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RESEARCH ARTICLE

Interdisciplinarity in engineering education: An empirically grounded typology

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Abstract

Background: The concept of interdisciplinarity has gained considerable traction in engineering education. However, research has primarily focused on its impact on students' learning experiences and outcomes, while relatively little is known about how engineering teachers conceptualize interdisciplinary education. Additionally, there have been calls for theoretical insights into interdisciplinary education.

Purpose: Drawing on Weber's concept of the "ideal type," which aims to capture salient theoretical features of social phenomena, this paper seeks to contribute to a theoretical understanding of how engineering teachers conceptualize the nature of interdisciplinary education.

Design/Method: Eighteen engineering teachers from three universities across three Nordic countries, all experienced in teaching interdisciplinary courses, participated in semi-structured interviews. The analysis proceeded in two stages. First, an empirical analysis, where the interview transcripts were subjected to thematic analysis. Second, a theoretical analysis developed an ideal-type conceptualization of interdisciplinary education and examined it through a socio-cultural lens.

Results: The analysis led to the development of a typology comprising of four ideal-type conceptualizations of interdisciplinary education. The typology, taking the form of a two-by-two matrix, advances theoretical understanding by discerning two modes of disciplinary *interaction* (epistemic and social) and two roles of *integration* (integrationist and generalist) in interdisciplinary education.

Conclusions: The typology weaves together our empirical findings with key theoretical strands and positions on interdisciplinarity identified in the scholarly literature into a cohesive framework that informs both the theory and practice of interdisciplinary education. The typology can be used as a "boundary object," a conceptual tool that facilitates collaboration between teachers across disciplinary boundaries.

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KEYWORDS

boundary object, interdisciplinarity, interdisciplinary education, teacher conceptions, typology

1 | INTRODUCTION

The concept of interdisciplinary education has gained considerable traction as a way to rethink and reshape engineering education (Van den Beemt et al., 2020). Consequently, an increasing number of initiatives have been developed to promote interdisciplinary education, and higher education teachers have engaged with interdisciplinarity in education in multiple ways. For example, teachers have formed student teams based on disciplinary diversity (e.g., Henderson et al., 2025), designed authentic problems that draw on multiple disciplinary perspectives or methods (e.g., Dym et al., 2005), and co-taught courses with colleagues from other disciplines to develop integrated course content (e.g., Shooter & McNeill, 2002). These diverse practices may suggest that there are also diverse understandings of the concept of interdisciplinary education.

However, a deeper engagement with the concept of interdisciplinarity is scarce in the engineering education literature. Where the concept is discussed in more detail, the focus is usually on distinguishing it from neighboring concepts such as multidisciplinarity and transdisciplinarity (e.g., Feng et al., 2023; O'Connell et al., 2026; van den Beemt et al., 2020). A related weakness that we argue is typical of research on interdisciplinarity in engineering education is that studies import their working definition of interdisciplinarity from other fields without addressing the fact that the concept can be construed from several perspectives. Interdisciplinarity is thus positioned as a "universal" concept with a single meaning. However, "interdisciplinarity is not everywhere conceived and implemented the same way" (Lenoir et al., 2015, p. 39). Klein (2010a) makes clear that the natural sciences, social sciences, and humanities have different conceptualizations of interdisciplinarity. For example, interdisciplinarity in the natural sciences is frequently centered on problems or issues to be solved, whereas in the social sciences it tends to expand beyond disciplinary limitations in understanding (Klein, 2010a). Even in fields with a well-established body of literature theorizing interdisciplinarity, such as the humanities, debate remains regarding its nature (e.g., Repko, 2007). Given these debates and varied views on the nature of interdisciplinarity, it is worth exploring how interdisciplinarity is conceptualized within engineering education.

Previous research on interdisciplinarity in engineering education has mainly focused on the *application* of the concept rather than on the concept *itself*. Such research typically investigates the impact of interdisciplinary courses and curricula on engineering students' learning experiences and outcomes (e.g., Holmén et al., 2021; Lattuca et al., 2017; O'Connell et al., 2024; Richter & Paretti, 2009). However, relatively little is known about how engineering teachers understand the concept of interdisciplinary education. Here we echo Lattuca's (2003) assertion that efforts to theorize interdisciplinarity need to consider the views of the teachers who design and deliver these interdisciplinary courses. This is especially pertinent with the increasing number of interdisciplinary courses offered to engineering students (e.g., Crawley, 2018; Enelund & Henricson Briggs, 2020).

It is against this theoretical and empirical backdrop that the present paper sets out to answer the following research question:

> **RQ.** How do engineering teachers conceptualize the nature of interdisciplinary education?

To answer this question, we conducted semi-structured interviews with teachers responsible for interdisciplinary courses or programs within engineering education from three universities across three Nordic countries.

The analysis of the interview transcripts proceeded in two stages. The first stage of the analysis employed a reflexive thematic analysis to discern recurring patterns of meaning within the data (Braun & Clarke, 2006). However, we note a recent commentary on the field of interdisciplinary education by Markauskaite (2025) who points to a lack of theoretical development:

> "[T]he field of interdisciplinary education continues to rely heavily on practical case studies, which, while rich in detail, often lack transferable theoretical insights. [...] studies that successfully bridge this gap are invaluable but rare." (p. 3)

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In recognition of this imbalance between applied and theoretical interests, we therefore augment our empirical analysis with a theoretical one. Building on the empirical analysis, the theoretical analysis makes use of Weber's (1949) notion of the "ideal type," which seeks to capture salient theoretical features of social phenomena (Freund, 1968). This allowed us to develop a typology outlining four *ideal-type conceptualizations* of interdisciplinary education. The typology weaves together our empirical findings with key theoretical strands and positions on interdisciplinarity identified in the scholarly literature to discern two modes of disciplinary *interaction* and two roles of *integration* in interdisciplinary education. As an additional part of the theoretical analysis, we examine these ideal-type conceptualizations of interdisciplinary education through a socio-cultural lens.

