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Multidisciplinary education through faculty members' conceptualisations of and experiences in engineering education

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ABSTRACT
Engineering education has become increasingly multidisciplinary in order to prepare future experts to transcend disciplinary boundaries and to co-construct solutions to solve grand challenges. However, faculty members' perspectives and experiences have been largely ignored in the literature. To understand and support faculty members, the present study investigated faculty members' conceptualisations of multi-, inter-, and transdisciplinary education. We conducted semi-structured interviews with 13 faculty members from engineering, business, art and design with varied experiences with multidisciplinary teaching, course design, and programme management. We found that while some faculty members conceptualised multidisciplinary education as an encompassing concept, most used disciplinary integration to distinguish multi-, inter-, and transdisciplinary education. However, their conceptualisations of the differences between multi-, inter-, and transdisciplinary education were nuanced. Summarising the perceived nuances in different aspects of course design, we propose a typology to demonstrate the variety of types in faculty members' course design. By identifying the diversity and complexities of faculty members' conceptualisations, this study attempts to help faculty members achieve an in-depth understanding of their conceptualisations and practices, as well as support engineering educators in designing courses with disciplinary integration.

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Engineering education; multidisciplinary education; interdisciplinary education; disciplinary integration; course design

Introduction

As engineering students prepare to meet grand challenges in their future careers, such as those related to sustainability, industry innovation, and equality, as expressed in the United Nations' (UN) sustainable development goals (SDGs) (UN 2015), engineering education faces a critical question: How can students best be supported to transcend their disciplinary boundaries so that they can understand the interdisciplinary nature of many of these challenges and develop the ability to co-construct solutions? Consequently, it has become necessary to consider what knowledge should be included in the curriculum, what pedagogies teachers should employ, and what competencies students should develop. In engineering education, multidisciplinary teamwork is included in the curriculum as a core learning competency (ABET 2016). More specifically, in capstone engineering design courses, students learn design processes by working on projects in multidisciplinary teams

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(Dym et al. 2005; Ylirisku and Filz 2018). The multidisciplinary approach is also used to help students gain knowledge from such fields as mathematics and engineering (Costa et al. 2019; MacLeod and van der Veen 2020), architecture and engineering (Li et al. 2015), business studies and engineering (Jensen, Utriainen, and Steinert 2018), and sciences and engineering (Gero 2017; Dochshanov and Tramonti 2017), and social work studies and engineering (Gilbert et al. 2015), to name a few.

Many studies have identified the benefits of multi – or interdisciplinary education. For example, students perceived interdisciplinary education as particularly beneficial for their future work with real-life projects and highlighted the development of transversal skills (Costa et al. 2019; White and Nitkin 2014; Spelt et al. 2017). Because of many demonstrated benefits, multi- and interdisciplinary initiatives are implemented across disciplines and in various course offerings and are embedded in diverse themes, such as sustainability (Jacob 2015).

However, implementing multi-, inter-, and transdisciplinary initiatives is a complex endeavour; it requires coordinated efforts by faculty members from different university departments and different disciplines (Webb 2020). When faculty members across disciplines collaborate, they face difficulties in navigating what to teach and how to teach in interdisciplinary education contexts (Holley 2009). The main challenges that faculty members encounter include reaching a common understanding and agreement on relevant terminology used for planning learning objectives, ensuring that they possess the necessary skills in problem- or project-based teaching methods, and having prior experiences with team teaching (Spelt et al. 2009; Feng and Hölttä-Otto 2022). Moreover, faculty members may experience discomfort when they are unfamiliar with some disciplines and may feel uncertain about whether students can learn from other disciplines (Stentoft 2017). Conceptual ambiguities in multi-, inter-, and transdisciplinary education are also likely to contribute to the overall discomfort that many faculty members experience (Borrego and Newswander 2010; MacLeod and van der Veen 2020), which might affect the quality of teaching and learning.

The current literature on the perspectives of engineering faculty members consists primarily of case studies detailing single course designs, focusing on the use of specific pedagogy, students' performances and assessment (McCrum 2017; Gilbert et al. 2015; Klaassen 2018; Costa et al. 2019); faculty members' perspectives and experiences have been less studied. Although Aram's (2004) study examined faculty members' perspectives on interdisciplinarity, the participants were selected only from liberal arts programmes, and the focus was on interdisciplinary research, rather than on educational settings. Several other studies have examined faculty members' experiences of interdisciplinarity but in a limited capacity, presenting faculty experiences in certain narrower contexts, such as teacher training seminars (Frost and Jean 2003), team teaching (Vesikivi et al. 2019), and student-centred teaching (Boklage, Coley, and Kellam 2019). As faculty members differ in their disciplinary backgrounds, academic positions, and teaching experiences, their conceptualisations of multi-, inter-, and transdisciplinary education may be radically different as well (Van den Beemt et al. 2020; Holley 2009; Spelt et al. 2009). However, there is a limited understanding of faculty members' various conceptualisations and experiences with multi-, inter-, and transdisciplinary education, which can bring challenges to faculty members in their communication and collaboration with their peers, as well as in using effective pedagogies for teaching and learning.

Therefore, the aim of this study is to gain a deeper understanding of faculty members' conceptualisations of multi, inter-, and transdisciplinary education, focusing on faculty members who possess experiences in course teaching, course design, and programme management. By identifying faculty members' conceptualisations and experiences, we ultimately aim to facilitate dialogue between engineering and non-engineering educators and contribute to the development of more effective designs of multi-, inter-, and transdisciplinary education.

