Interdisciplinary Education:
a case study at the University of Twente

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ABSTRACT

The ability to cross boundaries is considered fundamental to the ability of scientists, engineers and others to solve modern real-world problems. As with other educational fields engineering higher education needs to find suitable interdisciplinary approaches to meet these requirements. While there is much current study of interdisciplinary learning it remains a challenge to formulate general strategies for implementing interdisciplinary education in a way that students become skilled collaborative problem-solvers. At the University of Twente there are currently opportunities to explore different responses educators have to this challenge, through the study of the *High Tech Human Touch* minors: a programme which offers minor courses to meet interdisciplinary learning objectives. This case study performs a comparison between the 10 *HTHT* minor courses relying on the education model ADDIE, to elicit similarity and diversity, and related challenges, with respect to how instructors in each course have responded to their interdisciplinary task. To make this comparison the student-perspective has been taken into account through interviews and evaluations, in addition to desk-research and semi-structured interviews with teachers. In current literature there is little information about how students perceive interdisciplinary education, yet such information can help understand the complexity needed for an interdisciplinary ‘pedagogy’. Comparing the 10 *HTHT* minors, a range of different interdisciplinary educational designs can be identified, with distinct challenges to each, beyond the canonical model of collaboration-based designs. Especially noteworthy is the fact that students consciously opt for these *HTHT* minors to learn from other disciplines, but that this is not often the learning outcome, signalling a frequent gap between student expectations and educational outcomes.

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1 INTRODUCTION

Modern engineers are expected to possess professional skills, but also the ability to operate across disciplinary boundaries in order to overcome contemporary and future challenges which cross those boundaries [1]. As such universities across the world are putting more emphasis on interdisciplinary programmes to educate students in the hope that they acquire those skills. Literature reveals that there are different strategies with respect to how interdisciplinary education can be organized. For example, an educational programme may include study material from other disciplines in its own discipline [2], or an educational programme can be set up in a way that the population of students in the course consists of students from multiple disciplines [3]. Nevertheless, there is at present a lack of concrete differentiation and categorization of the different interdisciplinary learning course structures applied in educational programmes. Mostly interdisciplinarity is conceptualized these days in terms of collaborative skills or the ability to integrate disciplines through the agency of collaboration [4].[2] Additionally, there is not much reported on interdisciplinary programmes in which there is a combination of engineering disciplines and social sciences [5]. This is important, given the goals governing interdisciplinary learning for engineers often demand engineers to have the ability to address complex problems requiring the integration of environmental, medical, social and economic aspects into their work [4,6]. Overall according to the ABET criteria, solving problems subjected to multiple non-engineering constraints and non-engineering success criteria is a necessary skill engineering students need to master, to be able to function in their field [7]. This means that we need to teach students to reflect critically on their own discipline in relation to others, and recognize limitations and advantages of different perspectives [8]. Although research has been done examining these kinds of interdisciplinary skills [9], there is not much known about the student experience in interdisciplinary programmes [10]. Nevertheless, the student-perspective is of great help understanding and evaluating novel educational approaches [11].

As an answer to these challenges the University of Twente changed their bachelor education in 2013 from a subject-based approach to a more holistic approach of project-oriented education, employing what is known as the Twente Education Model (TOM). TOM aims to educate students to become entrepreneurial T-shaped professionals; students who are not afraid and capable to venture off the beaten path, apply their disciplinary knowledge in broader contexts, in collaboration with other disciplines and society [12].

The aim of this case study is to analyse the experiences of the High Tech Human Touch (HTHT) minor courses. This HTHT programme was developed in line with TOM to create space in the curriculum for interdisciplinary topics which might give monodisciplinary students skills to cross boundaries particularly into political and social realms. Instructors were given tasks to design material to fit those ends. More concrete, the goal of this study is to understand and evaluate how instructors addressed this task set by the HTHT programme, through their conceptualization of interdisciplinary visions and goals, and how well students themselves perceived and

[2] In this review study two-thirds of the reviewed interdisciplinary engineering education papers reported on a collaborative project or problem-based learning course or programme structure.

conceptualized these goals and felt their expectations were met. As a result we extend knowledge on the potential educational designs of interdisciplinary programmes including in cases where biological, engineering and social scientific knowledge is involved. To extract elements of design and assess their performance, we have relied specifically on the ADDIE model, in conjunction with instructor interviews, student interviews and student evaluations.

2 BACKGROUND INFORMATION

2.1 Twente Education Model

All 19 bachelor programmes at the University of Twente implemented the Twente Education Model (TOM) in 2013; a major curriculum innovation with the aim to better prepare students for the future labour market. One of the three pillars of TOM is project-led work; an overarching didactical approach that fits the university's vision in which students are facilitated and encouraged to develop an entrepreneurial attitude using non-academic problem-solving and co-creation skills [13].

TOM consists of a pre-defined curriculum structure, with courses of 10 weeks each 15 European Credits. Moreover, in a bachelor programme at the University of Twente there are 4 courses a year, resulting in 12 courses in total. As shown in *Figure 1*, in the third year of the TOM bachelor programme students have the freedom to choose a minor course, which is a compulsory six-months of education amounting to 30 European Credits.