2 | BACKGROUND

2.1 | The concept of interdisciplinarity

An important point of departure for this paper is the observation that the concept of interdisciplinarity in education has been construed in various ways in fields outside of engineering education. Indeed, efforts to establish a universal definition of interdisciplinarity have been challenged by varying disciplinary perspectives, differing institutional contexts, and the dynamic nature of emerging fields (Newell, 2001; Repko & Szostak, 2021). What follows is a brief account of how interdisciplinarity has been theorized, focusing on key perspectives and debates in the field of interdisciplinary studies.

One key debate revolves around the notion of integration. From the literature, we have identified two theoretical positions on interdisciplinarity. The dominant position, termed "integrationist," considers integration to be integral to the idea of interdisciplinarity (e.g., Keestra & Menken, 2016). That is, interdisciplinarity is understood as the integration of insights and methods from different disciplines. From this perspective, without integration, the collaboration between disciplines should rather be characterized as multidisciplinary (Keestra & Menken, 2016). The second position, termed "generalist," downplays or rejects the position that integration is a defining characteristic of interdisciplinarity and instead sees interdisciplinarity as "any form of dialog or interaction between two or more disciplines" (Moran, 2002, p.16). Here, there is a suggestion that integration takes a backseat to dialogue and collaboration. However, we note that there is debate as to what is considered integration, and we note that Boden (1999) outlines how there can be different levels of integration and interdisciplinarity. Consequently, the delineation between integrationist and generalist may not be as straightforward as theorists such as Newell (2001) suggests.

There is also some debate about the necessity of collaboration across disciplines for interdisciplinary work. Fiore (2008) equates interdisciplinarity with teamwork, arguing that it is difficult for an individual to develop a deep understanding of more than one discipline. In sharp contrast, Klein (2010a) states that "many believe that interdisciplinarity is synonymous with collaboration. It is not" (p.19). The implication of this position is that it is possible for monodisciplinary groups or even individuals to engage in interdisciplinary work.

It has been argued that differences in the understanding of interdisciplinarity can be attributed to differences in epistemological assumptions both between and within disciplines. Lattuca (2003) points out that efforts to define interdisciplinarity inevitably reflect the priorities of the disciplines involved. Newell (2001) discusses some of the differences between, on one hand, the natural and social sciences, and the other hand the humanities, explaining how their view of interdisciplinarity is ingrained in their theoretical perspectives. A clear example of how theoretical perspectives shape the understanding of interdisciplinarity is the emergence of what has been termed "critical interdisciplinarity" (e.g., Stoller, 2020), which draws heavily on insights from critical theory. As such, critical interdisciplinarity "interrogates the dominant structures of knowledge and education with the aim of transforming them" (Klein, 2010b, p.23). The opposing, and more prevalent, position is instrumental interdisciplinarity which takes a pragmatic approach and is centered on solving complex problems (Klein, 2010a; Welch IV, 2011). Proponents of critical interdisciplinarity criticize this "instrumental" approach as it fails to question the status quo.

These theoretical deliberations warrant an analytical focus on how interdisciplinarity is conceptualized in engineering education. Such an analysis serves as a significant counterbalance to studies in engineering education that tend to import their working definitions of interdisciplinarity from other fields without addressing the fact that there are different theoretical traditions surrounding the concept.

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2.2 | Teachers' conceptions of interdisciplinarity

Interdisciplinary education has been presented as an opportunity to better prepare engineering students for the future challenges they will face upon graduation (Hadgraft & Kolmos, 2020). This has seen interdisciplinarity become incorporated through courses offered as electives that sit outside the regular curriculum (e.g., Enelund & Henricson Briggs, 2020), or as part of a wider degree program (e.g. Koira, 2016). Additionally, both problem- and project-based learning (PBL) have been promoted as effective ways to implement interdisciplinarity in engineering education (Hadgraft & Kolmos, 2020). Consequently, PBL is the most prevalent approach for implementing interdisciplinary education in the field of engineering education (van den Beemt et al., 2020).

There have been some studies examining teachers' conceptions of interdisciplinarity in higher education, and the findings from these studies reflect key debates in the broader literature on interdisciplinarity. Chittle et al. (2023), for instance, examined how science teachers conceptualize interdisciplinarity, and while interdisciplinarity was generally seen as the combining of disciplinary knowledge, not all teachers emphasized the importance of integration between disciplines. In contrast, integration was a significant component of conceptions of interdisciplinarity in Kans and Gustafsson's (2020) study, but the understanding of the object of the integration varied among those interviewed. For students, it was primarily seen as the integration of people from different disciplines, whereas teachers saw it as primarily being the integration of disciplinary knowledge.

Lattuca (2003) interviewed faculty engaging in interdisciplinary research and interdisciplinary education to discover how they conceptualized interdisciplinarity. Lattuca noted that while science faculty members were more likely to see integration as necessary, faculty from the humanities and social sciences were split, with some rejecting the notion of integration because of the perceived power imbalance between disciplines. These opposing positions reflect the previously mentioned split between integrationists and generalists (Repko, 2007). While it might be tempting to view the fault lines between these positions as synonymous with disciplinary backgrounds, Lattuca (2003) suggests that epistemological beliefs are a better explanation for what concept of interdisciplinarity faculty believe in rather than their discipline. It should therefore not be taken as a given that a shared discipline or field of study will result in a shared understanding of interdisciplinarity.

