessment which together with the final demonstration, the peer review and project leaders' grade made out of the whole individual and group mark for the project.

## 6. Results

The Power Conversion project has gone through different iterations in its design in the last three academic years, and therefore effects on students' designs were expected. In order to investigate what the effects on students are as a consequence of the project instructional design, we compared the results of the project in three consecutive years. The comparison included the quality criteria of the final design system. The criteria consisted of the transferred power (W) of the system, the efficiency, the implementation of an MPPT, the load detection, the grade in the final demonstration.

Table 4(a)–(d) shows the differences among students' groups along the years regarding the criteria to judge the quality of the designed systems. Based on these experiences along the years, we observed that the influence of the project characteristics such as for instance *open-ended* in 2012/2013 has influenced students' design as the criteria efficiency, MPPT and power tracking shows interesting differences. With regard to power (W); however, results do not show dramatic changes along the years as the efficiency. A clear increase in system efficiency can be observed in 2012/2013, which seems to be reduced in 2013/2014 in which the students did not have sufficient time for system optimisation due to the reduced period in which the project was conducted.

With regard to supervision, we compared the groups' marks according to the assessment given by the teachers on the demonstrations, presentation of group work and report, and on the project leaders' assessment on group progress based on the items described in the rubrics. Results indicate that there are no major differences in the students' average marks with regard to the final demonstrations, the group final presentations, the final reports, and the project leaders' marks on students' progress based on the items of the rubrics in the first two years we compared. However, we presume that the feedback given on interim products and individual performance following the items in the rubrics has had some positive influence in students' design products in 2012/2013 as the quality criteria of efficiency, MPPT and power tracking increased in that year. With regard to the students' average marks in 2013/2014, we observed a decrease. This is consistent with the fact the number of hours for the project implementation in 2013/2014 was reduced and that there was less time for feedback and number of mid-term deliverables.

Furthermore, the influence of the project characteristics such as for instance *open-ended* in 2012/2013 has influenced students' design as the criteria efficiency, MPPT, and load detection and have shown interesting differences as comparing the designs in different years. With regard to Power (W); however, results do not show dramatic changes along the years. A clear increase in system efficiency can be observed in 2012/2013, which is reduced in 2013/2014. In the last version of this project, the students did not have sufficient time for system optimisation due to the reduction in terms of project weeks in which the project was conducted.

Moreover, the role of the project leaders (tutors) has played a major role. As exposed earlier in this paper, both the role of the project leaders in giving feedback, supervising and coaching students, as well as the development and improvement of the instruments to provide coaching have been decisive to influence the quality of the students' systems. In addition, the improvement over time in design performance is also a common by-product of the teachers in having better understanding of the problem after multiple iterations of the project.

Regarding the average of students' presentations in 2013/2014 there is no data available. We present in Figure 5, the results of the average groups' marks (scale 0–10 points).

We also compared the average of students' items in the rubrics in 2012/2013 and 2013/2014. This information is difficult to compare because as the project implementation time was reduced in 2013/2014, students had to carry out the project tasks in a shorter time and less supervision and mid-term deliverables were included. Therefore, the average of the individual scores of the students on the items in the rubrics is lower in 2013/2014 than in 2012/2013 where the supervision and feedback was intense. In Figure 6, we provide an overview of the average students' assessment based on the items in the rubrics (scale 0–10 points).

**Table 4.** (a)–(d) Students' outputs in different academic years

(a) Students' outputs in 2011–2012

| Groups | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Power (W) | 129 | 187.5 | 190 | 100 | FAIL | 145.5 |
| Efficiency (%) | 58% | 78% | 73% | 79% | FAIL | 62% |
| MPPT | No | No | No | No | No | No |
| Load detection | No | No | No | No | No | No |
| Grade demonstration | 6.5 | 8 | 8 | 8 | 6 | 7 |