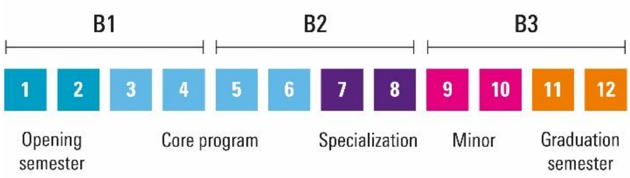

Figure 1. The TOM bachelor programme

The university offers diverse options among which are the *High Tech Human Touch* (HTHT) minor courses. The *HTHT* courses are required to be open to students from any background and focuses on problems in society, with the aim of giving students knowledge and skills to address political, social, environmental and medical problems outside their usual disciplinary sphere of activity and to develop sustainable HTHT solutions. Naturally there is an opportunity, if not necessity, to conceptualize some of the skills required as interdisciplinary ones. The choice however of how to do that has remained with the instructors.

There are 6 minor packages of 30 EC and 4 minor courses of 15 EC. An example is the minor course 'Aeronautical Engineering and Management'. In this minor course, students get acquainted with the development and operation of an aircraft. The aerospace industry is a fine example of the interrelationships between technology, economics, social and human sciences. Students explore how the needs of organizations, such as airlines, define the aircraft that aerospace manufacturers Boeing and Airbus develop, how technology is used to turn the aircraft from ideas into reality, and what is required of humans to operate them safely.

In all minor courses the project is central. A problem is outlined as the starting point of the student's learning process. In other words, these courses are designed using a project-based learning approach. Because of the interesting combination of social sciences, medical and engineering education, there is large variation in the degree programme of students undertaking minor courses and in the project-based learning strategy applied. The HTHT minor courses provide an excellent opportunity to examine the questions: 'how do instructors address the task of building courses on subjects outside the domain of participating students, who come from multiple backgrounds, and how well do students themselves perceive and conceptualize these goals and feel their expectations are met?'

2.2 ADDIE model

The ADDIE model provides a systematic instructional approach to course design, which in turn offers a framework for delimiting essential instructional features and comparing how the interdisciplinary courses we review have been designed to meet the HTHT interdisciplinary and societal programme goals. The ADDIE model stands for the five steps *Analysis, Design, Development, Implementation* and *Evaluation*. It is a guiding framework with an iterative process often used in designing educational programmes [14]. See *Figure 2*.

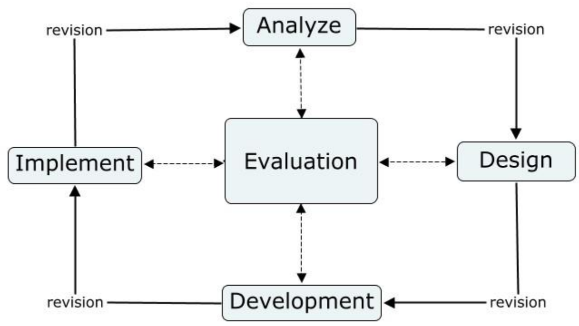

Figure 2: ADDIE model

The first step, *Analysis*, relates to the vision and overall aim of the course, programme or other educational unit; what do you want students to learn- and how are the learning objectives related to this. According to Borrego & Cutler this is essential to determine in order to be able to evaluate and enhance the learning process of students [15]. The *Design* phase addresses realization - how is the vision of the course put into practice through the structural design of the course including learning goals, -activities and assessment? In the next step, the *Development* phase, learning content and tools are developed in alignment with the design and vision. This phase answers questions: How will students be facilitated to reach the learning goals and what will the contribution of the teachers be? In the *Implementation* tools or instructional strategies are tested during a run of the course with actual students. *Evaluation* runs the length of the course, in which the quality of the design is assessed. Target questions include 'How do students experience the course?' and 'What are successful elements?' [16].

At first sight, the components within the different phases of ADDIE seem comprehensive, but no mention of constructive alignment is made explicitly. According to Biggs 'constructive alignment' is an essential factor of educational quality, measuring how well educational aims link to educational designs [17]. However constructive alignment is arguably at the heart of the ADDIE system, the extent to which each phase is assumed to align the components it develops with previous ones up the chain. As such to investigate the interdisciplinary HTHT courses in this case study the ADDIE model and constructive alignment are applied together as an evaluative framework for the educational designs.

3 METHODS

3.1 Research Design

This case study used a qualitative descriptive research design to examine how interdisciplinary education is designed in practice, specifically in the HTHT minor courses of the University of Twente. Qualitative research following the ADDIE model gives the opportunity to gain in-depth understanding with respect to the differences in design and motivation these minor courses apply to interdisciplinarity. The data was collected in the 2018 iteration of the programme during and at the end of the minor courses, to receive the most current and reliable information. The questions formulated for the interviews are in accordance with the framework of Interdisciplinary Learning in Engineering Education, which is based on a literature review of 110 articles in engineering education on interdisciplinary learning [4, 18] (*Figure 3*).

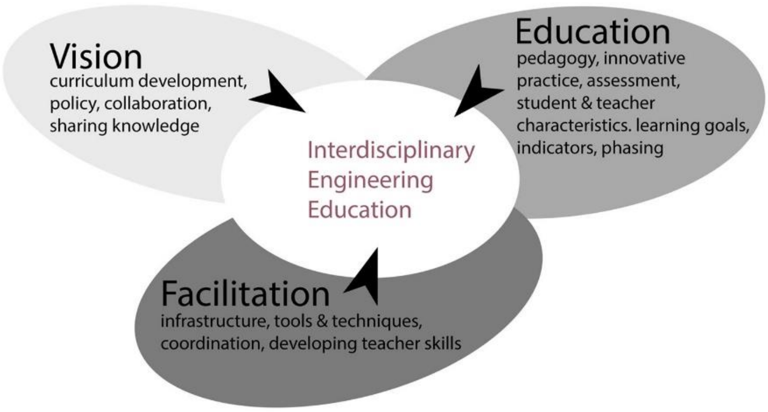

Figure 3. 3TU – Centre for engineering education – framework (Beemt and Ven [18], Beemt et al. [4]).