Turning specifically to engineering education, an initial explorative search of the literature resulted in only four studies that have an overlapping analytical interest with our research question. An additional more systematic search of SCOPUS using the string "((engineering education) OR (higher education)) AND (nature of interdisciplinar*) AND ((teacher concept*) OR (teacher belief) OR (teacher understanding) OR (teacher defin*) OR (lecturer concept*) OR (lecturer belief) OR (lecturer understanding) OR (lecturer defin*) OR (educator concept*) OR (educator belief) OR (educator understanding) OR (educator defin*) OR (faculty concept*) OR (faculty belief) OR (faculty understanding) OR (faculty defin*))" failed to reveal any additional relevant studies. The search resulted in 86 papers, after screening 6 seemed relevant but after further reading they were found to not be focused on teachers of higher education or addressing their conceptualization of interdisciplinarity. Of the four studies we found Lattuca and Knight (2010) compared engineering faculty and administrators' definitions with their own definition of interdisciplinarity. However, they did not attempt to look deeper into how the teachers conceptualize interdisciplinarity. Ming et al. (2025) asked engineering teachers and graduate engineers to rank competencies according to their importance to interdisciplinary education. From this ranking, they then theorized the participants' perspectives of interdisciplinarity and what it is. Another study by Ming et al. (2026) attempted to discern the different ways faculty and engineering practitioners conceptualize and interpret interdisciplinarity in education. They categorized interdisciplinarity as capacities, identity, and institutional practices. Finally, a study by Feng et al. (2023) categorized how engineering teachers defined the terms multidisciplinary, interdisciplinary, and transdisciplinary with a focus on the role of integration. These were then used in the creation of a framework for course design. This limited research attention suggests a need for further exploration of teachers' conceptualizations specifically in engineering education.

3 | THEORETICAL AND METHODOLOGICAL APPROACHES

3.1 | Positionality statement

The authors represent a wide range of cultural backgrounds and academic expertise. All authors have previously published studies that either focused on or incorporated the concept of interdisciplinarity within the field of

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engineering education research. Consequently, each author brings their own, and sometimes different, conceptions of interdisciplinarity, and the analysis is therefore not free from prior understandings. However, it is not the intention of the authors to derive an objective definition of interdisciplinary education, but rather to explore and theorize how engineering teachers conceptualize interdisciplinary education and how these conceptions are situated within and shaped by socio-cultural contexts.

The authors also come from diverse disciplinary backgrounds (four from STEM fields, two from business and sustainability fields, and one from education) and bring different disciplinary and interdisciplinary perspectives to the study. We do not aim for consensus; rather, we acknowledge how our perspectives shape the way we interpret the data. At the same time, we recognize the importance of maintaining "attentive and conscious" to participants' own meanings and voices. In line with reflexive qualitative research practice, we have consciously engaged in practices of questioning ourselves and each other throughout the interviewing, analysis, and reporting processes in the joint meetings (Patton, 2015). At the time of the study, six of the authors were affiliated with universities selected for this study. The remaining author had been affiliated with one of the participating universities in the past.

The core data analysis team (MO, XF, and JS) has substantial prior and ongoing experience with interdisciplinarity and entered the study with pre-existing understandings of interdisciplinarity as opposed to multidisciplinarity or transdisciplinarity. To address this, we began by independently coding the same transcript in blind mode before meeting to discuss convergent and divergent patterns and questions emerging from the data. During the initial coding phase, we tried to use participants' own terms where possible to highlight their voices. Throughout the analysis, we took notes and held regular discussions to reflect on how our positionalities influenced interpretations.

3.2 | Theoretical orientation

To clarify what we mean by "teachers' conceptions" and to situate our theoretical orientation, we turn to long-standing discussions of *teachers' beliefs*. For more than five decades, this construct has drawn sustained attention in educational research, not least because teachers' beliefs are understood to "filter, frame, and guide experience, decisions, and actions" (Fives & Gill, 2015, p. 1). Although definitions of teachers' beliefs vary somewhat across the literature, Zembylas and Chubbuck (2015) build on the foundational work of Kagan (1992) and Pajares (1992) to offer the following definition:

> "Teachers' beliefs are understood as the interconnected, affective, conceptual, and evaluative perspectives that teachers develop about themselves, their students, student learning, methods of instruction, curriculum, and schools as social institutions." (p. 174)

In the present study, we use the term "teachers' conceptions" to denote our analytical interest, emphasizing the conceptual dimension of teachers' beliefs while setting aside the affective and evaluative aspects.

A range of theoretical perspectives can guide research on teachers' beliefs (Ashton, 2015). Over the past two decades, however, a growing body of scholarship has argued that a cognitive perspective is insufficient for understanding the complexity of teachers' thinking and learning (Kelly, 2006). Recognizing this critique, we move beyond cognitive accounts and adopt a *socio-cultural* perspective, which views teachers' beliefs as formed, negotiated, and enacted not only within the immediate contexts (e.g., classrooms where teaching and learning takes place) but also within the larger social and cultural contexts where the interaction of teaching and learning is embedded (Lattuca, 2002; Wallace & Priestley, 2011). We also consider the potential effect the teachers' disciplinary backgrounds can have on their perceptions of interdisciplinarity (Lattuca, 2003; Newell, 2001).

3.3 | Research context and participants

The study was conducted within the context of Nordic higher education, and we targeted three institutions that have a long history of developing interdisciplinary education practices and are well-known in the region for their initiatives in interdisciplinary education. All three universities offer three-year "ordinary" bachelor's degrees with an optional two-year master's add-on, as well as integrated five-year master's degrees compliant with the European

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Union's Bolonga process, ensuring they adhere to a common educational standards and level of quality (see European Commission, 2022).

