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A qualitative approach

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Perceptions of Interdisciplinary Learning: a qualitative approach

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Abstract: *Despite the fact that interdisciplinarity is on top of the agenda at many higher education institutions, there are few practical guidelines on which to build interdisciplinary engineering curricula. This study focused on how interdisciplinarity is perceived at TU Delft, which interdisciplinary skills are assessed in these programmes, how these are assessed and how they relate to the interdisciplinary problem being addressed. Results indicate that the perception of interdisciplinarity varies thereby influencing programme design. Communication and collaboration skills are important interdisciplinary skills. Assessment of these skills seem in its infancy. We may conclude that interdisciplinarity seems only occasionally to be a systemic endeavour due to different interpretations of interdisciplinary education itself and subsequently the knowledge of how to design interdisciplinary education.*

Introduction

The Royal Academy of Engineering in the UK identified in 2006 the new engineer as integrator: a graduate who can operate and manage across boundaries and who can be very technical or organisational in a complex environment (Schoenmaker, Verlaan & Hertogh, 2015). Despite the fact that interdisciplinarity has been on the top of the agenda at many higher education (Holzer et al., 2016), there are few practical guidelines on which to build interdisciplinary engineering curricula. In the TU Delft Educational Vision, interdisciplinarity is one of the important learning outcomes for future engineers. This paper, therefore, aims to gather insight into the design of interdisciplinary courses at Delft University of Technology, The Netherlands. Six interdisciplinary minor and one master programmes were evaluated by means of semi-structured interviews and document study and analysed in a qualitative way.

Intrinsic to scientific research is the development of an overall education in which the individual should do scientific research to discover new scientific territory (Scott, 2016). The Humboldtian academic model in which independent research, study and academic freedom was intended, has been adapted to modern day higher education via the Bologna agreement. These principles are still at the very heart of academia and are revived in different formats of teaching for 21st century.

One of these formats is interdisciplinary teaching/learning. Interdisciplinary learning is currently not systemically embedded into our university. As interdisciplinary learning offers a close relationship between research and teaching, it creates autonomy for students to pursue their own research questions. Many researchers Repko (2008), Thompson Klein et al., (2014) and De Greef, Post, Vink & Wenting (2017) tried to capture the complexity of what interdisciplinary teaching/learning entails, the opportunities for innovation and how to design it for engineering students. Yet various researchers point out that from different educational research paradigms, the best interdisciplinary teaching and learning design has not yet been extensively addressed (Boon & Van Baalen, (2019), Spelt et al., (2017) and Macleod et al., (2016)).

Earlier research (Klaassen, 2018), evaluating two MSc curricula at TU Delft, shows that the design of interdisciplinary learning is based on the chosen problem and the research paradigm chosen to solve this problem. This problem is, thus, central to the learning outcomes, the level of integration and the constructive alignment of the programmes. The perception of teaching staff of interdisciplinarity thus indicates to what extent this idea is of relevance to the design of interdisciplinary education at our university.

The research question in this study is: “How is interdisciplinary education currently structured in engineering education in the perception of programme coordinator/lecturers and which key parameters can we identify to support future curriculum design?”

Theoretical framework

Interdisciplinary research can be defined as an integrated approach of different disciplinary methods, knowledge, skills, theories, and perspectives, to realize innovative solutions and knowledge advancement in uncharted problem areas, by a team or individual scientists (Castán Broto, Gislason & Ehlers, 2009, Lam, Walker & Hills, 2014, Menken & Keestra, 2016, Boix Mansilla & Dawes Duraising, 2007). In interdisciplinary education students acquire the skills to conduct interdisciplinary research in practice or in science. These skills are framed as interdisciplinary thinking. What interdisciplinary thinking is, however, is widely debated. Some researchers talk about “knowledge of” in depth knowledge of another field and “about-knowledge” a rudimentary form of knowledge about another field (Priaulx & Weinel, 2018) or they talk about skills (De Greef et al., 2017). Additionally, it matters whether interdisciplinarity is narrowly defined (within one domain) or between broadly different domains (Gantogtokh & Quinlan, 2017). Spelt (2017), eg. states interdisciplinary thinking is the capacity of students to integrate interdisciplinary knowledges from broadly different disciplines and more narrowly related disciplines. Boon et al., (2019), frames it as metacognitive awareness and application of disciplinary paradigms, theories and methods. Repko’s (2008) states perspective taking and structural problems solving inquiry by understanding interdisciplinary problems and integration of knowledge is needed. Klaassen (2018) shows students are taught different skills dependent on the scientific disciplinary approach, i.e. design abductive or inductive/deductive research methodologies, resulting in different levels of integration.