In *table 1* an overview of the instruments used for data gathering are presented.

What	Instrument
minor course coordinators perspective on educational design of interdisciplinary minor	Semi-structured interviews using the ADDIE model [14], in accordance with the framework on interdisciplinary learning developed by a consortium of the 3TU Centre of Engineering Education, with an emphasis on 'education' (See figure 3).
Student perspective on educational design of interdisciplinary minor	Semi-structured interviews using the ADDIE model, in accordance with the framework on interdisciplinary learning developed by a consortium of the 3TU centre of Engineering Education, but rephrased from a student perspective. The interview sessions were organized with groups of students, functioning as a panel. We chose groups of students rather than individuals as students can reinforce each other's views and experiences, and help formulate answers to unfamiliar questions, since they are all in the same position'; i.e., they are all students, have none to little experience in interdisciplinary education, and have similar levels of knowledge and experience. For these interviews the interviewer kept in mind that every student in the panel had input and should be invited directly to participate.

SEQ (Student Experience Questionnaire) on educational design of interdisciplinary minor	The Student Experience Questionnaire (SEQ) is a standard evaluation of the TOM courses in the bachelor. For the minor courses the SEQ is extended specifically on the interdisciplinary learning aspect. These specific questions are taken into account in this case study to elicit the student-perspective. An example of a question is 'it was an advantage that the students in my minor were from different disciplines' that can be answered on a scale from 1 to 5.
Analysis of documentation (e.g. minor course/minor manual) on similar aspects as semi-structured interviews	All minors have a minor course manual for students. In this manual the structure of the programme, learning objectives, learning activities and assessments are presented. Also in the University's Learn Management System (Osiris) some basic information of the minor is shown. Of three courses, we obtained access to their CANVAS page, where all documents related to the minor course were available. This documentation clarified and supported our understanding of the educational design of the HTHT minors.

4 RESULTS

The results of this case study of the 10 HTHT minor courses are analysed using ADDIE and constructive alignment in accordance with our research goal: to understand and evaluate how instructors address the task of building courses on subjects outside the domain of participating students, who come from multiple backgrounds, and how well students themselves perceive and conceptualize these goals and feel their expectations are being met'. Below a short explanation is given of how different phases of ADDIE were used to structure the interviews. The results of the ADDIE analysis are shown in Appendix I, *table 2*. Based on these outcomes, three representative minor courses each with a different interdisciplinary approach were chosen for in-depth interviews with students. The summary of qualitative information from those interviews can be found in 4.2 below.

4.1 Application of ADDIE to HTHT courses

With respect to *Analysis*, all instructors face the challenge of constructing a course which can encompass a societal dimension, technical knowledge and a diversity of students of different backgrounds. This is the specific context in which notions of interdisciplinarity and strategies for training could be freely developed by HTHT instructors. For the *Design* phase we focused here on learning objectives, learning activities, assessment, and constructive alignment. For the *Development* phase we considered the learning content, tools and contributions of the teachers which facilitate students obtaining, in this case, interdisciplinary learning goals. In *Implementation* we examined if teachers are trained and if instructional strategies are tested to foster interdisciplinary learning and thinking. Finally, in *Evaluation* we assessed the quality of the design through the use of the SEQ results which track student perceptions.

4.2 In depth-interviews with students

In this section we give a summary of three specific courses and present some of the student reactions and comments. These courses are illustrative of the diversity of approaches instructors are taking with respect to the HTHT task. Based on the interviews with module coordinators, review of course descriptions and handouts we distinguish 3 different interdisciplinary design structures amongst the minors courses: 1) training largely mono-disciplinary students in an interdisciplinary domain, 2) training new knowledge and skills for a mixed discipline group, and 3) training interdisciplinary collaboration and integration as necessary skill. Each of the 10 courses matches broadly in design with one of these.

4.2.1 Biorobotics

In this minor course a large mono-disciplinary group of students is trained in an interdisciplinary domain. Biorobotics applies high-tech systems & control knowledge of robotic design to the biomedical interaction with the human body, and thereby combines a vast number of disciplines. Much of the interdisciplinary materials and skills required in this minor course is the same for all students. Although this minor course is open to all students, only a very small amount of students from engineering programmes outside biomedical engineering or advanced technology follow it. The principal challenge for instructors is providing a course design which helps students create links between their background knowledge in biomedical engineering or advanced technology and the new interdisciplinary knowledge of robotics.

In the interview session students (4 in total) stated that their goal in following this minor course was to learn in more depth about different subjects from another field of study, in this case ‘robotics’. Interdisciplinary collaboration was not a stated learning goal of the course. Students reinforced this stating that guidance or learning activities related to interdisciplinary integration and collaboration were not necessary to complete the project. They agreed upon the fact that they were all on the same level, because each was undertaking a degree in biomedical engineering. Nonetheless one student stated to us: “The integration of the human aspect could have had more attention, also how you could effectively integrate this in your solution, and for sure I think an interdisciplinary project team helps to learn to understand another discipline better.” The comment suggested that the lack of interdisciplinarity somewhat limited their ability to fully appreciate and integrate the new material they were learning.