The first institution, Aalto University in Finland (Aalto), is a multidisciplinary university that prioritizes sustainability, creativity, and entrepreneurship as cross-cutting themes in research, education, and outreach (Aalto University, 2024). To support this strategy, Aalto implements interdisciplinary educational activities across its six schools: science, engineering, electrical engineering, business, chemical engineering, and arts, design, and architecture. Notable interdisciplinary programs and courses offered at the master's level include the International Design Business Management master's program, the Product Development Project at Design Factory, and the Sustainable Global Technologies elective program. These initiatives enable students from diverse business, arts, science, and engineering fields to learn together via real-world problems.

The second institution, Chalmers University of Technology in Sweden (Chalmers), consists of 13 departments across a wide range of science and engineering fields, such as architecture, civil engineering, microtechnology, and nanoscience. Chalmers recently launched "Tracks," a large-scale educational initiative that enables students and teachers from different programs and departments to collaborate on real-life projects as part of elective courses (Enelund & Henricson Briggs, 2020). Tracks courses are offered at basic (bachelor's and above) and advanced levels (master's and above), are open to PhD students, and some courses even allow alumni and professionals to attend. Tracks courses combine a mix of lectures and interdisciplinary group projects addressing current societal challenges.

The third institution, Aalborg University in Denmark (Aalborg), is internationally recognized for its problem-based and project-organized curriculum—the so called "Aalborg Model" (Kolmos et al., 2004). Aalborg's four faculties include the Faculty of Social Sciences and Humanities, Technical Faculty of IT and Design, Faculty of Engineering and Science, and Faculty of Medicine. At Aalborg, students devote half of their study time to semester-long project-based teamwork facilitated by academic staff and the other half to structured courses (Habbal et al., 2024). Recent initiatives have enhanced systematic integration of diverse forms of interdisciplinary education into Aalborg's curriculum (Routhe et al., 2023), ranging from monodisciplinary to narrow interdisciplinary as well as single to multi-teams learning designs (Kolmos et al., 2024).

We interviewed 18 participants that were selected via convenience sampling: five from Aalto, six from Aalborg, and seven from Chalmers (see Table 1). The participants were identified by locating interdisciplinary programs and initiatives at the three universities that involved engineering students and contacting the teachers of these courses or initiatives directly by email or in person. Participants were selected based on their diverse disciplinary backgrounds (e.g., civil and mechanical engineering, architectural design, intercultural communication), their relevant interdisciplinary teaching experience in courses that involved engineering students, and varying academic positions (e.g., professors, university lecturers, and post-doctoral researchers). The participants' teaching represented both narrow and broad interdisciplinary courses in engineering education. The terms "narrow" and "broad" interdisciplinarity refer to the "closeness" of the disciplines involved. Narrow interdisciplinarity encompasses disciplines that share similar conceptualizations, epistemologies, or domains, whereas broad interdisciplinarity is more diverse, with disciplines sharing little to no such similarities (Huutoniemi et al., 2010). Some participants taught exclusively in engineering programs, while others taught courses shared across engineering and other degree programs. While all teachers had experience in project- and/or problem-based courses, not all of them taught interdisciplinary versions of such courses. For each institution, one of the co-authors from said institution took on the task of contacting and inviting participants for the study. All those that responded positively to the invitation to participate were interviewed.

The research study received ethical approval from all three participating universities, and all participants were informed with a privacy notice, a research information package, and a consent form outlining confidentiality and data handling procedures when inviting them to the study. Participants were contacted via email and provided with a brief description of the study and the information package. Printed privacy notices and consent forms were brought to the interviews, and all participants were offered digital versions as well if they wished. To ensure anonymity, participants were provided with pseudonyms which incorporated their university's initials and a number: AAx for Aalto, CHx for Chalmers, and AAUx for Aalborg.

3.4 | Data collection

Semi-structured interviews were used as the data collection method. This method allowed in-depth exploration of participants' conceptions and experiences, while retaining flexibility to probe emerging topics and enabling reciprocity in

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TABLE 1 Participants' institution, their assigned ID, their disciplinary backgrounds, and the level they teach. For confidentiality reasons, specific fields and positions are not linked to individual participants.

Institution	ID	Discipline	Course level
Aalto	AA1	Engineering, design, and management	Master's
Aalto	AA2	Engineering and business	Master's
Aalto	AA3	Chemical engineering	Master's
Aalto	AA4	Business and management	Bachelor's
Aalto	AA5	Mechanical engineering	Master's
Aalborg	AAU1	Computer science	Bachelor's
Aalborg	AAU2	Bio-medical engineering and control systems	Bachelor's
Aalborg	AAU3	Mechanical engineering	Bachelor's
Aalborg	AAU4	Intercultural communication	Bachelor's and Master's
Aalborg	AAU5	Business administration	Master's
Aalborg	AAU6	Chemistry and bioscience	Bachelor's and Master's
Chalmers	CH1	Applied chemistry and material science	Master's and PhD
Chalmers	CH2	Civil engineering	Master's
Chalmers	CH3	Chemical physics	Master's
Chalmers	CH4	Bio-medical engineering	Bachelor's and Master's
Chalmers	CH5	Applied mechanics	Master's and PhD
Chalmers	CH6	Acoustics	Bachelor's and Master's
Chalmers	CH7	Architectural design	Master's

the conversation (Galletta & Cross, 2013; Kallio et al., 2016). The interview guide was developed iteratively: initial questions were informed by prior broader research on teachers' conceptions and experiences of interdisciplinary education (Feng et al., 2023; Kjellberg et al., 2023), with revisions by all authors to finalize the content of the guide. The final guide consisted of four thematic areas, and the first area, teachers' conceptions of interdisciplinary education, constitutes the focus of this paper.

