Enhancing interdisciplinary hands-on education in the field of Magnetic Levitation Mobility and Signals Analysis and Control

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INTRODUCTION

Imagine a world with environmental-friendly, soundproof and safer modern trains. The second-year Design-based learning bachelor project *Signals and Systems* has introduced an interdisciplinary and hands-on approach to let students explore physics concepts of Maglev trains. This type of modern train is not resting on wheels but is levitated in a contact-free and friction-free way. The rationale to integrate interdisciplinary engineering approaches from Electrical and Mechanical Engineering domains is based on stimulating the application of trial-and-error methods in order to enhance out-of-the-box thinking. Physicists, however, apply a mathematical approach to analyze physical models using differential equations and Laplace transformation.

The integration of the interdisciplinary and hands-on approach in this compulsory project of the Applied Physics curriculum at the Eindhoven University of Technology (TU/e) is two-fold: first of all, we introduced more explicitly a limited number of engineering design steps also common to other disciplines, e.g. *analyse the problem, exploring graphic representation of the problem, or building a model*. Secondly, we also included interdisciplinary elements from Electrical Engineering, e.g. extension to the fully digital domain, Z-transform, and pole manipulation in the digital (z-transform) domain. In addition, the Mechanical Engineering input consisted of working in the frequency domain, recording a Bode plot of the open system, and optimizing control action.

In this project, we also have groups of students who carry out the DBL *Signals and Systems* project in the Innovation Space (InnSpace) at the TU/e university campus. This InnSpace location has been specially created to accommodate students' groups working on multidisciplinary collaboratively projects.

In this study, we explore to what extent interdisciplinary elements embedded in the DBL *Signals and Systems* project have influenced the quality of the students' final products. In addition, we examine whether the Innovation Space has encouraged students to work in a more creative and collaborative manner.

1 INTERDISCIPLINARITY IN ENGINEERING EDUCATION

1.1 Rationale for interdisciplinary education

Interdisciplinary education is becoming more and more an essential component of the curriculum of engineering studies and applied technical programs in higher education. The rationale to pay more attention to interdisciplinary in upper education curricula lies in the fact that the requirements of the industry are more demanding for newly graduates [1]. As the labour market is dynamic so are the developments of new products and equipment, technological processes and applications to meet societal, health, energy and economical demands [2]. These challenges in society claim for a broader approach to work in teams with experts from other disciplines *making use of tools, integrating information and data techniques, and using concepts or theories to solve complex problems* [3].

The need for interdisciplinary education becomes even more relevant as the expected knowledge and skills of both engineers and physicists are framed in accreditation frameworks [4]. This to assure that the output to the industry meets the expected requirements [5].

1.2 Theoretical considerations

Definitions on the concept of interdisciplinary in higher engineering education are numerous in the research literature [6]. The differences in the definitions lies in the models and focus of application in education. Interdisciplinary education is interpreted as a mean to teach students to solve challenging problems from multiple disciplines and perspectives [7]. Other modern approaches and supporters of interdisciplinary argue that this type of education is embedded in technological innovations in which interdisciplinary knowledge is essential to resolve complex problems in iterative loops in order to create joint solutions [8].

When applying interdisciplinary approaches into courses and projects to design interdisciplinary education, the level of integration varies by nature depending on different considerations [9]. From an interdisciplinary research perspective, interdisciplinary education can be implemented by applying gradually different knowledge sources (multidisciplinary, interdisciplinary and transdisciplinary) [10]; by the degree of collaboration among the disciplines [11]; by induction as a method to structurally apply in program design [12] or by the so-called design abduction [13]. Furthermore, prescriptive forms of designing education by constructive alignment can provide suitable means to design interdisciplinary education by focusing on the teaching and learning environments [14].

1.3 Innovation Space

The Innovation Space (InnSpace) concept is a rather new creation at the TU/e. The motivation to build such a creative environment was generated by models elsewhere such as the Design Factory at the Aalto University in Finland. Inspired by this model, the InnSpace at the TU/e aims at stimulating students to work on hands-on and challenging projects in multidisciplinary teams in a collaborative manner. The purpose is to create linkages with the industry, research organizations and businesses in order to generate an ecosystem of technological development. One of the main goals of this macro project is to create a community of students and support them in interdisciplinary engineering projects to generate prototypes together with staff and companies. In addition, the purpose is to *transform prototypes into products and services for society, creating new businesses and valorizing research at the university* [15].