4.2.2 Smart ways to get smart cities smarter

In this minor course a mixed student group is trained new knowledge and skills. The goal for students is to acquire understanding of how the construction of Smart Cities affects the physical urban built environment, and how such Smart City solutions can be implemented in existing city spaces. Besides working together with students from different disciplines, the students in this minor course are working with an entirely new set of methods and concepts that are not based on a specific scientific background. Central is a step by step plan designed for finding smart city solutions. The content is thus novel and actively taught by teachers. In this model of interdisciplinary learning collaboration or peer learning is hoped to facilitate students’ ability to acquire new knowledge and skills in an unfamiliar area. More specifically, instructors do require that students are able to explicate and transfer their specific domain knowledge to fellow students from other fields (peer-learning), but only by means of applying these new methodological skills effectively. As such interdisciplinary collaboration is more of a learning context, than a specific problem-solving requirement.

The interview session included two students from the minor course ‘Smart ways to get smart cities smarter’; one from mechanical engineering and one from University College Atlas. They stated that scaffolding the collaboration process could have helped to get more out of the interdisciplinary collaborative learning process. As one student put it: “It would have been nice if there were process tutors who coach and guide you in the collaboration process by focusing on how we could use each other’s expertise; someone capable of bridging the gap between different disciplines.” According to Borrego a key element for improving the success of interdisciplinary collaboration is providing instructors and tutors capable of bridging perspectives [19].

4.2.3 Science to Society

An example of the third design is the minor course ‘From science to society’, a package of 30 EC. In this course students, who come from a wide range of disciplines, need to design a prototype and a solution to a societal challenge by using multiple scientific approaches. During the first 10 weeks (minor course 1: from Idea to Prototype) the students are introduced to the foundations of different scientific disciplines and skills to ensure that they share a common set of appropriate skills and methods in their project team. Next, they delve into the state-of-the-art of the science behind the theme of their choice, with the goal to look for novel ways of applying their own background expertise in a closely guided yet agile design process. Students walk the path from a general idea to one or more scientifically and practically grounded prototype(s) for the challenge at hand. In the second half of the minor (minor course 2: from prototype to society) student project teams focus on realizing the prototypes developed in the first part, and researching issues surrounding the implementation and use of the product-in-development. Accordingly, the prototype is enriched with a business model addressing the feasibility of the product. In this design the focus is on interdisciplinary collaboration. Interdisciplinary collaboration skills are a central learning goal, in which each student is expected to bring their background expertise to the table. For example one of the learning goals of the minor course ‘From science to Society’ is: ‘students are able to apply a design process while working in a multi-disciplinary team, and ‘student need to be able to reflect on his and the other team members’ role and contribution to the team.’

In the interview session students of the minor course ‘Science to Society’ stated that they perceived the workshops of interdisciplinary team work as useful, but it was in their opinion not enough to support the interdisciplinary collaboration process. One of the students of the minor course ‘Science to Society’ said: “I now understand better that you have to acknowledge and understand the strengths of everyone to find the best solutions, but it was hard to find my own role in the group and find out how my expertise could be used”. However, one student of this minor course said: “Travelling to the industry stakeholder, and other informal team activities, helped in the process of getting to know each other’s expertise.” As stated by Borrego interaction is time one of the key elements to improve the success of interdisciplinary collaboration [19], and identification and integration of individual knowledge and skills in the common knowledge is not always easy, but the creation of a common ground can have a noticeably positive effect on interpersonal relationships [20].

5 DISCUSSION

Although in all the HTHT minor courses learning goals related to interdisciplinarity are formulated, the educational value of interdisciplinarity as specific types of skills or knowledge is conceptualized differently depending on the nature of the knowledge and skills the instructors wish to convey, and the relevance of interdisciplinarity to problem-solving in that area. Notably while collaborative and integrative problem-solving skills are often singled out as relevant learning targets central to interdisciplinary learning in education, only four of the design structures require it as a specific learning goal based on our analysis, even if “collaborative skills” or teamwork skills are otherwise cited as a learning goal. Nevertheless, opening up students to different perspectives outside their basic disciplinary orientation is accounted for in all course designs. Students in the minor courses all absorb the message that it is important to be able to speak ‘another language’ and that the human aspects in technical solutions should have more emphasis in their educational programme. This is one of the main reasons, students report, as to why they choose an HTHT minor course.

In addition, while an ADDIE analysis brings forth relatively clear and distinct interdisciplinary learning goals in each case, these are not always well mapped or constructively aligned to elements of *design*. For instance although all students are expected to develop interdisciplinary teamwork in the course of problem-solving, in the majority of the minor courses there are no explicit learning activities for training these skills or assessment events. Only in some minor courses students are asked to submit a reflection on the project process, for example about their own contribution to the group work and what they learned from other disciplines. However, this part counts for a small percentage of the total grade and the majority of the interviewed students did not feel that sufficient guidance was given regarding the interdisciplinary collaboration process. As such while the various courses develop a variety of interdisciplinary learning goals to suit their educational visions, design elements which reinforce or implement these explicitly are limited.

Regarding the *development* phase, where facilitation by tools or teachers are central, most minor courses show that they make use of tutors. Most of the time an expert in a specific domain, to whom students can ask questions related to that topic. Only in three minor courses are ‘process’ tutors available, to whom students can ask questions related to the process or collaboration process. For example in the minor course ‘Science to Society’ master-student assistants have the role of ‘process’ tutor, but these only have to act upon their role on the initiative of the students. In the minor course ‘Innovations in sustainable chain management’ and ‘Aeronautical engineering and management’ there are tutor meetings on a regular basis to monitor group work.