Each interview began with an introduction of the two interviewers, an outline of the study, and details on how the participant's data will be handled. Participants were first asked to describe their disciplinary background and the interdisciplinary courses they taught as a "warm-up." They were then asked to elaborate on their understanding of the nature of interdisciplinary education. The interviews lasted from 30 to 70 min. All interviews, except for one conducted online, were held face-to-face on campus. Sixteen of the interviews were jointly conducted by the first and third authors, one by the first and fourth authors, and one solely by the third author. All interviews were audio-recorded, transcribed using Speech2Text software, and manually verified for accuracy.

3.5 | Empirical analysis

The analysis was conducted in two stages: an empirical analysis of the interview data, followed by a theoretical analysis, which is described in the next sub-section. The empirical analysis was conducted using ATLAS.ti software (web version). The authors conducted a reflexive thematic analysis (Braun & Clarke, 2021). This inductive and iterative analytical strategy consists of reading and re-reading the transcripts, developing and refining codes (units of meaning), and sorting and sifting codes into emerging themes. We chose this analysis due to its interpretative and flexible nature. While approaches such as content analysis often emphasize identifying and quantifying recurring semantic patterns, reflexive thematic analysis enables deeper engagement with participants' meaning-making processes, particularly in contexts where similar expressions may carry different meanings across participants (Vaismoradi et al., 2013). For example, integration could refer to integration between disciplinary knowledge or individuals or something else. An inductive approach was suitable for the explorative nature of our research (Charmaz, 2006; Saldaña, 2009), and themes were developed for the research question: How do engineering teachers conceptualize the nature of interdisciplinary education?

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In the initial round, three authors independently conducted open coding (Strauss & Corbin, 1990) of the transcripts, generating preliminary codes aligned with the research question. After this initial coding, the three authors compared, refined, and grouped these codes into emerging themes connected to the research question. Significant meanings were identified by examining patterns of recurring codes, their relevance to the research question, and their salience across participants' accounts, which then guided the grouping of related codes into broader themes. The central organizing concept, codes, and sample quotes underlying each theme are illustrated in Table 2.

Regular meetings were held throughout the analysis process to resolve discrepancies, maintain analytical consistency, and enhance reliability and trustworthiness. In addition to these meetings, we kept brief analytical memos within ATLAS.ti to record evolving interpretations and maintained a shared codebook documenting changes to code definitions. To verify and align coding interpretations, one interview transcript was independently coded by all three authors. The previously mentioned pseudonyms were used throughout the data handling process to protect participant confidentiality. Consistent with reflexive thematic analysis, we developed themes on the basis of their significance rather than their frequency (Braun & Clarke, 2021). However, we nevertheless acknowledge that some readers appreciate some sense of the spread of evidence behind the theme (Braun & Clarke, 2025). Thus, while the quotes presented in Section 4 were selected because they articulate a theme most clearly, they also illustrate patterns that are present more widely in the dataset rather than constituting the sole evidence for them.

3.6 | Theoretical analysis

The second stage of analysis was a theoretical analysis of the empirical findings. The purpose of a theoretical analysis is not only to address descriptive "what" or "how" questions but also explanatory "why" questions (Jasso, 1988). That is to

TABLE 2 Overview of themes, organizing concepts, codes, and sample quotes.

Theme	Central organizing concept	Codes	Sample quotes
T1. Knowledge cross-pollination	Encountering fundamentally different disciplines as a source of learning transfer	Disciplines are distinctive Cooperation between disciplines affect engineering students	"If I should point out one single thing that has most affected the quality of our engineering graduates, it is the cooperation with the design [students]. The engineering education is very much focusing on the problem-solving skills [...] use proper ideas, processes or equations to find answers to the problems. But design education is much more about finding the right problems. That's their fundamental difference" (AA 5)
T2. Knowledge integration	Integrating and synthesizing multiple disciplinary perspectives for (a more) holistic understanding	Blending disciplinary perspectives Working across overlaps and gaps between disciplines	"If I should make an impact, I have to work interdisciplinary. I need to understand the needs of clinicians and biologist in order to develop an idea or a system that makes sense." (CH 4)
T3. Envisioning cooperative roles	Interdisciplinarity is only seen through the cooperation of specific experts and what they contribute.	Sub tasks are divided They have to talk together Electrical engineers and mechanical engineers address different technical aspects	"The electrical engineers, they were responsible for sizing the batteries, electric motors, and the mechanical engineers were responsible for making the chassis, suspension system and drive chain. These sub-tasks were divided [...] but [they] have to talk together because [...] at the end I need to have a driving car." (AAU3)
T4. Open entry across disciplines	Interdisciplinarity here denotes openness, whereby learning is non-gated regardless of disciplinary background.	Accepting students from all departments Welcoming everyone	"It depends on how you define interdisciplinarity [...] This course [...] is the most interdisciplinary one, because we accept students from really all the departments, basically, by definition. It's not that we have all students from all the departments, but we welcome everyone." (CH2)

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say, a theoretical analysis seeks to explain why certain patterns were observed in the empirical material. Due to this explanatory aim, a theoretical analysis often involves a certain degree of speculation (Jasso, 1988).