Neither the knowledge level nor the skills are precisely defined. The assessment thereof is a challenge. There is a lack of methods for judging interdisciplinary education and its direct impacts on student learning, especially at the undergraduate level (Repko, 2008). In this study we have looked at what we can learn from emerging practices at our institution. We have used an analysis model which has been validated in 3TU context and particularly looks at the course design parts vision and education (Figure 1). The framework was established on the basis of a literature review of 93 Scopus articles on interdisciplinary learning in engineering education and on the basis of data collection of six case studies across the three technical universities in the Netherlands. The framework primarily focuses on the constructive alignment of the courses; i.e. conceptualizes this alignment between the educational vision, operationalization into pedagogical approaches and facilitation by support structures and together are indicators for the analyses of educational design (Klaassen, 2018). In this paper we focused on the vision and educational part of the framework.

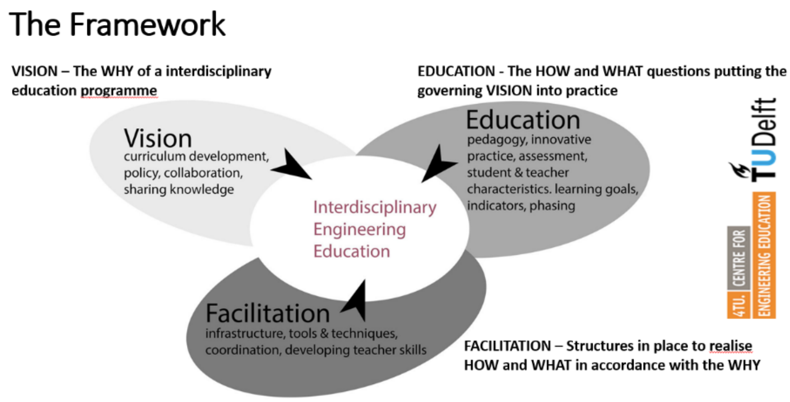

Figure 1: Framework for Interdisciplinary Engineering Education (4TU Centre for Engineering Education).

Methods

In this study we have chosen to use qualitative semi-structured interviews, to get a handle on a broad range of processes used and the perceived reasons for using a particular educational design format. The open topicalised questions allow for explorations of the insights and perceptions of the interviewees.
The sampling of the interviewees focused on programme responsible coordinators as they largely decide, with their staff, what a programme should look like, which values it comprises and how it ought to be assessed. To start, we have chosen programmes at our institution, which in the study guide have been announced as interdisciplinary[1]. These turned out to be minor and some master programmes, by and large in the area of design engineering or sustainability in both of which interdisciplinary problem solving is important. This study is part of a larger study in which around 15 interviews will take place. At the time of writing seven interviews were conducted of which the results are reported here. The interview questions were in line with those used in the framework and 4TU Case studies (Van den Beemt, forthcoming, Boon et al., 2019, Klaassen, 2018). The 4 main interview questions discussed in this paper are (1) What is your vision on how to realise interdisciplinary education? (2) Which type of problems are addressed in the programme? (3) Which skills and knowledge need to be acquired in the interdisciplinary programme? (4) Which methods of assessment are used? These questions are a selection of 10 questions used in the interview and corroborating the indicators.
The interviews were transcribed and analysed in Dedoose (a qualitative research software package). The analysis involved coding of the interviews on 11 indicators, together covering the fore mentioned framework by three coders. Due to limited space, in this article results are presented of 4 indicators only, which are Vision, Interdisciplinary problems defined, Skills and knowledge of students and Assessment, together covering the Vision and Education part of the Framework. These 4 codes are chosen as they address the constructive alignment of curriculum design. The codes are equally derived from earlier studies by Van den Beemt et al. (forthcoming), MacLeod (2017), Boon et al., (2019) and Klaassen (2018).

Inter reliability is used to sustain the consistency in coding and come up with more reliable results then random interpretation (Keyton et al., 2004). In Table 1 the number of excerpts for each code is listed, the interrater reliability, Cohens Kappa (CK), between each pair of raters and an overall average kappa across the 3 raters. Although the interrater reliability is ideally calculated via a method which includes multiple raters, we were limited by the possibilities in the research software package. We therefore concluded CK between raters and overall across raters as the closest measure of reliability available. CK for each indicator was moderate to fair. The average CK was .67 moderate to fair (Sun, 2011).