From interviews with students it became clear that a useful tool for developing their interdisciplinary skills was the step by step plan used in the minor courses ‘Science to Society’, ‘Aeronautical engineering and management’ and ‘Smart ways to get smart cities smarter’. These plans provide a systematic approach to designing a solution, which, according to students, also help to structure the collaboration process and develop a common way of working. However apart from these initiatives most students are left to manage the interdisciplinary learning aspects themselves without explicit resources.

As such the student perspectives we encountered here suggest a strong sensitivity of students to interdisciplinary goals, and demand for assistance meeting them, rather than being left to handle them themselves. Further, students show a preference towards assessment tasks that can help them develop a concrete understanding of what their interdisciplinary learning objectives are. This information reinforces the importance and necessity of constructive alignment, particularly in interdisciplinary contexts.

Further, results from the *implementation* phase, suggest how important it is for teachers themselves to manage how they educate and guide a mixed group of students from different disciplines. Some of the teachers received tutor training, and a smaller proportion received training which did address interdisciplinary groups. However many teachers in the HTHT minor programme do not have this training and guide the students based on their own experience and expertise. In addition tools or instructional strategies are rarely tested in terms of their ability to facilitate interdisciplinary learning and thinking of students. Only in the minor courses ‘Science to Society’ and ‘Aeronautical engineering’ teachers gathered qualitative information by interviewing students about the methods that were used.

6 CONCLUSION

In spite of numerous positive student learning outcomes the design and development of interdisciplinary programmes is not without difficulties. Our results suggest that when instructors are given an ostensibly interdisciplinary task, they will formulate a diversity of responses which conceptualize the educational value and content of interdisciplinarity in different ways. Not all these responses will rely on or promote interdisciplinary collaboration. This means that what counts as effective design and constructive alignment in one case will not be in another. Educational scholars should take account of this diversity when arguing for or evaluating interdisciplinary learning. However while our instructors did demonstrate capacity to shape learning goals and an overall course structure to meet the open-ended interdisciplinary goals of the HTHT programme, the generation of learning elements to support the ability of students to obtain those goals, and elements of constructive alignment, were still lacking. This creates a disjunction between the expectation the students had of a course regarding what they would get out of it, and what they eventually did. Students need to be provided with specific teaching approaches to support the development of interdisciplinary skills. These approaches, and the awareness of what is needed in an interdisciplinary educational setting are essential in the design of interdisciplinary programmes to be able to produce quality interdisciplinary work in future professional lives and to solve complex problems [4, 19].

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8 APPENDIX I

Table 2: results of semi-structured interviews with module coordinators/teachers of HTHT minor courses

Minor Courses ADDIE phase	Analyse	Design	Development	Implementation	Evaluation
30 EC package					
Aeronautical Engineering and Management	The minor consists of two courses 'aircraft engineering (1)' and 'aerospace management (2)'. The first course focuses more on the technical/engineering part whereas students in the second course learn how these technical aspects are integrated with the social aspects/human factors.* The two courses of the package are self-contained, and though collaborative work is a prerequisite of the design process followed by the interdisciplinary student	Most learning objectives are related to the content of the courses, with the comment that students need to be able to take the technical and human factors into account when making strategic and operational decisions. Some learning objectives are related to design or project skills, with the prerequisite to be able to work and operate in an interdisciplinary project team. Students are prepared through a series of	Students are, during the process of their project, supported by tutors; this can be an expert in a specific domain, to whom students can ask questions related to that topic, but can also be a "process tutor" who helps to improve the collaboration process. Tutor meetings take place on a weekly basis. Besides, students work according to a	Teachers have experience in aeronautical engineering and management; a broad and creative field of research and expertise. Most of the teachers did receive tutor training, but are not trained specifically to educate and guide interdisciplinary group of students. The workshops, and design process are the tools used to foster interdisciplinary	In course 1 students experienced it as an advantage to have students in their project group from different disciplines. Also on average they think they learned much about the other disciplines, and think it is valuable for their future work. In course 2, students didn't experience the

	teams, the aim of the package is to provide students new knowledge and skills for aeronautical engineering and management.	workshops (3 in total) to become more effective as a team in an interdisciplinary setting. All the other learning activities are content related. The knowledge and skills are tested by 6 content specific tests, assignments and a simulation game, but also twice a report (with a small reflection part) and presentation including an oral exam are part of the assessment.	design process and are prepared by 3 workshops about interdisciplinary effective teamwork.	team work. These tools are qualitatively examined by the teachers by interviewing students [21].	advantage of having an interdisciplinary project group and also stated that they did not learn from students from other disciplines. Looking at the composition of the student groups, this could be a result of the homogenous student groupings in part 2. (Results from SEQ).
Geographic information system and earth observation	Students who take both courses get a comprehensive introduction to acquiring, storing, analysing and visualizing geo-information. They can directly make the relation between how one can sense processes on earth and how that can be translated to information on a global,	All learning objectives are related to the content of the course and are not focused on the collaboration process, or on interdisciplinary skills. As stated by the module coordinator of these minor courses: “These minor courses, as well	Students at the faculty of ITC are educated with the method of decision-supported questions: the perspective of diverse experts needs to be taken into account for a solution which can handle real-life problems.	Teachers are not trained, but only briefed about the expectations of the courses. Also students are not trained on interdisciplinary skills and no specific tools are used to foster	From the SEQ (student experience questionnaire) only information of course 2: earth observation is available. 9 students indicated that the project was valuable, and