To theorize the themes developed from our empirical findings, we draw upon sociologist Max Weber's (1949) notion of the *ideal type*. As Freund (1968) explains, the ideal type "departs from empirical reality in order to gain a better theoretical view of it" (p. 111). The term "ideal" should therefore not be understood in an evaluative or normative sense, but rather as denoting a conceptual abstraction. These abstractions help render complex phenomena more intelligible, enabling scholars to interpret and explain empirical observations. The way that ideal types explain is "via the subsumption of the particular under the general" (McIntosh, 1977, p. 266). Swedberg (2018) offers a lucid account of how ideal types can be systematically constructed and used in sociological inquiry, emphasizing their value as tools for classification. For instance, Worsley (1984) developed a typology consisting of four ideal-type conceptualizations of culture. In a similar vein, our theoretical aim is to construct ideal-type conceptualizations of interdisciplinary education.

Positioning engineering teachers' beliefs as a socio-cultural construct, as we do, has important methodological implications. Chief among these is the necessity of engaging with different levels of analysis, ranging from the micro to the macro (cf., Englund et al., 2018), where macro-level phenomena "are those concerned with long sweeps of time and space and with large numbers of persons" (Collins, 1988; p. 2). To meet this methodological imperative, this theoretical analysis *also* expands the analytical horizon from the micro-level in the empirical analysis to include the meso- and macro-level. The aim here is to explain or interpret the ideal-type conceptualizations of interdisciplinary education by examining the potential influence of socio-cultural factors.

4 | EMPIRICAL FINDINGS

In the following, we present the results of the thematic analysis of engineering teachers' conceptions of the nature of interdisciplinary engineering education. The results are illustrated with exemplary quotes from participants with their pseudonyms, grounding the findings in teachers' voices and highlighting the richness and diversity of their perspectives.

The analysis led to the development of four themes reflecting the teachers' conceptions of the nature of interdisciplinary education: (1) *knowledge cross-pollination*, (2) *knowledge integration*, (3) *envisioning cooperative roles*, and (4) *open entry across disciplines*. These themes represent a broad range of conceptualizations where interdisciplinary education is envisioned as the bringing together of disciplines or people.

4.1 | Knowledge cross-pollination

Knowledge cross-pollination focuses on how distinct disciplines, whilst being fundamentally different, nonetheless learn from one another. Particularly, this theme highlights how one discipline's way of working and thinking enriches another. One participant elaborated on this through the contrast between engineering and design education, and how engineering education is improved through design:

> "If I should point out one single thing that has most affected the quality of our engineering graduates is the cooperation with the design [students]. The engineering education is very much focusing on the problem-solving skills [...] uses proper ideas, processes or equations to find answers to the problems. But design education is much more about finding the right problems. That's their fundamental difference." (AA 5)

This description is not about framing problem-solving in engineering and problem-finding in design as competing approaches. Instead, the participant tried to argue that engineering graduates can gain an orientation that they would be unlikely to develop from within their own training. Cross-pollination, in this reading, is the productive use of what lies within the other discipline. However, the differences between disciplines also come with potential pitfalls as one participant noted:

> "But interdisciplinary for me means that we are not only bringing different disciplines together, but somehow maybe recognizing their differences or the pain points of bringing them together, maybe also the opportunities of bringing them together." (AA 1)

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This narrative acknowledges the value that cross-pollination of different disciplinary knowledge brings while also recognizing that it is not necessarily a simple or straight process.

4.2 | Knowledge integration

Unlike cross-pollination, where distinct disciplines remain separate and learn from one another, knowledge integration describes how a problem or product cannot be addressed from within a single field and needs to draw several together at once. This theme emphasizes integrating multiple disciplines as a coherent whole, and that the value lies in the fusion of disciplines. Participants pointed to the integrative nature of their work as well as the changing nature of the work:

> "If I should make an impact, I have to work interdisciplinary. I need to understand the needs of clinicians and biologist in order to develop an idea or a system that makes sense." (CH4)

> "It's very rare to have simple mechanical development projects anymore. It's a combination of mechanics, electronics, embedded systems, radio communication—often combined to services or logistics or such things." (AA 5)

These two accounts focus on the cognitive process of weaving together different strands of knowledge into a cohesive one. A more reflective conception builds on this perspective by emphasizing that interdisciplinarity arises not only from connecting disciplines, but also from engaging with the gaps and overlaps that exist between them. These gaps are understood as products of how universities divide and define knowledge, and as potential spaces for new ways of thinking. One participant reflected that:

> "There's a lot of gaps between the (study) programs that's not covered, there's unknown knowledge... Interdisciplinarity might be in this gap between worlds of knowledge and understanding." (AAU 4)

This perspective sees that "reality" cannot be described by a single discipline and how interdisciplinarity can be used to address the disconnects created by disciplinary structures. Rather than taking knowledge from disciplines to be integrated, as in the first theme, this theme frames interdisciplinarity as a way to restructure and integrate disciplines, filling the gaps that emerge between traditional disciplinary boundaries.

4.3 | Envisioning cooperative roles

The third theme does not position interdisciplinarity as occurring between disciplines themselves, but through a social dimension that emphasizes the envisioning and structured coordination of cooperative roles within projects. These teachers described interdisciplinarity through the lens of project requirements, requiring the deliberate selection of individuals from specific disciplines to meet the demands of a given project. Two teachers articulated this process as:

> "When we [the teachers] team up, say we want to have a person that looks at the coupling between electrochemical potential and mechanical strain, then we have a mechanical engineer together with an electrochemist." (CH 5)

> "The electrical engineers, they were responsible for sizing the batteries, electric motors, and the mechanical engineers were responsible for making the chassis, suspension system and drive chain. These sub-tasks were divided [...] but [they] have to talk together because [...] at the end I need to have a driving car." (AAU 3)

Interdisciplinarity, in this perspective, is goal-oriented and project-driven, where the successful integration of disciplines relies on each individual fulfilling a predetermined role. Interdisciplinarity then is the practical assembly of

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individual expertise to meet specific objectives rather than being an academic pursuit. This view therefore differs from the previous themes as interdisciplinarity is between people from disciplines rather than between knowledge from disciplines (cf., theme 1).