Conceptualising mono-, multi-, inter-, and trans-disciplinarity

Concepts such as multi-, inter-, and trans-disciplinarity are often used in the context of education; scholars and educators, however, use the terms in practice inconsistently and sometimes interchangeably (Lattuca and Knight 2010). For example, interdisciplinary learning is often mixed with multidisciplinary learning, the latter of which focuses on gaining additional knowledge from many disciplines, while the former concerns gaining knowledge by integrating multiple disciplines (Dezure 2017; Holley 2009). Below, we attempt to provide a synthesis of the literature on the conceptualisations of mono, multi-, inter-, and transdisciplinarity with a focus on their application in education, based on their level of integration across disciplines. The focus is on engineering and engineering education.

Monodisciplinarity

The lowest level of disciplinary integration can be found in curricula that seek to educate specialists in a particular domain, such as particular kinds of mechanical or electrical engineers: machine designers, solid mechanics engineers, integrated circuit engineers, electromagnetic motor specialists and so on. Monodisciplinarity involves mature disciplines with firm boundaries which, according to Miller (1982): '*refer to areas historically delineated by departmentalisation … [and a] peculiar combination of subject matter, techniques of investigation, orienting thought models, principles of analysis, methods of explanation and aesthetic standards*' (4). In engineering education, monodisciplinarity is related to the ideology of engineering (Williams 2003), referring to the type of engineering education that trains engineers with a distinct technical domain of knowledge and specialist skills. Therefore, students are trained with specific disciplinary discourses and cultures, including disciplinary knowledge, traditions, beliefs, languages, and practices (Becher and Trowler 2001).

Multidisciplinarity

Multidisciplinarity is the first step towards a more integrated approach across disciplines. According to Miller (1982), the multidisciplinary approaches involve '*the simple act of juxtaposing several disciplines*' and make '*no systematic attempt at integration or combination*' (9). This form of disciplinary education merely exposes students in one discipline to content from a different discipline. Interactions between disciplines are minimal, as each students continue to learn in their own distinct universes of discourse. Lattuca and Knight (2010) argue that multidisciplinarity '*does not synthesize or integrate the various elements of disciplinary knowledge into a cohesive whole*' (3), as the representatives of a particular discipline are merely representing their discipline and will not try to change it through, for example, dialogue with experts from other fields. Klein (2015) supports this view on multidisciplinarity: '*Individuals also remain anchored in their respective expertise, and collaboration is lacking*' (p.15). Multidisciplinarity may be seen as partial interdisciplinarity, as it borrows only one part of that approach: that is, representing multiple disciplines.

Inter- and cross-disciplinarity

The terms inter- and cross-disciplinarity are often utilised interchangeably, but we have identified several attempts to define these terms with a more precise meaning. Specifically, Jantsch (1972) defines cross-disciplinarity as a practice where the tools and methods of one discipline are borrowed to explain another discipline. Regarding interdisciplinarity, one common understanding is its emphasis on integration in interdisciplinarity. In educational settings, scholars tend to agree that with multidisciplinary learning, several disciplinary insights are combined, but the disciplines remain discrete, whereas interdisciplinary learning outcomes are achieved through the integration of knowledge and modes of thinking from different disciplines (Klein 1996, 2006; Lattuca et al. 2017).

Lattuca and Knight (2010) associate the '*integration of disciplinary contributions*' with interdisciplinarity (4). This means that the individual disciplines are not discernible in the students' or teachers' contributions to interdisciplinary courses. Klein (2015) describes interdisciplinarity as characterised by the '*integration of information, data, methods, tools, concepts, and/or theories from two or more* *disciplines or bodies of specialized knowledge*' (15). Interdisciplinarity provides students with a more holistic understanding of a topic than a multidisciplinary approach, as the focus is typically on collaborations such questions, topics, themes or problems by individuals or teams that require a wide range of viewpoints. With regard to teaching and learning, studies show that faculty members employ an array of innovative pedagogical approaches, such as problem- and project-based learning, collaborative teaching, experiential learning and service learning (Brassler and Dettmers 2017; Holley 2009; Klein 2006).

Transdisciplinarity

The term transdisciplinarity, like multi- and interdisciplinarity, was first used in the 1970s to describe an intellectual endeavour that unifies knowledge beyond disciplines, such as anthropology conceived as the science of humans (Apostel et al. 1972). According to Klein (2015), transdisciplinarity involves a restructuring that detaches it from other disciplines and enables to forming something new. Today, it is also used to refer to the co-production of knowledge with various stakeholders in society; that is, going outside traditional disciplinary boundaries to solve real-world problems (Klein 2018). Transdisciplinarity treats the various fields of disciplinary knowledge and expertise as potential resources for co-production, but the focus is always on collaborative achievement and increased relevance in the context of complex, dynamic and networked challenges.

Aims of the study

Since the literature suggests that faculty members still struggle with conceptualising multi-, inter- and transdisciplinary education (Borrego and Newswander 2010; Holley 2009; Lindvig and Ulriksen 2019; MacLeod and van der Veen 2020), we aim to investigate their actual conceptualisations of multi-, inter-, and transdisciplinary education. We also seek to shed light on the '*jungle of phenomena*' (Klein 1996, 134) that relate to multi-, inter-, and transdisciplinary teaching and learning and hope to synthese key findings into useful concepts that can be employed by both scholars and educators when planning multi-, inter-, and trans-disciplinary activities. We thus seek to answer two research questions:

(1) What kinds of conceptualisations do faculty members have regarding multi-, inter-, and transdisciplinary education?
(2) What aspects of teaching and learning do faculty members associate with multi-, inter-, and transdisciplinary education?