	national or even individual level.* The two courses of the package are self-contained, and though collaborative work is a prerequisite of the design process followed by the interdisciplinary student teams, the aim of the package is to provide students new knowledge and skills in Geo-information systems and Earth observation.	as the faculty of Geo-information System and Earth observation, where these courses take place, are interdisciplinary in itself." The learning activities are set-up in a way that students are introduced to new concepts which they can apply in the projects. The assessment consists of multiple assignments, presentations and written exams, all related to the subject of study. An important aspect of study is retrieving geo-information in combination with effective communication to stakeholders.	Practicals are used to support students in linking the data (that has been collected for multiple purposes) and the application. In analysing this connection students need a technical and social view, which can enhance interdisciplinary thinking. There is minimal supervision / tutoring to support students in their collaboration or learning process. The students self-regulation of learning is seen as very important.	interdisciplinary thinking.	they learned the most of the cooperation with other students and liked the integration of subject matters. No answers specifically on the 'interdisciplinary' aspect was given.
Innovation, entrepreneurship & business development	The first course of this package prepares for independent venturing, based on commercialization of a product/service idea into a plan that assesses feasibility of the idea.	Most learning objectives are related to the content of the courses. Only one explicitly states: "students are able to collaborate multi-disciplinarily using	Students are taken by the hand: there are fixed moments for feedback, peer review and intermediate pitches of ideas. In both courses there are methods used for	Teachers in these minor courses are all experts, who started a company or own one. They share their expertise and their experience. They connect theory with	From the SEQ it can be concluded that students think the learning path is extremely fixed. So they cannot decide

	The second takes this knowledge into an inquiry that aims at exploiting an invention by identifying conditions and potential adopters and users of the technology for the decision either or not to appropriate it by the UT for future technology transfer purposes.* The aim of the courses is to develop students' entrepreneurial mind, provide them new knowledge and project management skills, and develop their ability to appreciate and use each other's expertise in real life cases.	project management skills." (course 2). Students are introduced to the different aspects of innovation, entrepreneurship & business development by virtue of an "acceleration game", lectures and tutorials, homework assignments and in the end in both courses a project (where students work on real-life problem situations companies have dealt with). Subparts are assessed separately (individually) but for the project (business plan) students: -report -peer review -reflection report -get feedback product & process of tutors (formative) -presentation.	the process students have to follow to finalize their project. For example in the first part students use the 'Lean start-up' approach. Students from social sciences and technical sciences are combined in one group and guided through the process by a 'coach'; an expert teacher of the module team.	the practical side of the project. The set-up – namely, real-life cases, real-life business methods, regular feedback - should help students improve their interdisciplinary thinking (which is not tested explicitly). However, the involvement of real-life companies and the extreme diverse group of students makes it also complex to implement this module (as stated by the module coordinator).	when, how and what they learn. In course 1 student stated that it is an advantage that students were from different disciplines, but they also stated that they didn't learn a lot about the disciplines of others. Overall however they are satisfied and enjoyed learning and working in an interdisciplinary course. In course 2 students are satisfied about with the 'interdisciplinary' aspects, but doubt about the learning effect, assessment and teaching methods.

Philosophy and Governance of Science and Technology	In this package consisting of two minor courses students develop a basic understanding of how science and technology can influence the human being and society, focusing on human behaviour, knowledge and values, and on evaluating and governing social change. They will do so using insights and perspectives from philosophy (course 1) and from science and technologies studies and governance studies (course 2), and by applying those to projects in which students will work on concrete examples of technologies in collaboration with the UT science and technology institutes (both courses).* The aim of the minor courses is that students develop skills to systematically and critically reflect on science & technology and their social roles.	All learning objectives are related to the content of the courses, but these can be seen as 'interdisciplinary'; "students are able to explain how technological and societal dynamics mutually influence each other drawing on concepts and theories from science, technology and innovation studies". Regarding the assessment all subparts are assessed separately with assignments and an exam. In course 1 projects should integrate all components in the study of an engineering or scientific lab. In course 2 students should integrate components in preparing strategy recommendations for an innovation actor.	The teacher team decides the composition of the groups; to mix students from different disciplines. However, there are many students from psychology, and a few from other studies. No specific tools, workshops or guidance is given regarding the 'interdisciplinary aspect'. Students are made aware of the influence the research fields have on each other; so the content is interdisciplinary in that respect.	The set-up, with real-life cases connected to theory and discussion moments these minor courses hope to achieve that students improve their interdisciplinary thinking (which is not tested). Teachers are all experts, and it is expected from them that they improve their education based on the feedback they get from students; they are not trained to work with interdisciplinary group of students.	The SEQ results showed that students in general appreciated the project, and working in groups. Also, they stated that the minor helped to understand that a technical solution and society are connected to each other. However, students do not report learning much about other disciplines, or collaborating across boundaries.
Science to Society	This package uses real-life problems that need to be solved in multidisciplinary	The learning objectives are very diverse, focusing on the	Students are, during the process of their project, supported by	Most teachers have experience in educating students	SEQ results show that students