The InnSpace at the TU/e is an open area in which students work in teams and interact with other groups. Students can work on experiments, make measurements, solder pieces or build own models in order to generate designs. The space contains meeting rooms and With this vision of interdisciplinary education and innovation in mind we selected a group of students to carry out part of the project in the Innovation Space. Our interest was to identify whether this innovative environment of the InnSpace would have an impact on students' final products.

2 THE DESIGN OF THE DBL SIGNALS & SYSTEMS PROJECT

2.1 Design-based learning and hands-on education

The aim of the DBL *Signals and Systems* project is to explore systems to maintain a Maglev train levitating by experimenting with repulsion forces between the magnets in the train and the electromagnetics in the track. The assignment is hands-on as students experiment with the levitation of a ball by measuring pull-up and pull-down forces. Students work through the open-ended design-based [16] project by exploring how a control system works, reviewing stabilization time and experimenting with calibration.

2.2 The interdisciplinary design of the DBL *Signals and Systems* project

Grounded in the theoretical considerations mentioned above and more specifically in Biggs & Tangs' constructive alignment theory, we focused on one of the elements of the model of teaching and learning in higher education, i.e. learning environment. Following the constructive alignment theory, we made more explicit a limited number of engineering design steps from engineering disciplines. The engineering design steps are taken from Mehalik and Schunn's taxonomy [17] and these are *analyse the problem, use graphic representation and build the model.* This taxonomy is validated and based on an empirical analysis of engineering design steps that take place in engineering disciplines. For the purpose of our study, we only applied however a few design steps of this taxonomy that fit the content and context of the DBL *Signals and Systems* course.

In addition, we also included Electrical Engineering (EE) and Mechanical Engineering (ME) interdisciplinary elements following Klein's approach on the degree of collaboration among the disciplines. In this regard from the Electrical Engineering field, we integrated topics such as the extension to the fully digital domain, Z-transform and the pole manipulation in the digital (z-transform) domain. With respect to the Mechanical Engineering field, we added elements such as the frequency domain, recording a Bode plot of the open system, optimizing control action from that viewpoint. Furthermore, students were to start with the system with open loop stable (upside-down configuration: electromagnet is below permanent magnet, pushing the permanent magnet upwards), optimizing and later extending this towards the "normal" configuration, with the electromagnet magnet above the permanent magnet, pulling it up, where the open loop is unstable, and an open loop Bode diagram cannot be recorded.

Moreover, following the open-ended approach of the design-based learning educational concept, the integration of the EE and ME elements has not been introduced in the form of a framed assignment. On the contrary, short introductory lectures have served to present new concepts on disciplinary topics in order to widen students' understanding on those. The open-ended character lies therefore in providing students with insights so that they are stimulated to further conduct experiments and analysis, carry out tests and based on results to apply iterations in the models. By doing so, students gather new information and facts in each design step and apply this new knowledge in order to generate and produce new insights [9].

It is worth mentioning that the rationale to integrate EE and ME disciplinary themes was not only based on including elements of these disciplines but also to stimulate a rather trial-and-error approach to problems and look for solutions. On the contrary, the physicists' approach follows rather linear process to analyze physical models using differential equations and Laplace transformation.

3 METHODOLOGY

3.1 Research methodology

The methodology we have applied in this study followed a triangular approach. In order to collect students' perceptions on the interdisciplinary elements in the DBL *Signals & Systems* project, we developed a structured Likert-scale questionnaire (1 to 5 scale). The majority of the questions for this survey were taken from a previous research study and has been readjusted for the purpose of this research. The questionnaire has been previously validated [16]. We also interviewed students, tutors and lecturers to identify interdisciplinary elements applied in exploring physics concepts and in delivering a proof of principle model system. Finally, we reviewed the students' reports in order to identify whether the interdisciplinary and hands-on elements have influenced the quality of the products, the approach taken towards solving the problems or the steps followed in order to solve the problem.

3.2 Participants

The participants in this study were second year bachelor students enrolled in the Applied Physics study program. The total number of students that followed the course DBL Signals & Systems was 146. For the purpose of this research N= 45 students took part in the study, N= 22 students conducting experiments in the Innovation Space location and N= 23 students working at the AP building premises. The selection of the groups involved in this study was done as follows: we selected four groups at random in order to collect perceptions and observe students' approach to solve the problems within the regular labs. In addition, four other groups were selected to carry out the project in the Innovation Space premises. The selection criteria to choose these four InnSpace groups were based on their progress shown in the first part of the course involving levitation of a ping pong ball emulating the levitation magnets of a train, and in particular representing the effectiveness of a configuration for a train and the system to keep the ball afloat. Likewise, the selection of the tutors was completely arbitrarily done as the tutors were previously randomly distributed among the groups.