Methodology

We conducted one-on-one interviews with 13 faculty members from engineering, science, business, art, and design using semi-structured interviews. The semi-structured interviews were chosen as they allowed the participants to use their own language to describe their experiences and thoughts (Merriam 2009). We employed thematic analysis (Braun and Clarke 2006) to identify overarching themes within the faculty members' perspectives on multi-, inter-, and transdisciplinary education. The management of data in this project is informed by the ethical principles of research with human participants and ethical review in the human sciences in Finland, published by the Finnish National Board on Research Integrity TENK (2019).

Research context

The study was conducted at Aalto University, where multidisciplinarity is placed strategically central for education and research. Aalto University was established in 2010 as a merger of three universities: the Helsinki University of Technology, the Helsinki School of Economics, and the University of Art and Design Helsinki. There are six schools within the university emphasising science and technology, design and art, and business and economics, including three schools of engineering, one school of science (which also encompasses industrial engineering and biomedical engineering), one school of business, and one school of arts, design and architecture.

After the merger, Aalto university established its mission to shape the future through '*science and art together with technology and business*' (Aalto University 2018, 6) with multidisciplinary goals. These goals have been pursued through research and education initiatives (Tavin, Tervo, and Löytönen 2018). The university has also piloted a series of multidisciplinary initiatives, both at the course and programme level.

Participants

The participants in this study (Table 1) were 13 faculty members with experience in teaching, research, course design, or programme management in multidisciplinary education contexts. Purposive sampling (Merriam 2009) was used to maximise disciplinary diversity among the participants and present multiple perspectives from faculty members. Faculty members who taught multidisciplinary courses in the engineering school were first identified by the co-authors. They were contacted and interviewed by the first author. Through these contacts, more participants from other schools were recommended by the participants.

Prior to scheduling the interviews, we collected demographic information from all participants via a survey to ensure a varied representation of our study participants. All participants had experience in multi-, inter- or transdisciplinary education, either in teaching, course design, or programme management, and all had experience with teaching engineering students. The ages of the participants ranged from 25 to 64 years old, with the majority being between 35 and 44 years old. There were six male participants, six female participants, and one undisclosed participant.

Data collection

We conducted semi-structured interviews with the participants. A qualitative approach is appropriate because it allows for investigation into participants' experiences and the meanings they have constructed (Merriam and Tisdell 2015). The 1-hour interviews consisted of two parts. First, the

Table 1. Participant demographics.

Participants	Academic Title	Teaching experience (years)	Multidisciplinary teaching experience (years)	Academic discipline (example)
1	Lecturer	6–10	6–10	Chemical engineering
2	Professor	11–20	11–20	Mechanical engineering
3	Senior Lecturer	11–20	11–20	Design
4	Professor	11–20	11–20	Organizational studies
5	Designer	6–10	0–5	Design
6	Senior Lecturer	11–20	0–5	Art
7	Lecturer	0–5	0–5	Business
8	Researcher	6–10	6–10	Organizational studies
9	Professor	11–20	11–20	Mechanical engineering
10	Lecturer	6–10	6–10	Mechanical engineering
11	Professor	11–20	6–10	Design
12	Senior Lecturer	0–5	0–5	Electrical engineering
13	Lecturer	6–10	6–10	Business

faculty members were asked about their understanding of multidisciplinary education, and if they would differentiate between multi-, inter- and transdisciplinary education. Then, they were asked to elaborate, using examples from their own experiences in teaching, course design, or programme management, on how multi-, inter- or transdisciplinarity is manifested in their educational practices. Questions, such as '*Which courses that you are teaching or have taught would be multi-, inter-, or transdisciplinary, and why?*' were used to probe their experiences. They were also encouraged to elaborate on the kinds of students they taught, what kinds of topics they taught, their own view on the pedagogy or didactics that they used, the perceived benefits and challenges, and if and how they were utilising co-teaching in their practice. Online course materials also helped complement the interviews, when certain information about courses was not covered during the interviews, such as student disciplines, co-teacher information, or more detailed course content, schedules, and arrangements. The study was conducted during the COVID-19 pandemic, whereby, all interviews were conducted online. The interviews were an average of 48 min and 30 s long, with the shortest lasting 24 min and the longest 70 min. All interviews were recorded and transcribed.

Data analysis

We used thematic analysis (Braun and Clarke 2006) to identify, analyze, and report themes. The analysis process started with open coding (Strauss and Corbin 1990) on the margins of the transcripts to identify initial first-level codes. Following open coding, the codes were collated into secondary-level categories across all participants and compared to the literature. Then, we organised the categories iteratively into themes. The codes, categories, and themes were shared and discussed within the research team to improve the quality of the results (Maxwell 1992). Table 2 presents the codes, categories, and themes. To enhance the reliability of the analysis, the research findings, including raw anonymized data, were presented to three external experts in engineering education who raised critical questions and helped assess the credibility of the findings (Merriam 2009; Creswell and Poth 2016).

Findings

In the following, we respond to the research questions, first in sub-chapters 5.1 and 5.2. to RQ1: *What kinds of conceptualisations do faculty members have regarding multi-, inter-, and transdisciplinary education?* and thereafter in a sub-chapter 5.3 to RQ2: *What aspects of teaching and learning do faculty members associate with multi-, inter-, and transdisciplinary education?* We summarise by proposing an initial typology framework for course designs, based on disciplinary integration. Finally, we discuss how the framework can assist faculty members in planning multi-, inter-, and transdisciplinary course designs.

Multidisciplinary education as an encompassing concept

Faculty members ($n = 4$) conceptualised multidisciplinary education as a broad concept, which encompassed teaching or learning activities that involved multiple disciplines. They tended to have a more general view of multidisciplinary education, as multidisciplinary courses have input from various disciplines. For example, P13 (Lecturer in Business) stated that '*multidisciplinary education is about people from different educational or professional backgrounds teaching or learning together*'.

