TEACHING DESIGN ENGINEERING IN AN INTERDISCIPLINARY PROGRAMME

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ABSTRACT
ATLAS, the Academy of Technology and Liberal Arts & Sciences, is an interdisciplinary three-year Bachelor of Science honours programme for talented students that opened its doors in September 2013. This international programme uses the concept of project-led education to teach students to integrate both technical and social perspectives into a new engineering approach. It aims to educate the so-called 'new engineer': a generalist who can combine technological and societal approaches with design solutions that can be implemented in a range of technical, social, and cultural contexts.
The programme has a thematic structure, in which a large project is the foundation of every semester. At the start of the semester the students write their own personal development plan framed by three domains (Engineering, Mathematics and Social Sciences) and six learning lines (Research, Design, Organization, Communication, Learning Capacity and Interdisciplinarity). In an interdisciplinary programme like ATLAS students have to learn to use knowledge from different disciplines and integrate it. This is also demanded by the project description, which is always a complex open-ended interdisciplinary problem. Design models from both engineering and social sciences are combined to develop new solutions for boundary-crossing problems.
In this paper we will describe the programme and its underlying educational principles in detail. We will show the interdisciplinary design-engineering model that we use in our programme. We will reflect upon our first experiences with the programme and define a set of challenges for teaching design engineering in an interdisciplinary programme.

Keywords: New engineer, engineering education, design education, interdisciplinary design methodology

1 INTRODUCTION

The call for a new engineer – a broadly educated engineer who is engaged with complex societal problems and has the technical and social competences necessary to work on solving these problems – is often heard in the academic world and in practice [1]. The Academy of Technology and Liberal Arts & Sciences (ATLAS) at the University of Twente is a university college Bachelor of Science programme that aims to educate these new engineers. The mission of ATLAS is 'to provide optimal learning opportunities for advancement in technology and liberal arts & sciences for the personal benefits of talented and ambitious students, who value interdisciplinarity and international perspectives on societal issues'.
University colleges in the Netherlands generally adhere to a liberal arts type of bachelor education as established in the USA. Classes are typically small with a high teacher-student ratio. In general, Dutch universities are prohibited from selecting students for their (bachelor) programmes and therefore have to accept any eligible high school student. For university colleges this is different. They are selective, taking in only ambitious top students with a broad interest. Currently, there are eight university colleges in the Netherlands [2]. ATLAS, being the first with an engineering approach, started in September 2013 as a residential college, where students live and study on campus in an enriching learning environment. The focus of the programme is not (just) one subject, but rather a broad education, preparing students not only with a sound academic foundation but also with essential professional competences.
ATLAS targets very talented, broadly interested students. However, what makes it unique is its focus on technology and its use of interdisciplinary Project-Led Education (PLE). Because of the distinct

purpose, the programme was designed as a radical educational innovation, inspired by other programmes at the University of Twente and other institutions (such as Utrecht University College in the Netherlands, Olin College in the USA and Aalborg University in Denmark), but did not copy existing templates. Central in this process were multi-disciplinary teams, a programme council and a curriculum development group in the preparatory phases, and a core team of lecturers for the actual development and implementation. The broadness and ambitious nature of ATLAS is also reflected by this core team. The lecturers come from different disciplines, in particular mechanical engineering, biomedical engineering, physics, mathematics, philosophy, history, psychology, communication science and business administration. They are selected based on demonstrated education excellence, and their experience with PLE and/or multidisciplinary education.

This paper contains the reflections of the core team of lecturers on the development and implementation of the programme. We will describe the concept and underlying principles of the programme and present our interdisciplinary design-engineering model that underlies the projects. We will evaluate our first experiences and define some challenges for teaching design engineering in an interdisciplinary honours programme.

2 EDUCATIONAL PRINCIPLES

2.1 Interdisciplinary thinking

One of the aims of interdisciplinary education is to develop interdisciplinary thinking. The programme has incorporated the conditions for interdisciplinary education as presented by Spelt et al. [3]. They define interdisciplinary thinking as “the capacity to integrate knowledge of two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means” (p. 365). Research has shown that most programmes that claim to be interdisciplinary are in fact multidisciplinary: multiple perspectives are educated; however, students are not supported in the integration of disciplinary knowledge throughout the curriculum.

The focus on interdisciplinarity and self-regulation (§2.2) is embodied in PLE. Students work every semester on a realistic, complex open-ended project in which they must solve a problem that contains both technical and social elements. In the projects, students are confronted with phenomena that exist in both disciplines (e.g. power, feedback and interaction). The research and design skills from both disciplines are taught at the same time to learn how research and design principles can be used in the different disciplines. A unified cross-disciplinary terminology, as a design-engineering model (§2.3), is used to aid the student’s learning process. In addition, teachers from different disciplines are together responsible for the design of a semester and supervision of the project groups.