Some teachers highlighted the boundaries of interdisciplinarity, suggesting that not all disciplines are equally suitable for integration into certain projects. For example, one teacher provided a hypothetical scenario:

> "What do you think [...] should be introduced in the context of making a mission for the moon? Because of course we have all the technical engineering stuff, but what should be interdisciplinary? Because if it's mixing students from different technical backgrounds, I totally do agree. But I think putting economi[sts] in it is very difficult." (AAU 2)

This perception frames interdisciplinarity as a pragmatic approach, where only disciplines that are deemed relevant and close are included in a project.

4.4 | Open entry across disciplines

The fourth theme similarly positions interdisciplinarity through a social dimension, in which people rather than knowledge are central. However, unlike the third theme, there are no constraints or predetermined disciplinary expertise dictating who contributes to what. Interdisciplinarity here refers to the absence of a gate at entry for learning and the breadth of the intake. One participant shared that:

> "It depends on how you define interdisciplinarity [...] this course [...] is the most interdisciplinary one, because we accept students from really all the departments, basically, by definition. It's not that we have all students from all the departments, but we welcome everyone." (CH 2)

However, teachers also reflected on a potential challenge in facilitating these interactions. A critical component of successful interdisciplinarity is the need to establish a shared understanding or "common language" among students, enabling them to overcome disciplinary divides. One teacher noted:

> "You want to achieve interdisciplinarity. [...] I mean it's not necessarily achieved with different kinds of students but [...] to create a kind of language within the students or between the students in the different groups." (CH 7)

This perspective reflects a conception of interdisciplinarity as requiring more than just non-gated learning and teamwork. This teacher highlights the need for students to be able to communicate with each other through a common language.

5 | THEORETICAL ANALYSIS

Drawing on Weber's concept of the "ideal type" and the empirical analysis, we now present a typology comprising four ideal-type conceptualizations of interdisciplinary education. In this section, we situate our empirical findings in relation to the theoretical positions on interdisciplinarity—specifically, the instrumental versus critical and the generalist versus integrationist orientations—outlined in the background section. The typology discerns two modes of disciplinary *interaction* and two roles of *integration* in interdisciplinary education. We end this section by discussing the theoretical value of the typology.

5.1 | Socio-cultural explanations for the empirical findings

Various socio-cultural contexts may have shaped the teachers' conceptualizations of interdisciplinary education. Although certain teachers' accounts of interdisciplinary education resonate with a more critical stance, the majority reflect a

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predominantly instrumental orientation. This tendency likely stems from the specific pedagogical contexts in which these teachers work, namely problem- and project-based learning environments. These project- and problem-based courses within engineering education are often run on the assumption that they can recreate real-world conditions or prepare students for such (Hadgraft & Kolmos, 2020). This would place the teachers into a cultural group and may explain their instrumentalist view of interdisciplinarity. Therefore, another aspect to consider for this predominantly instrumentalist perspective is the "engineer" element of engineering education. The engineering teachers in this study appear to align with Boon and van Baalen's (2019) description of an engineering paradigm, which is focused on using functionally constructed knowledge to solve real-world problems. Accordingly, we preface our analysis by situating both the discussion and the resulting typology within an instrumentalist framework.

However, within this instrumentalist orientation, there was a clear variation in teachers' conceptions of interdisciplinary education, as reflected by the four identified themes in the empirical analysis. There is a suggestion by previous studies that these variances are due to factors such as institutional policies, institutional organization, teaching culture, and peer influence (Lawrence & Lentle-Keenan, 2013; Rubie-Davies et al., 2012). However, while performing the thematic analysis we made the observation that there appeared to be no alignment between a teacher's conception of interdisciplinary education and the institute they worked for. Although our empirical material did not reveal systematic differences between institutions, the predominance of certain conceptions may nevertheless reflect a shared socio-cultural context of Nordic higher education. This context is characterized by strong traditions of collaborative and problem-based learning, egalitarian teacher-student relations, and policy commitments to sustainability and innovation (Kallo & Välimaa, 2025). These features shape the educational environment in which teachers form their understandings of interdisciplinarity. From this perspective, the observed ambiguities and overlaps in teachers' conceptions may not simply indicate a lack of clarity but rather reflect the complex interplay of shared Nordic educational values and disciplinary practices. This interpretation aligns with Lattuca's (2002) socio-cultural view that teachers' understandings of interdisciplinarity are situated within broader cultural and institutional frameworks.

5.2 | Developing the typology

Based on our empirical analysis, we discern two distinct modes of disciplinary *interactions* underlying teachers' conceptions of interdisciplinarity: an *epistemic* mode and a *social* mode. The epistemic mode concerns how teachers perceive the relationships among disciplines and bodies of knowledge and how such knowledge can be combined, translated, or synthesized across disciplinary boundaries. In contrast, the social mode relates to how teachers frame interdisciplinarity in terms of people, roles, and relationships – that is, how individuals from diverse disciplinary or professional backgrounds collaborate, communicate, and negotiate within practice.

The distinction between the epistemic and social modes is significant since it can be understood as a way of elucidating *where* interdisciplinarity occurs—between disciplines or between people from disciplines. These modes are echoed in the broader literature on interdisciplinarity and are highlighted in theoretical work by Bernini and Woods (2014). They acknowledge the prevalence of the view of disciplines as entities, which aligns with our epistemic mode, and they argue that interdisciplinarity should be considered to occur between practitioners of disciplines in a similar vein to our social mode. However, Bernini and Woods view this social integration as a cognitive process, and while we recognize the important role of cognition, we feel they neglect the socio-cultural aspect of interdisciplinarity.