Similarly, P9 (Professor in Mechanical Engineering) shared that '*any activities that combine a few fields, [such as] technology … art, and business can be considered to be multi- or interdisciplinary*'. P12 (Senior Lecturer in Electrical Engineering) also stated that '*My understanding of … multidisciplinarity [is] … the inclusion of experts from other schools, [which] I do not have the expertise and or teaching capacity for*'.

Table 2. The coding process with illustrative quotes, codes, categories, and themes.

Sample quotes	First-level codes	Second-level codes	Themes
'Multidisciplinary education is about people from different educational or professional backgrounds teaching or learning together'.	• Different backgrounds • Teaching or learning together	• Different disciplines or fields • Bringing, combining, teaching or learning together	Conceptualising multidisciplinary education as an encompassing concept
'Any activities that combine a few fields, [such as] technology … art, and business can be considered to be multi- or interdisciplinary'.	• Any activities combining different fields	• Conceptual ambiguity	
'Multidisciplinarity [is] … the inclusion of experts from other schools, [which] I do not have the expertise and or teaching capacity for'.	• Inclusion of experts from other schools		
'There's a big discussion about multidisciplinarity in the context [of engineering school] because their practice typically is more mono-disciplinary … . The rhetoric is that … when we (designers) interface with engineers, we would explicitly say … this is multidisciplinary … as we approach things different [from] our discipline'.	• Other disciplines interface with engineers • Approaching different disciplines		
'Multidisciplinarity has the purpose of bringing people from different backgrounds together regardless of what we call it'.	• Different backgrounds • Bringing people together • Regardless of terminology		
'Certainly, there are [differences between multi-, inter-, and transdisciplinary education], but I think they are understood only by specialists'.	• Differences understood only by specialists		
'For interdisciplinary education, it would require … that people collaborate, rather than [individuals] representing their disciplines and learn from the others. There's an additional depth and exchange [of disciplinary insights]'.	• Interdisciplinary education requiring collaboration • No individual disciplinary representation • Exchange of disciplinary insights	• Multidisciplinary education combining disciplinary expertise • Interdisciplinary education requiring an exchange of expertise • Transdisciplinary education building a new identity and trying different ways of education	Conceptualising based on disciplinary integration
'Multidisciplinary education means that you have engineering, business, arts, and design students … working together … but they retain their individual epistemological modalities … . In contrast, when students work in interdisciplinary teams, their [disciplinary] boundaries start to blur, and they try to understand each other's reasoning rather than just bringing their own expertise to the table. Finally, in transdisciplinary education … the team begins to build its own … transdisciplinary identity'.	• Multidisciplinary students working with individual epistemologies • Interdisciplinary students understanding others' reasonings • Transdisciplinary team identity		

(*Continued*)

Table 2. Continued.

Sample quotes	First-level codes	Second-level codes	Themes
'For multidisciplinary education, I see it having people from different disciplines working together, but they only contribute to the project from their own disciplines … . I use the term transdisciplinary education to focus on emergent education and generative learning and teaching … to try out different ways of thinking, learning and teaching'.	• Multidisciplinary work contributing from own disciplines • Transdisciplinary education through different ways of teaching and learning		
'I always have students from different disciplines … but [we need to] make sure that true interaction happens between them'.	• Students from different disciplines • True interaction	• Student background • Student interaction • Teacher collaboration • Teacher background • Course content	Disciplinary integration manifested in course design
'I introduce other lectures to the course, primarily people from industry with different or same backgrounds with students … to tell the stories of their experiences in venturing into different disciplines and explain how to develop their ideas into products while sustaining [the viability].'	• Lecturers from industry • Lecturers with different or same backgrounds • Sharing experiences		
'My courses are always co-[taught], meaning that there are teachers [who] have different backgrounds. So, I'm there with my design background, and my colleagues have their science background, and we work together throughout the course.'	• Co-taught • Teachers with different backgrounds • Work together throughout the course		
'I'm giving a course that … combines life science … mechanical and electrical engineering'	• Course combining different disciplines		

Slightly different from P9 and P12 emphasising the combination or inclusion of other disciplines, P1 (Lecturer in Chemical Engineering) underlined the importance of interactions between disciplines to distinguish multidisciplinary education from monodisciplinary courses and stated that '*for me, multidisciplinarity [means that] interactions [between disciplines] happen [in the course], not just people from different disciplines sitting in the same room [listening to the] same lecture without any interaction*'.

Such a view conceptualising multidisciplinary education as a broad concept may stem from the tradition of monodisciplinary education in technical schools. As P3 (Senior Lecturer in Design) observed that the concept of multidisciplinarity is actively used in engineering schools to differentiate multi- and interdisciplinary courses from the typical mono-disciplinary engineering courses. P3 said,

> *'There's a big discussion about multidisciplinarity in the context [of engineering school] because their practice typically is more mono-disciplinary … . The rhetoric is that … when we interface with engineers, we would explicitly say … this is multidisciplinary … as we approach things different [from] our discipline'.*

Another reason for the broad view of multidisciplinary education is related to conceptual ambiguities beyond the distinction between multidisciplinary and non-multidisciplinary education. For instance, P12 used the terms '*multidisciplinary*' and '*interdisciplinary*' interchangeably. When asked if there's any difference in the meanings of multi- and interdisciplinary education, P12 said that they were not sure about the differences between the two terms, '*I have caught myself using them interchangeably. That might come from the fact that I might not be a hundred per cent sure on when and how I would make the nuances between the terms*'. P9 also discussed the challenges of conceptualising the differences between terms, '*certainly, there are [differences between multi-, inter-, and transdisciplinary education], but I think they are understood only by specialists*'. Therefore, besides the influence of technical schools, conceptual ambiguities may also play a role in faculty members' conceptualisation of multidisciplinary education as a broad concept.