Table 1: Number of excerpts for each indicator and interrater reliability (Cohens Kappa).

Indicator	# Excerpts	Rater 1-2 CK	Rater 1-3 CK	Rater 2-3 CK	Average CK
Vision	181	0.64	0.55	0.57	0.59
Interdisciplinary problems defined	50	0.61	0.51	0.75	0.62
Skills & Knowledge students	109	0.70	0.56	0.63	0.63
Assessment	73	0.83	0.83	0.83	0.83
Total CK		**0.70**	**0.61**	**0.7**	**0.67**

For additional information on specifically the learning objectives and assessment methods, most interviewees referred to their study brochures, the online learning environment, and study guide information. This information has been taken into account in the interpretation of the interview results. Extensive discussions of triangulation and literature discussion go beyond the space available in this paper. The coded interviews excerpts agreed upon in the coding process have been clustered and summarised with the literature and other data-source in mind.

The results section will discuss the combined interview data on vision and education in a sequential order. First visions of curriculum design, subsequently the interdisciplinary problems defined, the skills and knowledge and assessment in the last paragraph. The paper will finish with a discussion on the findings.

Results

In the minors/masters selected in this study the main learning outcome focused on sustainability (four interviews) or design engineering (three interviews) and inherently are expected to have an interdisciplinary educational design.

The Framework: Vision

In the theoretical framework the research team has defined interdisciplinarity as: a team or an individual expert who integrates different disciplinary methods, knowledge, skills, theories, and perspectives, to realise innovative solutions and knowledge advancement. When talking to the interviewee's it surfaced in the conversations that each of them is struggling with what interdisciplinarity is and what it should or could be and what interdisciplinary design of education is. Differences in visions were established between interpretations of broad and narrow interdisciplinarity, inter and intra disciplinarity, differentiation between bachelor, minor and master foci in interdisciplinarity and possibly the irrelevance of talking about interdisciplinarity per se.

Broad (unrelated) and narrow (interrelated) disciplinarity is traditionally considered as going beyond one's own discipline to a large or limited extent (Gantogtokh & Quinlan, 2017). However, going beyond one's own discipline depends on the point of reference. If we look from the outside, one of our interviewee said, "*we are all engineers*". Interdisciplinary at that moment is going beyond the institutional boundaries. Two other quotes to illustrate this are:

"When we look inside our own institution, interdisciplinarity goes beyond the boundaries of the faculty or departmental education programmes offered, and does comprise engineering in all cases".

The interviewee further observes: "*Also depending on the topic, I may be closer to staff at other faculties dealing with the same topic from a different perspective than some of the staff in my own faculty".*

These viewpoints show the fluidity of the term interdisciplinary.

Inter and intra- disciplinarity provides a different view on the issue of definition. Intra is an approach where the problem is solved from one paradigmatic perspective, but the input is from multiple sources. It is particularly applicable to design and sometimes also categorized as transdisciplinary, where the solution asks for involvement of experts and laymen of different disciplines, but tends to be solved from one paradigmatic disciplinary view. One of the interviewees formulated the inter and intra-disciplinarity and even extents this intra to anti-disciplinary, as follows:

"*Interdisciplinarity is a difficult construct, as a designer, I think that most designers are not aware of the fact that they work interdisciplinary, it is however, the usual way of working to dive into different disciplines to make a product. Each design is operated in a different context, in which you need different sorts of knowledge and communications with different experts. In my opinion you are taught here to be flexible and talk/deal with different disciplines. Therefore I think we should not try to give everything a name when we are talking about content. I am anti disciplinary. After all disciplines are men made barriers or obstacles given a name".*

Bachelor, Minor, Master level courses can all be interdisciplinary in their design, yet have a completely different purpose. In the minor no prior knowledge is presumed, nor any overlap with course in other programmes. The idea is about building common ground, to broaden the perspective and acquire a different way of thinking. "*When they (=students) manage to come to a joint conclusion or decision it is already a wonderful result*". According to the interviewees it is more about providing "context".

The focus in the bachelor is to give a broad idea of a specific topic within a discipline. On having a complete understanding of lots of different parts. Interdisciplinarity in bachelor courses might therefor necessarily focus on collaboration and teamwork and less on integrative solutions.