	teams with the goal to cultivate increasingly important skills, such as; team player skills, communicative skills, and reflection skills. Real-life problems focus on societal challenges in diverse fields like energy, healthcare, learning and robotics. In part 1 students work on generating novel ideas and design concepts, transforming these into a prototype. In part 2 students evaluate critically how this can be realized using a business model addressing its feasibility.* The overall aim of this minor is that students become aware of their own (possible) impact in the whole design process and the (possible) impact of others, self-regulating the collaboration process and their own learning process.	implementation, use, validation and grounding, theoretical underpinnings, design method, results and teamwork/project management. For example; students need to reflect on their and the other team members' roles and contributions in a multidisciplinary team, but also need to be able to integrate multiple disciplines in the whole design process e.g. in the research question. (In addition, students are also asked to write down their own learning objectives). The idea of these courses is that students start a design using the iterative design cycle of the 'Design lab'. Small workshops about project management, product design, interdisciplinary teamwork, research	tutors; in this courses this can be an expert in a specific domain, to whom students can ask questions related to that topic, but also process tutors who help to improve the collaboration process. However, most of this support is only available on the request of the student.	from different disciplines. Most of the teachers did tutor training, with some receiving guidance in facilitating interdisciplinary group of students. The workshops, the design process, the lectures on research skills and project management are all tools used to foster interdisciplinary team work (qualitatively tested through interviews with students). One unique aspect of this minor is that it is structured solely around a project.	experience this minor as very valuable with a large learning effect regarding the cooperation with students from different disciplines. Also, students enjoyed working in a multidisciplinary group, learned from others, recognized their contribution and value for the project and that of others, see the advantage for their future and see the connection of social and technical sciences. The only things that can be improved according to the SEQ results is

		skills, and subject specific lectures related to the chosen project case are given for this purpose. Assessment is often formative providing students feedback. Peer-review, intermediate and final reports and presentations, are summative assessment tools.			the exchange of expertise between teacher and students and that feedback comes in time.
Innovations in Sustainable Chain Management	The central theme of this minor is the sustainability analysis and management of integral chain of resources, materials and societal processes. The need for knowledge on energy and resource efficiency, on process emissions, logistics, law and governance, chain (network) management , transition management, etc. to analyze and manage such chains from a sustainability perspective	The learning objectives are very diverse, focusing on the analysis, plan, validation and grounding, theoretical underpinnings, design results and individual interdisciplinary skills. For example; students need to be able to elaborate and synthesize different perspectives of individual students, and teachers into a plan for a	As stated by the module coordinator this minor is set-up in a way that students have to work in an interdisciplinary fashion otherwise they cannot fix the problems they face in real-life cases. Students are supported by teachers from the social sciences and technical sciences.	Teachers are all experts in one of the aspects that has to do with supply chain management. They are not specifically trained in guiding interdisciplinary student groups, or integration amongst their different fields. Tools, and the set-up are not tested regarding	There is minimal to no evaluation material available.

	makes this theme very suitable for a High Tech Human Touch module. In the first module (Analysis) students learn to map and analyze the interaction between materials, technology, economy and society in chains from different disciplinary perspectives. In the second module (Design) students practice how to design sustainable solutions for the problems found in the analysis. In both modules students expand knowledge in their own discipline, learn the basics from other disciplines and work in multidisciplinary teams in the analysis and the design in the real life case.* Overall aim of the module is that students learn to use different tools to analyse and design aspects of supply chains, and translate concepts into practice.	group assignment, and to be able to handle and synthesize and pull meaning from partial strategies and designs in a multidisciplinary environment by producing a report in the contexts of society and if relevant the commissioning organization (conclusions and advice/ recommendations). Teaching activities consists of lectures in which literature is reviewed, subject specific methods/approaches are explained, and students work on a real-life assignment. Based on this knowledge and work students write papers, do presentations, peer-review each other and hand in a group report.	They stimulate and facilitate interdisciplinary thinking by using an external client and by asking critical questions during the moments of contact.	interdisciplinary learning and thinking.	
15 EC minor course	**ANALYSE**	**DESIGN**	**DEVELOP**	**IMPLEMENT**	**EVALUATE**

BioRobotics	During the minor course, students need to construct a robot which interacts with the human body to improve the quality of life for an individual with a movement disorder. Worldwide scientific and industrial demand for skilled engineers with advanced systems and control knowledge of robotic systems who can apply this knowledge in biomedical or general high-tech systems is strongly increasing. The minor BioRobotics applies high-tech systems & control knowledge of robotic design and construction to the biomedical interaction with the human body, thereby combining a vast number of disciplines. The overall aim of the course is to educate students in the subject of bio-robotics. This subject is implicitly interdisciplinary.	All learning objectives are related to the content of the course components, but these can be seen as 'interdisciplinary'; i.e. designing a robot for application to a biomedical problem using multidisciplinary knowledge from mechanical, electrical, control and software engineering domains. Lectures on the diverse aspects are given; control of BioRobotic systems, robot kinematics, biological signal analysis, programming of embedded systems. The assessment consists of two MC exams where all subpart are tested, and for the project a report, project demo, presentation and oral exam.	Students are, during the process of their project, supported by tutors. These tutors are student assistants who help minor students in the process of developing their project (on their own request). Student work systematically through a design trajectory; preferably in a homogenous student group so students cannot distribute tasks. (on the basis that all student learn all aspects of the design) Also, the course tries to involve a patient with a movement disorder to motivate students. In the end students have to reflect on the ethical aspects of their design based on one lecture given on this subject.	The teachers that are involved are experts in the specific field of study; aspects of BioRobotics. No specific workshops, training for tutors or skills education is provided for students to foster interdisciplinary learning.	Almost all students are from the programme of Biomedical Technology or Advanced Technology (which are interdisciplinary in itself). So for them this is an in-depth minor. From the SEQ students stated that they had a valuable contribution to the project and are aware that social and technical sciences are by definition connected to each other. But they did not experience collaboration with other disciplines because of the homogenous groups.