2.2 Self-regulated learning

The programme is designed to challenge ambitious high-ability students. Ways to do this are using complex tasks, having high expectations and low teacher regulation [4]. In addition, the programme qualifies students for monodisciplinary master programmes in both technical and social science disciplines, while they do not receive an in-depth education in every discipline. Consequently, self-regulation is crucial in order to learn how to develop and deepen themselves further in a discipline (even qualify if needed), and to deal with the challenging programme. According to Nicol and Macfarlane-Dick [5], one of the aims of higher education is to empower students as self-regulators to improve their development also in future work situations. Self-regulated learning is often seen as a personal characteristic of students, but it is also a feature of the learning environment [6]. However, in most study programmes students’ self-regulated learning skills are not developed, since they do not get the opportunity to design their own learning goals, learning activities, and assessment.

2.3 Interdisciplinary design-engineering model

As a basis for the design projects we use an interdisciplinary design-engineering model, as shown in Figure 1. This model is based on existing models in engineering and social sciences. In this model, design is defined as the collection of activities aimed at developing working solution(s) for various societal-technological problems and opportunities. The activities are planned, systematic and transparent, and follow an iterative and/or chronological order. The different activities feed from knowledge products of fundamental and applied research from various disciplines, which implies that research and design go hand in hand. The collection of design activities consist of six main categories

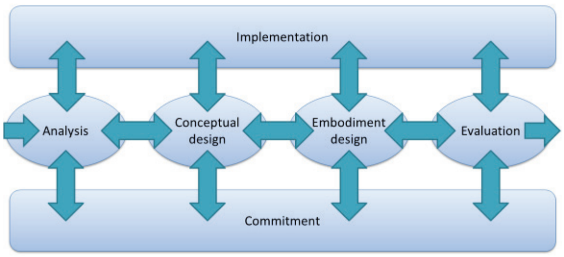

Figure 1. ATLAS socio-technical inter-disciplinary design-engineering model

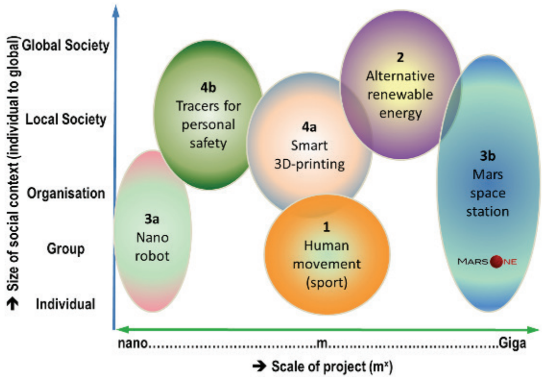

Figure 2. Themes per semester showing the programme's breadth

that are discernible in the various fields: *Analysis* of problems and recognition of opportunities, as well as identifying causes, needs and requirements relevant to the problem or opportunity at hand; *Conceptual design,* referring to all activities aimed at constructing a blueprint of an actual solution; *Embodiment,* constructing a concrete solution; *Implementation,* involving activities aimed at the delivery of the embodiment in a physical and social context; *Obtaining and maintaining commitment,* of all relevant stakeholders, before, during and after the design process; and *Evaluation*, both formative and summative. As shown in Figure 1, the model is defined as a network of interrelated design activities. Depending upon the nature of the problem and the scientific discipline(s) involved, the different activities vary in their importance and relevance.