Disciplinary integration as a meaningful difference

Although faculty members were not asked specifically about the role of disciplinary integration in multi-, inter-, or trans-disciplinary education, our findings revealed that the majority of them (n = 9) spoke about multi-, inter-, and transdisciplinary education in a manner that implied a greater integration in inter- and transdisciplinary education, in comparison with multidisciplinary education. The faculty members perceived multidisciplinary education as the least integrated form of the three and were more resonated with inter- and transdisciplinary education.

For example, P2 (Professor in Mechanical Engineering) emphasised the importance of '*working together*', '*interacting*', '*joint planning*', and 'changing the content' to define interdisciplinary education. P2 used the example of designers creating a guide for an engineering course without working with the engineering teacher to contrast with teachers from different disciplines working together to illustrate the differences in disciplinary integration between multi- and interdisciplinary education.

Similarly, P4 (Professor in Organisational Studies) stated that interdisciplinary education involves more exchange between individuals and is not limited to parallel play, '*for interdisciplinary education, it would require … that people collaborate, rather than [individuals] representing their disciplines and learn from the others. There's an additional depth and exchange [of disciplinary insights]*'. P7 (Lecturer in Business) also discussed the limitations of multidisciplinary education, where students '*work with individual epistemological modalities*'. P7 characterised multi-, inter-, and transdisciplinary education as a continuum from less towards more integrated. According to P7, the blurring of disciplinary boundaries in interdisciplinary teamwork can deepen interdisciplinary into transdisciplinary collaboration, leading to the formation of a new type of identity among student teams,

> *'Multidisciplinary education means that you have engineering, business, arts, and design students … working together … but they retain their individual epistemological modalities … . In contrast, when students work in interdisciplinary teams, their [disciplinary] boundaries start to blur, and they try to understand each other's reasoning rather than just bringing their own expertise to the table. Finally, in transdisciplinary education … the team begins to build its own … transdisciplinary identity'.*

P6 (Art Lecturer) agreed with the limitations of multidisciplinary education in which students only '*contribute to the project from their own disciplines*'. However, P6 and P7 had different views on transdisciplinary education, with P7 emphasising the '*building of team identity*' and P7 focusing on going beyond disciplinary integration. P6 stated that,

> *'For multidisciplinary education, I see it having people from different disciplines working together, but they only contribute to the project from their own disciplines … . I use the term transdisciplinary education to focus on emergent education and generative learning and teaching … to try out different ways of thinking, learning and teaching'.*

As many faculty members noted that multidisciplinary is a form of *collaboration*, P11 (Professor in Design) concurred but argued that it lacks '*true interaction*', and '*individuals stay in their own silos and do not reach out [to each other] much*'. The lack of true interaction in multidisciplinary education was also brought up by P8 (Researcher in Organisational Studies), who characterised multidisciplinary education as a form of compartmentalised collaboration, with tasks divided, based on existing disciplinary expertise rather than actual integration of different perspectives. P8 stated that, *'Interdisciplinary education is where students integrate perspectives and collectively make sense of the challenge at hand, whereas, in multidisciplinary courses, students work on tasks that are divided based on disciplines … and [students] who're the experts in one discipline take charge of that piece of task. However, I believe that the value in [tackling] the challenges lies more in interdisciplinary education, where students approach the problems together with others from different disciplines'.*

In conclusion, many faculty members showed a preference for inter- and transdisciplinary education over multidisciplinary education due to the deeper integration and collaborative nature of these forms of education.

Disciplinary integration manifested in course design

Although the majority of faculty members tend to converge towards adopting disciplinary integration to differentiate multi-, inter-, and transdisciplinary education, their conceptualisations of disciplinary integration are more nuanced and diverse. The most frequently discussed aspect by faculty members was student background (n = 13), followed by student interaction (n = 10), teacher background (n = 7), course content (n = 6), and teacher collaboration (n = 5).

Faculty members discussed courses with unconstrained participation regardless of students' disciplinary background, courses for a limited set of disciplines, and courses intended for a particular discipline. For example, P6 explained how their art courses are open to all students and enable them to integrate their experiences, knowledge, and skills from different disciplines. However, in courses for students from a limited set of disciplines or a particular discipline, in order to participate, students need to have specialised knowledge about specific topics, such as advanced field theory or programming. For example, P10 (Lecturer in Mechanical Engineering) discussed a specific engineering course for engineering students, saying '*The CAE (computer-aided engineering) course is for mechanical engineers only. It's like an excel tool for economists … . We teach [engineering students] to utilize it to see what [engineering analysis can be] achieved with this tool'.*

Student interaction was also discussed frequently by faculty members (n = 10), which is related to how students interact with each other. Faculty members talked about their courses where students work individually, collaboratively in teams, or a combination of both. When students work in teams, they are often from different disciplines P1, who teaches in a multidisciplinary bachelor's programme, cautioned about the importance of interactions between students and said that '*I always have students from different disciplines … but [we need to] make sure that true interaction happens between them'.*

Faculty members also placed emphasis on teacher background (n = 7) as a representation of multi-, inter-, or transdisciplinary education. Depending on how faculty members see the level of disciplinary integration in their disciplinary backgrounds, they may have mono, multi-, inter-, or transdisciplinary backgrounds. For example, P5 (Designer & Lecturer in Design) explained why they invited guest lecturers was because they have 'only a design background', implying P5's monodisciplinary background, whereas Participants 3 and 12 identified themselves as being interdisciplinary because of their industrial design computer science and sociology backgrounds as well as biomedical engineering backgrounds, respectively. Thus, they believe that they can help bring interdisciplinary content to their courses. Another participant (P6) set an example for having a transdisciplinary background, which goes beyond disciplinary boundaries and shapes one's approach to education:

'Transdisciplinarity is … transition, transformation … removing [oneself] from familiar settings and trying out new things … . My educational background is in art education, [which is about] reflection, discussion, and continuous reflection … . It's about critically reflecting on … existing skills and knowledge, thinking how we can do something different with them and how we expand them beyond disciplinary use'.