"*Master level interdisciplinarity is a dynamic system, it represents a process which develops its own standards and quality norms and occasionally, develops into a new discipline. Within the dynamic system one finds all kinds of frameworks and methods, each with their pros and cons. The key is to each time consider, what is the context, what knowledge is available and which questions need to be answered to proceed in the research/project. Which discipline it belongs to is less relevant."*

Interdisciplinarity per se is not a goal in itself as most of the interviewees have made clear. They even warn not to construct interdisciplinary courses for the sake of the courses;

"Is it complex because it is interdisciplinary or is it interdisciplinary because it is complex"? The warning is elaborated upon; "To solve a complex problem one needs different types of expertise to come to an innovative solution which is relevant for society. Yet we should not pretend to solve everything by realising integration or interdisciplinarity, when there are essential differences between the disciplines".

It is then stated a pragmatic way of working should result in reducing complexity. *"In the end a theory or method whether regular, integrated or interdisciplinarity is about reducing complexity, tying the right knots, broadening perspectives and creating resilience".*

The Framework: Education

In this section we will describe the results of interview questions 2 and 3 of the interview protocol, about the definition of interdisciplinary problems, skills and knowledge needed and assessment methods used.

Interdisciplinary problems defined

In these interviews we have noticed the design is shaped by the problem definition in both areas of design and sustainability.

The problems are characterized by open problem definitions of real life, societal and complex problems. These problems are usually defined by the students themselves within certain boundaries. The solution space typically involves the consultation with multiple stakeholders. Last but not least the problem is ideally resolved by abductive design research, allowing multiple problems with multiple solutions paths. Abductive design research would be more applicable to design and to a lesser extent to sustainability and engineering design.

The solutions space is broad - to very broad. The key to a “good” solution is a good problem statement, it should be i.e. controversial, complex, involving multiple stakeholders, inviting multiple perspectives, involving different scientific paradigms. The problem is solved by working from certain frameworks e.g. theory of systems, socio technical solutions space, etc.

A selection of various examples of problems defined by teaching staff and investigated by students within different cases are e.g.:

- Working on the green/blue structure of a deprived Neighbourhood in a big cities
- Fossil fuel is necessary for our energy transition
- A different solution for shoe laces, comfortable and supportive for everyone’s feet
- Monitoring human movement efficiently in particular situation.
- Guiding the blind (without dogs)
- Sustainable energy transition in harbour area
- Climate adaptation in the city
- Sustainable airport design

Students need to be able to work in an interdisciplinary way to come to a problem solution and they need to be able to frame their own problem definition. Obviously this needs to be learned gradually, by first providing a set of topics, gradually moving to more open and long term topics to be dealt with. According to several interviewees the innovation learning process is a precondition to acquire the capacity to actualize abductive design research and solve complex problems. The interviewees state the “innovation process” skills are only available in students with a design background and thus requires students in an interdisciplinary team to help solve these type of problems. Another perspective is that the technical, analytical power of the engineering students needs to be on board, otherwise solutions will be very superficial. Each interviewee had his/her own conviction as to what the different science fields bring to the table and the added value to the solution of the problem at hand in line with the epistemic differences in different scientific fields. Table 2 shows the contributions of different scientific fields to solution of the problem, in accordance with the interviewee’s visions on core skills in different disciplinary fields.

Table 2: Contribution of different science fields to problem solving according to the interviewees.

Science field	**Contribution to problem solution**
Technical	analytical & practical results
Natural	scientific substantiations, modelling
Social	writing skills, philosophical reasoning (logic)
Design	problem definition, ambiguity, visual representation

Student’s skills and knowledge (SKA) needed for interdisciplinary ways of working and their assessment

During the interviews we came past many instances where the interviewees reflected on what types of students were in their minors/masters, how they enrolled students and what they might actually need as an entry level to successfully work on the learning outcomes. Observations are that the students are from a wide variety of backgrounds ranging from social, natural sciences to all of the engineering and design sciences, equally many students have a multicultural background. Sometimes entry level criteria are formulated. These criteria are however rather general, as it seems hard to estimate both what the entry level is of the students and what might be needed in their own disciplinary course to realise a “good” enough learning outcome. General entry level criteria, pertain to relevant background knowledge, mathematics, English writing, communication skills and collaboration skills.