Materials for the design of the future	This minor course is a multidisciplinary profile course on one of the main research topics of the university and deals with the basics of different selected materials. In this module, students study the methodology of materials research and apply this knowledge to solve problems society is facing, or improving daily life of individuals. They learn how unique possibilities arise in the search for materials with interesting properties which enable the design of new functionalities for future applications. The overall aim of the minor course is that students are able to work on a smaller scale, at the molecular level, and on a larger scale, and integrate these levels.	Most ‘course’ objectives are related to the content of the course. However, in the materials requirements of sustainability, environmental and health hazards, recyclability etc are given as necessary to be considered. Also, the design must be evaluated from a technical and social view, i.e. students need to account for impact to humans and society. The learning objectives of the student are very technical. Learning activities consist mostly of subject specific lectures, lab work, and self-study. There is one lecture about human aspects. The assessment consists of two written exams of the two subparts (both 5 EC), an	Students can get guidance from the specific departments that are involved; MESA, MIRA + and mechanical engineering department. Research and the practical side of this field of study is involved closely. The practical assignment is a real-life question from Apollo (tires); this can motivate students to be creative and collaborate well with his peer-student (groups of two mostly an engineering student with a science and technology student).	The teachers that are involved are experts in the specific field of study; aspects of materials. Chemical teachers are often already at the interface of two disciplines, that makes them experienced in dealing with interdisciplinary aspects (as stated by the module coordinator). No specific workshops, training for tutors or skills education is provided for students to foster interdisciplinary learning.	The SEQ results showed that students in general appreciated the project. Also, they stated that the minor helped to understand that a technical solution and the broader social connection are by definition connected to each other. However, students did not acquire knowledge about other disciplines, or experience collaboration with students from other disciplines.

		assignment, project report and presentation.			
Smart ways to get smart cities smarter	In this minor students study how smart cities confront challenges related to urbanization, energy transitions and more accessible, reliable, safe and secure environments, and how urban life should be improved in smarter cities (e.g. through the use of smart energy grids, ubiquitous computing and location based services). In the first weeks, lectures focus on current developments toward smarter cities and attend lectures covering basic theory in geophysics, systems engineering, traffic data science, and robotics. Next, students are clustered in groups and assigned to projects. In groups they solve a real-life 'non-invasive city engineering' design problem. The overall aim is that students can systematically	Almost all learning objectives are related to the content of the course; aspects related to the container concept of smart cities (interdisciplinary in itself). For example, students are able to define how robotics, geophysics, and smart traffic solutions all can support construction of Smart urban life & mobility improvement. However, there is one learning goal focusing on an interdisciplinary skills: namely students should be able to explicate and transfer their specific domain knowledge to fellow students from other fields. The learning activities consists mostly of subject-specific lectures, tutor meetings, a company visit, and	Students need to know and must be able to work with the System Engineering V-model; a systematic process approach in this design project. Students are supported by tutors; but most of the time these tutor meetings were on by request only. In the second part, students work on a real-life case for companies for motivation. As additional motivation companies are formatively involved in the assessment of the students: they provide feedback. Students are made aware of the influence the research fields have on each other;	The teachers that are involved are experts in the specific field of study; aspects of smart cities. No specific tools, workshops or guidance is given regarding the ‘interdisciplinary aspect’.	The SEQ results show that students enjoyed working in groups, with different disciplines, and also perceive that the broader social context and technical solution are by definition connected to each other, and think their contribution to the project was valuable. However, students do not learn much about other disciplines, or learned a lot regarding the cooperation with students from other disciplines.

	design a solution for non-invasive city engineering problems.	project meetings (on own initiative). Regarding the assessment, there is one large written exam covering all subjects, two assignments, two pass/fail products (poster/symposium) and a group report.	so the content is interdisciplinary.		Remarkable in this module is that they stated the module was not intellectual stimulating or challenging.
Cybersecurity & cybercrime	This minor introduces students to the fields of Cybersecurity and Cybercrime. Cybersecurity encompasses measures taken to protect a computer system, a network, or the Internet as a whole, against unauthorized access or attack. As far as the Internet is concerned, however, the spectrum of abuse is large: it ranges from cyber deviance (a behaviour outside or at the edge of the formal norms of society, but not yet illegal) to real cybercrime (an activity that violates a set of legal norms). The overall is that students need to include	All learning objectives are related to the content of the courses, which is in itself ‘interdisciplinary’; students should be able to explain the principles of a situational approach to crime, social engineering and compliance in relation to cybersecurity and cybercrime, and develop ideas for social intervention. The learning activities consist mostly of subject specific lectures, tutorials and project meetings, with the exception of one	Students are supported by tutors; but most of the time these tutor meetings were by request only. Students work on a very open project assignments, and the composition of groups is really mixed. One 2 hour workshop is used, to help students collaborate in an interdisciplinary project team. However, students are made aware by the teachers of all the perspectives that need to be taken into	Teachers are all experts in their own field of study, but they are not trained to educate or guide such interdisciplinary student groups.	Overall (based on the SEQ) students had mixed feelings about the minor course. For technical students it was too easy, for psychological students too difficult. They enjoyed being in an interdisciplinary project group, but overall they stated that the minor was not very challenging and intellectual stimulating. No

	technological, privacy, psychological, economical and ethical aspects into a cybersecurity solution.	workshop about interdisciplinary teamwork. The assessment consists of 2 written tests, more than 4 assignments, a final report and a presentation.	account when thinking of a cybersecurity solution.		results are available about the value of cooperating in an interdisciplinary project group.

**Students are not obliged to do both parts of this package*