P6 went on to explain the approach of art education and pondered upon the instances where teaching starts with unknowns and inviting students to explore and reflect with the teacher, rather than merely teaching a few '*competencies*' needed in the current job market.

Co-teaching was also discussed by faculty members in relation to teacher background, and they explained how co-teaching brings multidisciplinary co-teachers together. For example, P11 (Professor in Design) stated, '*my courses are always co-[taught], meaning that there are teachers [who] have different backgrounds. So, I'm there with my design background, and my colleagues have their science background, and we work together throughout the course'*.

Another aspect that faculty members mentioned is course content (n = 6). Faculty members referred to their course content as mono-, multi-, inter-, or transdisciplinary, based on whether there are multiple disciplines involved or the level of disciplinary integration. For instance, P12 talked about the interdisciplinary core of their course, *'I'm giving a course that … combines life science … mechanical and electrical engineering. Therefore, it's obvious from the first lecture that interdisciplinarity is at the core of it'*. Faculty members also contextualised the discipline they are teaching, recognising that teaching one discipline does not always mean teaching solely that discipline and does not automatically result in monodisciplinary course content. For instance, P3 viewed the teaching of design as multi- or interdisciplinary as the discipline of design inherently involves multiple disciplines throughout various phases of the design process and has multi- or interdisciplinarity as its central aspect.

Finally, faculty members discussed teacher collaboration (n = 5). They mentioned instances of teaching alone, bringing in guest lecturers from industry or other academic departments, or co-teaching. For example, P12 invited guest lecturers from outside academia to provide students with a different perspective, '*I introduce other lectures to the course, primarily people from industry with different or same backgrounds with students … to tell the stories of their experiences in venturing into different disciplines and explain how to develop their ideas into products while sustaining [the viability]'*.

Although faculty members favoured disciplinary integration to distinguish multi-, inter-, and transdisciplinary education, their views on what constitutes disciplinary integration were more diverse and nuanced, relating to course content, teacher background, student interaction, student background, and teacher collaboration. By referring to specific elements of course design, faculty members were able to conceptualise these differences in a more concrete manner.

Summarising these five aspects of course design and the different variables that faculty members discussed, we propose an initial typology framework for categorising course designs (See Figure 1). The different variables are aligned vertically, based on the level of disciplinary integration that faculty members emphasised when considering the differences between multi-, inter-, and transdisciplinary education.

This typology corresponds with faculty members' accounts of their teaching experiences and illustrates various types of multi-, inter-, and transdisciplinary education designs that faculty members employed. For instance, P2 reflected that,

> *'In one of my product development courses, I am the sole teacher. The course content incorporates aspects from other disciplines within engineering and design. It's based on my personal experience teaching with others, but it's not strictly multidisciplinary; Although I do have students from all disciplines [of engineering], I try to cater to a very student body. My other product development course [is] more of a classic interdisciplinary course, as it involves*

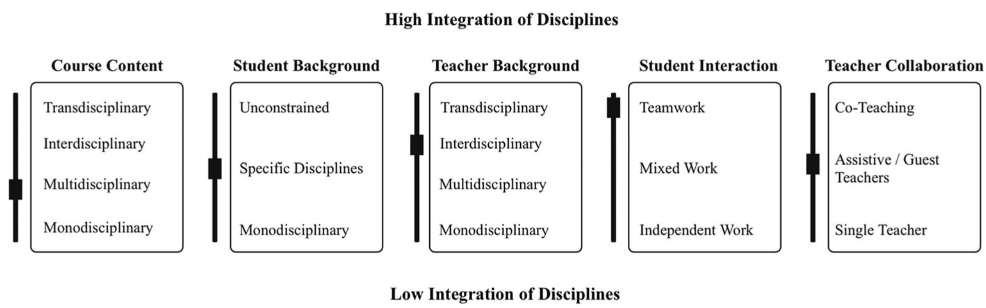

Figure 1. Typology framework on five aspects of course design in multi-, inter- and transdisciplinary education.

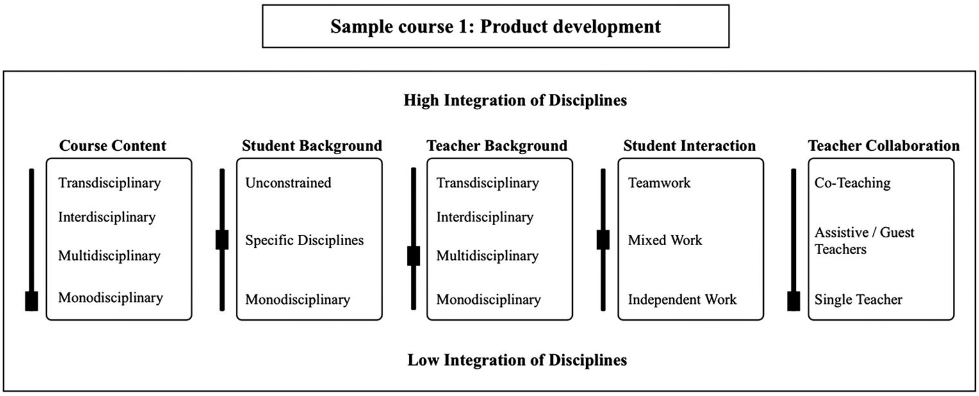

Figure 2. Sample course 1 on product development.