Other observations pertained to the age of the students: younger students need more guidance and input when sharing knowledge.

The unbalanced level of prior knowledge within one course often leads to boredom for some students and to challenges for other students in the same course. Interdisciplinarity would definitely benefit from flexible learning paths as described by some interviewees.

The skills set acquired in the interdisciplinary programmes tended to be two-fold. Skills necessary for working interdisciplinary and skills necessary to deal with the content offered in the programme. The skills for working interdisciplinary were communication skills and managing the groups' collaboration process in both the design and sustainability courses. Yet we find slight differences between the skills sets. An overview is given in Table 3.

Table 3: Student's skills for working interdisciplinary in sustainability and design courses as derived from the interview excerpts (LO=learning objective).

Sustainable : skills for working interdisciplinary	**Design: skills for working interdisciplinary**
Communication skills	**Communication skills**
LO: need to communicate ideas from different backgrounds to other teammates. LO: explaining own domain to others within other domains LO: teach them how to give feedback and how to work together LO: different jargons used in different disciplines should be discussed	LO: academic argumentation to support their design choices/plan LO: being able to work together with different disciplines LO: reflection LO: interpersonal capacities to lead others in your ideas LO: contribution to discussion
Manage group collaboration	**Manage group collaboration**
LO: integration of theories from different disciplines; but content level should be high level. LO: need input from other disciplines to deliver the output LO: working in a team and project approach, split in different working area's and deliver product LO: understanding the disciplines, knowledge and skills to be used for a certain solution and coordinate this LO: students need to think about their own skill development to help them with more in-depth knowledge	LO: how to work in interdisciplinary group LO: soft skills working together LO: how they work together peer review LO: taste of interdisciplinarity LO: working together interdisciplinary by going out of one's comfort zone (attitude)

When looking at communication skills (Table 3) deemed necessary for interdisciplinarity, there is more emphasis on explanation and understanding one another in the sustainable area, whereas in the design it seems to be more based on having the best argument for a particular concept. By following the theory of constructive alignment, we would argue that skills necessary for interdisciplinarity are also assessed. However, when we consider the assessment methods/criteria in design, there is no particular assessment method or criteria used to assess interdisciplinarity. In sustainability there is more emphasis on the relevance of each disciplinary contribution, which still is not really assessed (Table 4).

Table 4: Assessment methods and criteria in design and sustainability on interdisciplinary skills communication and managing group work, as derived from the interview excerpts.

Design	**Assessment methods**	**Assessment criteria**
Communication	Students need to talk to each other to integrate knowledge. This is not assessed	Solution not assessed on interdisciplinary aspects
Managing group work	Shared report based on student's contribution Assignment in interdisciplinary groups	Teambuilding not assessed Maybe assess working together and what they have learned rather than a better solution? Teamwork could

		be assessed if more structure to do this is provided.
Sustainable	**Assessment methods**	**Assessment criteria**
Communication	It is assumed that all students have integrated the knowledge and learned from the project. This is not assessed	No interdisciplinary criteria Explain why all different disciplines are required, how they strengthen each other No integration rubric available
Managing group work	Group work assessments 2nd year: report	Process is assessed, not so much the disciplinary knowledge Peer review

The other part of interdisciplinary skills necessary is to deal with the content offered in the programme. In the sustainable area we find there is a lot of emphasis on using other (relevant) disciplines and the integration thereof (Table 4). This tends to be assessed through the process/ peer review methods, through group work and report writing. In the design area the focus is more on teamwork and skills to work effectively in teams, this may have a taste of interdisciplinarity, but is not focused on it. Even the teamwork, albeit very important, is not the focus of assessment. Results of content skills mentioned and assessment methods and criteria are presented in Table 5.

Table 5: Content (cognitive) skills mentioned in sustainability and design programmes and their assessment method and criteria, as derived from the interview excerpts

Sustainable	**Design**
General skills/knowledge	General skills/knowledge
LO: able to reduce complexity LO: arranging input from other disciplines to deliver the output LO: integration of theories from different disciplines; but content level should be high level LO: using relevant information sources LO: work with different machines to be able to make concept scenario's LO: computer programming LO: design (of sustainable plan) and application LO: reporting and modelling skills LO: research and design skills	LO: modelling and calculations LO: how well is the plan supported by scientific argument in favour of a decision? LO: learn a certain process approach LO: technical plan is sufficient LO: design skills LO: materials knowledge, 3d- printing and other application techniques LO: how to develop a problem solving strategy
Particular skills/knowledge	Particular skills/knowledge
LO: system thinking; however not explicit LO: understanding economic trends and government aspects LO: Acquire a threshold level in three different disciplines involved in the solution. LO: transformation strategy knowledge LO: customer experience	LO: user based design is important LO: framing problem definition and creating multiple concepts. LO: visual drawing LO: forecasting, landside access, terminal design LO: aerodynamics, mathematics LO: innovation processes