4 RESULTS

4.1 Students' perspectives

We collected students' perceptions by a structured Likert-scale survey consisting of 12 questions. For the purpose of this study, we only present the results of the questions pertaining to the interdisciplinary character of the project (Q1 to Q3) and the questions related to the impact of the location, e.g. InnSpace or the regular lab premises (Q4, Q5 and Q12).

Table 1. Overview mean of groups with & without interdisciplinary elements

	Groups without interdisciplinary approach		Groups with interdisciplinary approach in Innovation Space	
	M	SD	M	SD
Q1	2.76	.99	3.31	1.04
Q2	2.90	.99	4.00	.69
Q3	2.65	.87	3.40	1.18
Q4	2.80	1.19	3.54	1.10
Q5	3.77	.75	3.40	1.25
Q12	3.76	1.09	3.22	1.02

The results in table 1 indicate differences in perceptions between the groups that have been exposed to the additional EE and ME interdisciplinary content within the Innovation Space and those that remained in the premises of the AP traditional labs. Looking at the results of some of the questions[2] (Q1, Q2, Q3) we perceive substantial differences in students' perceptions

[2] *Q1 – The project is interdisciplinary (i.e. design steps from other disciplines, for instance in designing a solution); Q2 – The project is interdisciplinary (i.e. there are concepts or topics from other disciplines rather than only Applied Physics); Q3- The location, Innovation Space, has inspired me to work in a more creative and innovative manner; Q4 – The location, Innovation Space, has inspired me to work in a more collaborative manner; Q5- The project is open-ended, e.g. there is no one solution given, there are possibilities to look for alternatives, no specifications of the final solutions are given; Q-12 – The project represents a real-life problem as, for instance, I was working in the industry (question for students in the labs). Working in the Innovation Space resembles better the idea of working in a real-life project representing industry problems (question for InnSpace students)*

related to the interdisciplinary character of the project, both in the design steps taken from other disciplines as well as the content provided. Regarding the perceptions on whether the location has inspired the students to work in a more creative and collaborative manner (Q4), results indicate that students working in the Innovation Space have a more positive opinion on the influence of this location in the way of working. This due to the fact that the premises at the InnSpace are open extensions in which students work around a table. This provides more opportunities for collaboration among the group members and with other groups as well. There is however little differences with respect to the open-ended character of the project (Q5) as the set-up of the course contains ill-defined aspects in the assignments. Finally, the question (Q12) on whether the Innovation Space resembles better the idea of working in a real life problem has not major impact on students' beliefs. Differences in results may be influenced by the fact that the four groups selected to carry out the project in the Innovation Space were chosen based on the quality of the mid-term results (i.e. groups managed to let the ball floating) they produced.

4.2 Analysis of reports

We selected specific criteria in order to compare quality of reports and appreciate whether essential elements of the design process and interdisciplinary education have been applied by the students. In the tables below we present an overview of the Innovation Space students and students carrying out the assignments in the labs. Some of the criteria on interdisciplinary cannot be used for comparison as the groups in the labs had not access to additional interdisciplinary education.

Table 2. Overview of students' Innovation Space scores

Groups / Criteria	3	5	7	15
Criteria to make adjustments in the model, or optimize performance	+	++	+	+
Adjustments in the model, or optimize performance and validating the model and analysing	+	+	+	++
(More) iterations as a result of testing different models of EE/ME elements	+	++	++	0
Z-transform, and pole manipulation in the digital (z-transform) domain (EE)	+	+	+	-
Optimizing control action (ME)	+	++	0	0
Group's final grade	9	9,5	9	8,5

Table 3. Overview of students' scores in lab premises

Groups / Criteria	2	4	9	11
Criteria to make adjustments in the model, or optimize performance	+	0	++	0
Adjustments in the model, or optimize performance and validating the model and analysing	++	+	+	+
(More) iterations as a result of testing different models of EE/ME elements	0	0	+	-
Z-transform, and pole manipulation in the digital (z-transform) domain (EE)	*N.A.	N.A.	N.A.	N.A.
Optimizing control action (ME)	N.A.	N.A.	N.A.	N.A.
Group's final grade	8	7	9	7,5