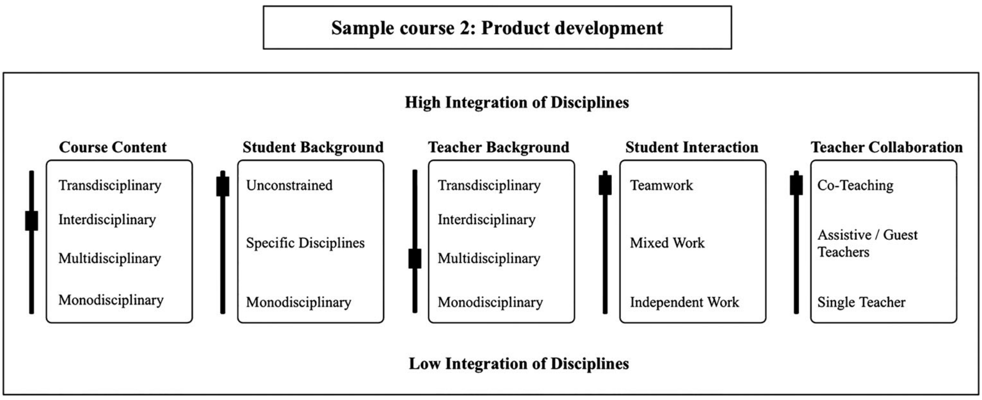

Figure 3. Sample course 2 on product development.

> *a global [teacher] team from different cultures and disciplines; students also come from different disciplines, and they work on projects together. So, that's truly interdisciplinary'.*

Through this comparison of two courses on product development (See Figures 2 and 3), with one being more multidisciplinary and the other interdisciplinary, it is clear that the second course has a higher level of disciplinary integration with the involvement of interdisciplinary teacher teams and student teams working together. Although the specific details of the teacher teams' work are not provided, the university's online course catalogue indicates that it's a co-taught course. We can also see that the process of comparing various course designs and reflecting on the differences, based on the level of disciplinary integration, enables P2 to understand what constitutes a truly interdisciplinary course.

In terms of course designs that contain transdisciplinary elements, P6 also provided examples in relation to the design of art courses (See Figure 4):

> *'What we do in our art studies is to provide students and faculty members with possibilities to try new things. If you are from business, you don't have to do 'business' stuff, you can do completely different; if you are from Art, you are not 'an artist' or 'designer' doing the design work. So that's the difference between [multidisciplinary and transdisciplinary education]'.*

This highlights P6's unique perspective on transdisciplinary education through a concrete illustration of a course design with transdisciplinary course contents and teacher background together with students from unconstrained backgrounds. They don't have to stick to their original disciplines and can branch out into something completely different.

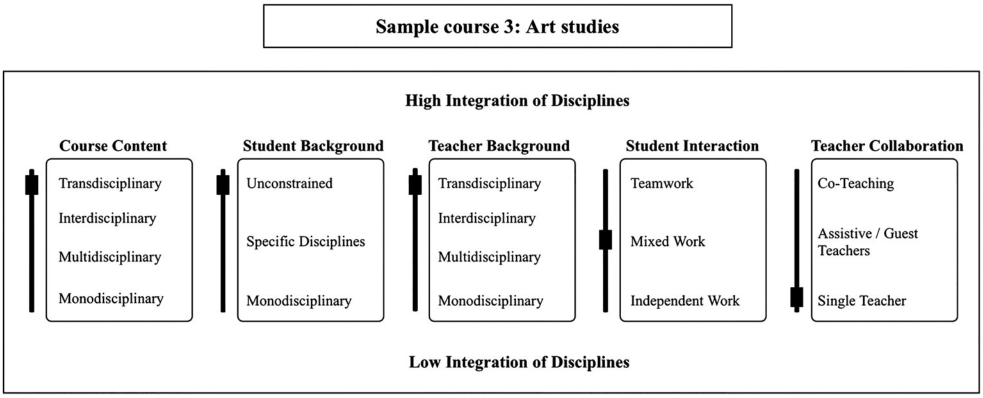

Figure 4. Sample course on art studies.

P4 also discussed the different designs of multidisciplinary education in comparison to interdisciplinary education through examples of product development projects,

> *'A classic example of a multidisciplinary course would be a product development project where students from design, marketing, and electrical engineering work in their respective fields, but they have some exposure to each other. For an interdisciplinary [product development project], I would require that students of marketing and electrical engineering work together. There's an additional depth and exchange [of disciplinary insights]'.*

We can see that by comparing two different scenarios of multi- and interdisciplinary education in practice, P4 envisioned different types of courses, paying attention to course content, student background, and student interaction.

Based on these examples, it can be concluded that despite the complexities of understanding multi-, inter-, and transdisciplinary education, faculty members have utilised different aspects of course design and variables associated with them to form their understanding of these concepts. By presenting an initial typology framework, we aim to provide faculty members with a useful tool to guide their course design, communicate with colleagues using concrete terms, and support their professional development.

Discussion

This study uncovered faculty members' different kinds of conceptualisations. We found that some faculty members, such as Participants 1, 9, 12 and 13, conceptualised multidisciplinary education as an encompassing concept to emphasise the combination, inclusion, and interaction of multiple disciplines in teaching and learning. Participants 9 and 12 explicitly discussed the challenges of understanding the differences between multi-, inter-, and transdisciplinary education. This may correspond to the specific disciplinary culture and discourses, as suggested by Becher and Trowler (2001). Engineering education, for example, has courses that teach either the technical domain of knowledge (Williams 2003) or the knowledge from other disciplines (Dym et al. 2005; MacLeod and van der Veen 2020). As such, faculty members from technical domains may simply find it accurate enough to talk about multidisciplinarity in contrast to the monodisciplinary courses in a binary fashion in order to have a meaningful discussion with colleagues about the topic.