(b) Students' outputs in 2012–2013

| Groups | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Power (W) | 94 | 170 | 101 | 100 | 218 | 175 | FAIL |
| Efficiency (%) | 73% | 87% | 77% | 77% | 78% | 75% | FAIL |
| MPPT | Yes | Partly | No | No | Yes | Yes | No |
| Load detection | Yes | Yes | No | No | No | Yes | No |
| Grade demonstration | 9 | 6 | 7 | 6.5 | 7.5 | 8.5 | 5.5 |

(c) Students' outputs in 2013–2014

| Groups | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Power (W) | 100 | 190 | 104 | 199 | 174 | 115 |
| Efficiency (%) | 70% | 66% | 63% | 71% | 65% | 73% |
| MPPT | No | Yes | Yes | No | No | No |
| Load detection | No | Partly | Yes | No | No | Partly |
| Grade demonstration | 5.5 | 7.5 | 8 | 6 | 7.5 | 6.5 |

(d) Students' outputs – quality criteria

| Groups | 2011/2012 | 2012/2013 | 2013/2014 |
|---|---|---|---|
| Power (W) | 150 | 143 | 135 |
| Efficiency (%) | 70% | 78% | 65% |
| MPPT | 0% | 43% | 43% |
| Power tracking | 0% | 43% | 29% |

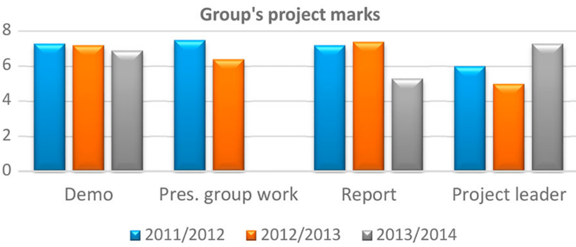


**Figure 5.** Overview of students' groups average marks.

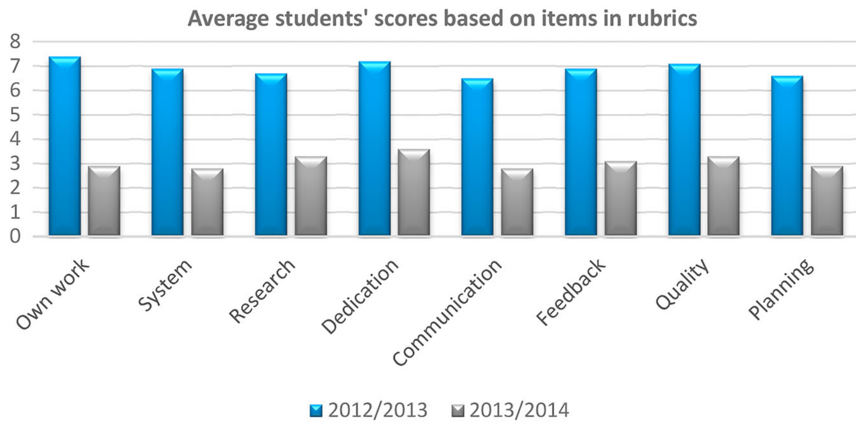


**Figure 6.** Overview of students' scores regarding the items in the rubrics.

Finally, we also applied Pearson correlation to correlate students' groups grades and students' scores in the different years. Results show no significant correlations. This indicates that the different modifications in the project set-up, structure and supervision have no had major impact on the students' project outcomes.

## 7. Conclusions and discussion

DBL is a promising approach to have students to gather knowledge and apply it in design product and systems. This approach fosters the process of working on engineering problems that supports students in exploring different routes, experimenting and developing solutions in iterations.

From these sequence of experiences, we can draw some conclusions. First of all, the *open-ended* set-up of projects stimulates students going through iterations that allows critical thinking. This inquiry process involves students testing and making decisions. This has influenced the quality of design products to some extent. Moreover, the integration of supervision methods that allows students to focus on own criteria and abilities may have had some impact in understanding better the assignment and improving students' performance against the criteria.

Despite these interesting results, other routes to improve students' design methodology are still to be investigated. The fact that authenticity, in the form of teachers as clients, has not have major influence in students' designs remains an area for further improvement and adjustment.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes on contributors

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