*N.A. Not applicable

From the lecturers' perspective, the Innovation Space groups with additional interdisciplinary input score roughly one point higher than the groups which remained in the AP building premises. However, it is worth mentioning that the InnSpace students were selected based on the quality they produced in the first weeks of the project. Furthermore, it is remarkable that the Innovation Space groups have certainly made more use of the additional interdisciplinary components. As a matter of fact and according to the lecturers' findings students have applied the Bode plot, used the low-pass filter as well as the discrete transformation among others. Surprisingly, students carrying out the project in the InnSpace mainly follow the physics approach during the project implementation and experimentation. Another observation by the lecturers is that the Innovation Space groups also had more possibilities to make use of the newly gained knowledge for instance through the experimentation with the disturbance of the light in the room (disturbing the optical sensor in the setup). In particular, one group even made a special box as this group certainly went deeper into their analysis to protect the floating ball from external factors such as light. Another annotation is that these groups also used more original display techniques and optimization techniques, e.g. 3-D plots from the poles, Ziegler-Nichols approach, etc.

The quality of the measurements and simulations is not very different between the AP lab and the InnSpace groups, but the quality of the analysis by the InnSpace groups is much better.

4.3 Students' observations and interviews

Semi-structured interviews with students carrying out projects at the InnSpace premises reflect similar findings regarding the working method. Students both in Innovation Space and in the traditional premises mentioned that the use of a trial-and-error approach is a logical process of testing how for instance the PID controller works when optimizing the system. In addition, the interdisciplinary components of the InnSpace assignment have not enhanced a different approach to work. The InnSpace groups recognize indeed the EE and ME components in the assignments and used for instance the theory on adaptive PID controller or linearization for discrete analysis although these have not been completely practiced by all InnSpace groups.

Reasons for this have to do with time constraints rather than with the assignment itself. According to the students, the influence of the interdisciplinary components has indeed enhanced the hands-on aspects of the project as it requires more experimentation with multiple ways of controller systems, the improvement of the systems, adjusting the frequency response and stimulates the options to use different methods. In terms of the engineering design steps, the fact that the InnSpace require more analysis and experimentation in designing the system and building the model implies therefore a deeper exploration of, for instance, how a low-pass filter works and the calculations of the values. This encouraged more iterations in building the model, for example, in making the system more stable with the use of lead-lag compensator. Regarding graphic representation, there is no difference between InnSpace and the other groups. The specific added value of the InnSpace is that the collaboration among group members and the communication with other groups has increased. Students have more possibilities to move around in the open space. This stimulates communication easily.

5 CONCLUSIONS

The implementation of the DBL *Signals and Systems* project has been an excellent opportunity to explore how interdisciplinary components can play an important role in education. Efforts made to embed these EE & ME components are obviously more evident in the InnSpace groups than in the groups working in the labs. Slight differences are also perceived in the analysis of the system and in building the model as the InnSpace groups studied and used additional theory, i.e. the Bode plot, used the low-pass filter as well as the discrete transformation and an adaptive controller in building the system. However, these steps are not commonly applied by all InnSpace groups. Likewise, although a different working approach was expected this has not been always obvious and students still use the physics way of conducting experiments by gaining first the insights from literature, using the linear process in analysing physical models and transforming these into differential equations to apply those in building a model.

The results of this project shows an interesting approach to introduce interdisciplinary as a vehicle to design challenging projects. We have gradually introduced content aspects from two engineering disciplines and observed that students make use of these disciplines in their designs. However, due to the fact that selected groups performed optimally in the first part of the project we cannot easily prove that the interdisciplinary aspects influenced the quality of results. This project opens up new venues for further experimentation to design interdisciplinary hands-on projects. Implications for further research imply adjusting the design and set-up of the DBL project *Signals and Systems* by, for instance, including more explicitly the engineering design steps from Mehalik and Schunn's taxonomy. This will reinforce the trial-and-error working method. It will also encourage a more in-depth approach to analyse, experiment and test while building a model. These adjustments in the assignment will ask as well for other forms to assess of students but also in teachers' and supervisors' attitudes in order to align the project more constructively.

Regarding the Innovation Space, this element depends strongly on the new premises being built at this moment at the TU/e. The vision of the Innovation Space is still under construction and the implementation of this ambition lies strongly on making a practical environment in which students can easily collaborate with students from other disciplines, create linkages with the industrial partners and foster creativity and innovation. This will immediately encourage the multidisciplinary vision of the Innovation Space.

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