3 ATLAS PROGRAMME

3.1 Set-up of the ATLAS programme

The ATLAS programme is spread over three years (six semesters). The first four semesters are theme-based, as shown in Figure 2, covering small and large-scale projects, and ranging from the individual level to society at large. The projects are organised according to the principles of PLE [7]. Together, the themes cover a substantial part of the interacting domains of the programme. Throughout the programme, domain courses cover the relevant fundamentals of engineering, mathematics, natural science, social and behavioural sciences. The third year is individually tuned to ensure the qualification for the chosen subsequent master programme(s). Next to the domain courses, there are six learning lines running through the programme that warrant the development of general academic competences: Research, Design, Organization, Communication, Learning Capacity, and Interdisciplinarity. These are to a large extent (but not exclusively) addressed within the projects.
In order to stimulate students to become responsible for their own development and to stimulate them to excel in several domains, an integrated feedback and assessment system is designed that can be tailored to the students' personal talents and developmental paths. The educational system demands students to develop their self-regulatory skills by designing their own learning goals, learning activities and assessment. Students are also explicitly supported in developing these skills, since developing their learning capacity is one of the learning goals of the programme.
With respect to the development of self-regulation, students choose for themselves what kind of role and expertise they want to develop. The talent development of the students is supported by their own Personal Development Plan (PDP), which is formalized at the start of each semester. Consequently at the end of the semester, students are self-responsible for providing their own learning evidence. They do this by writing a critical Self-Evaluation Report (SER). The SER forms the basis for the student's semester assessment. Twice a year, students receive a summative assessment on their self-chosen evidence. Three passing levels are possible: pass with condition, pass with honours and pass with excellence. Two other possibilities are a prolonged examination (i.e. students have to provide additional evidence before the assessment can be finalized) or a hold, implicating that the student is advised to switch to another program, fitting the student's capabilities and ambitions better.

Figure 3. Imperative fusion of domains and learning lines in Semester 1

Figure 4. Project result: a device to measure the rower's back angle

3.2 Semester 1: project, domains and learning lines

The first semester starts with a short open-ended exercise: a three-week freshmen project about myth busting. This introduces the main characteristics of PLE, as well as the skills needed to succeed. In groups of five, students work on a self-chosen myth to bust. They learn to define the problem, to set their own goals and deadlines, to work under time pressure, to integrate both technological and societal perspectives according to the design-engineering model of Figure 1, and to work in a team.
After the freshmen project, students are placed in groups of eight and start to work on their first large thematic project, which is the backbone of Semester 1. The project is on human movement (sport) in general and last year more explicitly on rowing. Students had to design a feedback system for coaches of a rowing team, who were real-existing clients. Connected to the project, the domains in Semester 1 provide an adequate orientation of Engineering (Newtonian Mechanics), Mathematics (Calculus) and Social Science (Psychology). The contents of the learning lines are in principle self-chosen by the students, but should somehow support the project. The domains and learning lines are always intertwined and are imperative to successfully complete the project, as visualized in Figure 3. Figure 4 shows the result of one of the groups: a device to measure the rower's back angle objectively, thereby improving the specific feedback the coach can give during a training session.

3.3 Student guidance

In this small-scale intensive programme students are coached in three different ways: by a teacher, a tutor and a mentor. The teacher is responsible for helping the students learn the content of a domain or learning line. Tutors guide student project groups (process, some content), while mentors coach individual students (study, progress, learning and development, goals versus achievements and redirection).

4 FIRST EXPERIENCES

One semester into the programme, we have some interesting experiences about how to design such an interdisciplinary programme and about how talented students go about learning in a project-led and self-steering environment.

4.1 Experiences with the set-up of the programme

The design and implementation of the programme itself was handled as an interdisciplinary design project: many different disciplinary experts, working together as a self-steering project group to come up with one integrated solution: the ATLAS programme. During the many discussions, we had to overcome the perceived differences between the technical and social sciences, and learn about each other's disciplines and the paradigms used. As a result, we developed a design-engineering model that can be used in both technical and more social-science problems.
In addition to the diverse disciplinary expertise, the teachers also had different experiences and ideas regarding best forms of teaching. Although this led to many stimulating and insightful discussions in the preparation phase, it sometimes also led to unclear conclusions on how to proceed and to a sub-

optimal integration of all domains and learning lines into the project. Looking back, we should have agreed upon a central educational idea in an earlier stage of the programme development.

We used a general planning for the design of the programme, to make sure that everything was ready on time. As the programme was new to all the teachers and we were not certain what we could expect of the students, certain aspects of the programme (e.g. workshops, assessment procedures) were optimized while the programme was running. Although the final decisions were of good quality, the late alterations resulted in workload peaks for the teachers, specifically around the assessment of the projects and of the complete semester. A good planning in the design phase of the programme, as well as making concrete decisions well in advance could help to diminish peaks in workload in the future.

4.2 Experiences with project-led education and interdisciplinarity

The three-week freshmen project was designed as an introduction to PLE, which functioned well. Students indeed learned to work as a team on a relative large assignment and got a good impression of what PLE is about. Students had to use their high-school knowledge and creativity to solve the problem. We noticed a general failure to make a thorough analysis of the problem, thereby remaining only at a superficial level and going for the quick solution. During a reflection session, the students indicated that they could have gone much deeper. Apparently, deep analysis and challenging yourself does not happen naturally, not even for ambitious talented students.