Design	**Assessment Methods**	**Assessment Criteria**
General skills/knowledge	Short presentation of report	Rubric available
Particular skills/knowledge	Disciplinary knowledge test Students could still only use their own knowledge in group project	Criteria are disciplinary. Higher Blooms level used in group work and lower Bloom level at individual level
Sustainable	**Assessment Methods**	**Assessment Criteria**
General Skills/ Knowledge	Group report	Teamwork and knowledge related. Assessment on sustainability aspect. Real life problem assessed by people who have worked in that area
Particular Skills/knowledge	Disciplinary knowledge test at end of module	quality of design knowledge

General remarks of the interviewees on the assessment in the design assignments is that it is important to involve all the teachers in the assessment and the alignment of the Rubric criteria. Most of the design projects need to be integrated as otherwise there is no solution possible. It is important to be aware that solutions in the design area, do not by definition need an interdisciplinary approach. Taking on board insights of other disciplines to resolve a design problem in a “designerly” way, is an activity within one disciplinary framework, according to the interviewees. General remarks in the sustainable area are that one should first know which learning methods are used, before the assessment methods are determined. Integration should be reflected in the individual contribution based on the diverse disciplines of group members interdisciplinary “attitudes”. Albeit the focus in sustainability is not necessarily on integration, it should be used as exit criterium. The difficulty with integration is that the content level becomes lower and does not compare to mono-disciplinary learning outcomes. Which makes the interviewees wonder how to get the best results of both worlds.

Discussion and Conclusion

The interviews performed in this research provided qualitative insight into two of the three key intertwined pillars of the interdisciplinary engineering education framework: vision and education. The results of the third pillar (facilitation) is not reported in this study.

The discussion in the Vision section shows that the staff’s primary interest in interdisciplinarity is not so much the definition, but rather whether the problem solving approach (reduction of complexity) results in some sort of scientific solution, given a particular context. In the problem definition section it is shown that within a framework students are stimulated to establish their own research questions and choose the best possible approach. The fact that this is done in interdisciplinary teams allows for a greater degree of freedom in coming up with appropriate integrated solutions. Yet at the level of assessment, we find that the ambitions in what students’ are to learn from working interdisciplinary (communication and group management) might contribute to the academic development of students. In the assessment, however, this is not supported as the assessment is done from a disciplinary perspective meeting the accountability criteria of disciplinary assessment standards. The latter is not unique as Boix Mansilla (2017) shows many teachers feel the students reasoning should be disciplinary grounded to meet quality standards.

Although the fact that the problems used in the courses are characterized by open problem definitions of real life, societal and complex problems and fulfill criteria of complex problems, they still could be solved within a single discipline. And above all, the students are not forced or informed about interdisciplinary approaches to solve such problems, thereby the solutions can still stay within the frame of one discipline.

The interviewees have defined interdisciplinary skills. Skills are related to communication and managing the group collaboration process, as well as content related, mostly focused on “about knowledge” gathering knowledge on specific domains relevant for the course. Most of these skills for interdisciplinary thinking are however not assessed. Meaning that the constructive alignment of the courses at hand is not fully aligned.

This brings us back to the research question of our research: “identifying how interdisciplinary education is structured in engineering education as perceived by the teachers and which key parameters can be identified to support future curriculum design”. Key parameters should include a clear vision on what defines interdisciplinary learning in a particular context, which problems are appropriate to come to solutions with an acceptable academic level and how can interdisciplinary thinking skills contribute to the academic development of students.
In this study we have realised a 1st exploration of a very small sample of teachers. At this point is therefore difficult to draw major conclusions. Yet it should suffice to start up the discussion on what educating students in interdisciplinary education means. The data richness shows there is a lot more to uncover in the additional interviews.

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1 To protect the privacy of the participants we cannot be more specific about the gender or disciplinary area's involved. The involvement across the faculties is fairly evenly distributed.

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