Besides faculty members who conceptualise multidisciplinary education as an encompassing concept, a majority of faculty members distinguished multi-, inter-, and transdisciplinary education, based on disciplinary integration. This is consistent with previous findings that faculty members and scholars favoured disciplinary integration as the criteria to differentiate between the terms (Holley 2009; Lattuca and Knight 2010; Lattuca, Knight, and Bergom 2012; Lattuca et al. 2017). Our findings also support the idea that faculty members have an underlying appreciation for disciplinary integration in education.

However, what's new to the existing studies is that faculty members discussed disciplinary integration in specific aspects of teaching and learning, including course content, teacher collaboration, student background, teacher background, and student interaction, manifesting more nuanced conceptualisations between each other. Moreover, they discussed various types of courses, based on the level of disciplinary integration. For example, the designs of product development courses can be different in the way the teachers design the course content, involve students from different disciplines, engage students in teamwork, and collaborate with other teachers.

Our findings on faculty members' different conceptualisations are likely to stem from the foundational process of how the conceptualisation process takes place in the interaction between people (Blumer 1986). Faculty members have gained their conceptualisations through working in, reflecting on, and comparing their courses with other courses they have seen or have taught previously. During such a process, they articulate, interpret, conceptualise, and negotiate the meaning of multi-, inter-, or transdisciplinary education. By referring to specific aspects of course design and reflecting on their practices, faculty members were able to construct meaningful conceptualisations. Although multi-, inter-, and transdisciplinary education are ambiguous and abstract concepts and it can be challenging to establish conceptualisations that function across teachers and contexts (Lattuca and Knight 2010), faculty members were able to construct their meanings to conceptualise in a tangible way by referring to a specific aspect of course design and reflecting on their practices,

Implications

We have uncovered faculty members' understandings of multi-, inter-, and transdisciplinary education through their narratives of different course designs. Instead of viewing disciplinary integration as a general criterion to differentiate between multi-, inter- and transdisciplinary education, we found nuanced conceptualisations from faculty members that can expand the existing literature on disciplinary integration in relation to a specific aspect of course design.

Based on this finding, we developed an initial typology framework for understanding different types of course design for multi-, inter-, and transdisciplinary education practices. For engineering educators who are interested in teaching with more multi-, inter-, or transdisciplinary elements, we hope that the integration framework helps provide a hands-on toolkit for course planning and designing, especially for those who are less experienced in multi-, inter-, or transdisciplinary contexts and would like to challenge the status quo of monodisciplinary teaching. For those who are more experienced, it would be worthwhile to consider the potential implications of different course designs for students' learning outcomes. For example, teachers with multi- or interdisciplinary backgrounds should aim to maximise the use of combined disciplinary insights, encourage students to explore other disciplinary areas, and integrate various knowledge and skills; transdisciplinary teachers can challenge the use of disciplines in teaching, go across disciplinary boundaries, experiment with different teaching methods beyond disciplinary use, engage with various stakeholders, and learn together with the students.

Since combining different aspects of teaching and learning can result in different course designs, it may indicate varying learning outcomes. Therefore, for teachers to make more informed educational choices that align with their teaching and learning objectives, it is crucial for teachers to reflect on the different learning outcomes as a result of utilising co-teaching versus inviting guest lecturers, and student teamwork versus student independent work.

Conclusion

In summary, this study examined faculty members' conceptualisations of multi-, inter-, and transdisciplinary education, as well as their representations of different aspects of course design. The findings indicate that whilst most faculty members are inclined to adopt disciplinary integration as a criterion for differentiation, their conceptualisations are much more nuanced and are related to specific aspects of course design, such as course content, teacher collaboration, student background, teacher background, and student interaction.

To provide a comprehensive overview of the aspects of course design discussed by the faculty members, we have proposed an initial typology that highlights various types of course designs, each demonstrating different levels of disciplinary integration. These courses can serve various learning objectives.

Although this study offers interesting results, we examined the conceptualisations of a limited number of faculty members in one institution in a Nordic country (anonymized) where most of the participants speak English as a second or third language. The heterogeneous disciplinary backgrounds of the participants can also impact the saturation of the data (Guest, Bunce, and Johnson 2006). Therefore, the research findings cannot be generalised across all faculty members who work in multi, inter-, or transdisciplinary education contexts. However, we attempted to mitigate this by using a semi-structured approach to the interviews, which enabled the emergence of common themes and patterns (Guest, Bunce, and Johnson 2006). Additionally, conceptual ambiguities were found to be prevalent among scholars and educators to this day, regardless of their institutions or countries, even among those whose first language is English. As a result, faculty members across institutions and countries may still share similar challenges and therefore find our study valuable in gaining insight into the perceptions of their peers. The small number of participants may also influence the development of the typology, but we used peer debriefings to enhance the validity of our analysis. Future research should validate the typology further and explore the effects of different types of course design on teaching and learning, as well as investigate the applicability of the typology model for course design and teachers' professional development.

Nevertheless, the present study serves as a good basis for an in-depth understanding of faculty members' perspectives by examining faculty members' conceptualisations and representations of different types of course design. By presenting a typology of different course designs, we hope to provide empirical guidance for faculty members to better understand the multi-, inter and transdisciplinary features of their course and construct courses suited to their teaching agenda. Such a typology can also help faculty members communicate more effectively with co-teachers concerning specific aspects of course design.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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