From the start, the human movement project was designed in an interdisciplinary way, including both technical aspects as well as social aspects. Knowledge from different fields was necessary to come up with and design a solution to the problem at hand. The integration of these fields, however, was not a natural step for the students. Most of the project groups divided the problem into two different aspects: a technical part and a social-science part, each with their own sub-group of students working on that part. The two parts were combined at the end of the project for the final product. Hence, the real integration of fields failed to materialize in most groups. The tutors tried to stimulate the students to work more on this integration, but apparently this needs much more attention. Next year the project description will be improved in such a way that the solution should be a natural integration of knowledge fields. Furthermore the tutors will force the students to focus much more on the integration of different domains in the final project outcomes.

4.3 Experiences with self-regulated learning

Writing a PDP at the start of the first semester posed a challenge for the students. Many were still unsure about what they wanted to learn and what kind of master programme they are aiming for, and thus described their personal learning objectives in a very general and broad manner. As a result, the PDP often could not be used effectively to direct their learning during the semester. A learning-style test (ILS [8]) taken halfway the semester also indicated that many students were not really aware of their own learning strategy, nor working consciously to improve this. We feel that this lack of self-awareness regarding their learning is likely caused by the fact that high-school programmes are not challenging enough for them to confront them with the (in) effectiveness of their learning strategies. Next year we will pay more attention to the development of the individual learning skills even earlier.

4.4 Experiences with student planning

Students indicated that they missed a clear structure in the programme. Even though the limited structure is core to the ATLAS programme and we therefore often informed the students about this, they were struggling with the broad description of the project, the limited number of guidelines, the self-directedness of the programme and the absence of intermediate deadlines. In the beginning of the project students did not spend much time on their project work but focused more on the assignments for the different domains and learning lines. As a result, they had to work much harder at the end of the semester, to make sure the project was finished before the deadline. That many of these talented students do not have good planning skills might seem strange at first, but is probably due to the fact that their cognitive talents always allowed them to immediately oversee the limited-size projects they experienced in high school. Moreover, most high-school programmes are very structured, thus diminishing the need for good planning skills. Next year we will introduce a few intermediate deadlines in the project to help getting students on track.

The lack of a structured programme, with only a very limited number of lectures and workshops, also gave the students the impression that they did not learn enough during the semester. However, at the end of the semester when the students had to reflect critically on their learning, almost all indicated that they learned (much) more than they had expected.

4.5 Experiences with the guidance and assessment of the students

During the first semester we monitored how the students were doing, using assignments, take-home tests and class observations. For most students the teachers felt they had a good impression about their progress. This impression proved to be right, as the final verdict at the end of the semester was for almost all students perfectly in line with the impressions halfway the semester.

The tutor's role is to help each student group with their project, focusing mostly on the process of the project work and the cooperation within the project team. We started with two tutors per project group, one with a technical and one with a social science background. We experienced that some steering by the tutors was necessary and that the combination of a technical and a social science tutor helped the students, as they each guided the group from their own perspective.

The mentor is the individual coach of the student, focusing on the general development of the student and the planning of his/her learning and the actual learning. Both tutors as well as mentors had regular meetings with the students. Similarly, the coaches met regularly to discuss student impressions so far. With this combination of different coaches, we had a good overview of the progress of all project groups and of the individual students.

5 CONCLUSIONS

This paper presented the interdisciplinary BSc honours programme of ATLAS at the University of Twente with its unique focus on technology and its implementation of PLE. Interdisciplinary thinking is demanded by the project descriptions by requiring the integration of both technical and social perspectives. For this an interdisciplinary design-engineering model was drafted by the core team of lecturers and taught to the students. To challenge ambitious high-ability students, PLE principles are enriched with self-regulated learning. Students draw their own learning goals in their PDP, work on them in the project and finally reflect critically on them in their SER. This is similar to what professionals must do in their working environment.

First experiences are shared based on the first semester rollout of this programme. When designing such an interdisciplinary programme, the team should be interdisciplinary itself as well. One needs to take time to learn from and overcome the differences in ideas and experiences between different disciplines. A good detailed planning can help with this, as well as taking important decisions well in advance. Even ambitious high-ability students are naturally inclined to go for the easy solutions without digging deeper. Forcing yourself to dig deeper and really challenge yourself must be demanded by the complexity of the project and the necessity to natural integrate the various knowledge fields. Similar observations were made with respect to the student's planning abilities. Most high-ability students have never felt this need and feel therefore unsecure when challenged with high workloads and competing task descriptions. This insecurity gives them the impression that they are not learning enough, when actually (in most cases) the contrary is true.

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