The framing of interdisciplinarity in terms of sociocultural theory is made by McMurtry (2011) who talks about the "known" versus the "knowers":

> "There are two important, but quite different, stories being told about the nature of disciplinarity and interdisciplinarity. One story emphasizes the complexity of the phenomena "known" [...]. The other story focuses on the socio-cultural dynamics within and among the various "knowers". Unfortunately, these two perspectives largely ignore one another's existence." (p. 26)

Identifying and bringing together these two perspectives—the epistemic (the "known") and the social (the "knowers")—within the context of interdisciplinary *education* constitutes one key theoretical contribution of this paper.

By examining these two modes of disciplinary interaction—the epistemic and the social—in terms of *integration* and its perceived role, we can further delineate them according to generalist and integrationist positions as outlined in the background section. When considering these positions within our duality, we can define a *generalist* perspective as

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one which emphasizes synergy, interactions, and interplay. Conversely, an *integrationist* perspective is one which emphasizes synthesis, coalescence, and coherence across disciplinary boundaries. This leads to a typology, a two-by-two matrix, comprising four *ideal-type* conceptualizations of interdisciplinary education: (1) *epistemic-generalist*, (2) *epistemic-integrationist*, (3) *social-generalist*, and (4) *social-integrationist*. This typology is depicted in Figure 1.

The epistemic-generalist orientation describes interdisciplinary education primarily as exposure to multiple disciplinary lenses and the development of literacy across diverse fields. Here, literacy refers to students' ability to recognize and understand the languages, methods, and underlying assumptions distinguishing each discipline, as well as their capacity to translate and communicate ideas across disciplinary boundaries. Interdisciplinary education, according to this ideal type, is achieved through the juxtaposition of distinct forms of disciplinary knowledge, which appreciates their complementarity, even if these domains are not formally integrated.

In contrast, the epistemic-integrationist orientation sees interdisciplinary education as a process of synthesizing disciplinary knowledge. This view emphasizes the construction of conceptual frameworks, the development of hybrid methodologies, and the formation of integrative models that cross disciplinary boundaries. According to this ideal type, interdisciplinary education entails negotiating diverse epistemic assumptions and developing a common conceptual or methodological foundation.

The social-generalist orientation sees interdisciplinary education not as the integration of knowledge, but rather as the collaboration of diverse individuals working toward a shared goal. According to this ideal type, the value of interdisciplinary education lies in social heterogeneity—the bringing together of individuals from different programs, disciplines, or professional domains. This perspective emphasizes the cultivation of heterogeneous networks and the coordination of individuals within a collaborative process toward a shared goal. Interdisciplinary competence, from this perspective, is understood as the ability to engage productively with others who frame and approach problems through differing intellectual paradigms.

Finally, the social-integrationist orientation differentiates from the previous ideal type by emphasizing coalescence and the joint framing of problems among diverse actors. According to this ideal type, interdisciplinary education is conceived as a socially integrative process through which participants negotiate meanings, share authority, and collaboratively frame problems and construct solutions. It entails a more transformative mode of engagement—one in which differences are not merely managed but actively integrated through processes of mutual learning and shared governance.

To interpret our typology accurately, it is important to recognize that ideal types do not necessarily show up in their pure form. Rather, they aim to capture salient theoretical features of social phenomena (Freund, 1968). By abstracting these features from the complexity of empirical reality, ideal types provide a framework for comparison and analysis rather than a direct description of empirical cases. Consequently, empirical cases may combine characteristics associated with multiple ideal types, reflecting the complexity and hybridity of social and political realities.

5.3 | The theoretical value of the typology

We recognize three principal ways in which this typology holds theoretical value. First, drawing on a wide range of theoretical discussions in the scholarly literature on interdisciplinarity, the typology weaves together key theoretical

	Mode of disciplinary *interaction*	
Role of *integration*	**Epistemic**	**Social**
Generalist	"Synergy"	"Interplay"
Integrationist	"Synthesis"	"Coalescence"

FIGURE 1 Four ideal-type conceptualizations of interdisciplinary education, distinguished by their mode of disciplinary interaction and role of integration.

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strands and positions on interdisciplinarity into a cohesive framework that informs the theory (and practice) of interdisciplinary *education*. Second, as a theoretical tool, the typology enables researchers (and teachers) examining interdisciplinary courses to "distinguish the aspects that are specific to a particular situation from those that are more likely to recur" (Sears & Cairns, 2015; p. ix). Third, by discerning different ideal-type conceptualizations of interdisciplinary education, and thus potential tensions between them, the typology helps explain why teachers may encounter difficulties in implementing interdisciplinary courses.

6 | DISCUSSION

6.1 | Implications for practice

Collaboration across disciplinary boundaries can be challenging for teachers, who may find themselves "sorely tested" in such situations (Fiscella & Kimmel, 1999; p. 181). The typology developed in this paper can serve as what Star and Griesemer (1989) termed a "boundary object"—a conceptual tool that facilitates collaboration between teachers across disciplinary boundaries. As McNair et al. (2015) observe, "Boundary objects can facilitate the interdisciplinary process by creating a 'trading zone', the space where differing knowledges, concepts, theories, and experimental approaches can evolve through negotiation and integration" (p. 48). Viewed as a boundary object, the typology provides a shared framework through which different conceptions of interdisciplinary education can be articulated, compared, and critically examined. When used by teachers when designing interdisciplinary project-based courses, the typology encourages teachers to consider where they view the focal point of interdisciplinarity. A social lens would see a focus on a diversity of disciplinary student backgrounds. Teachers would strive to ensure that each student group contains students representing a range of disciplines. Conversely, an epistemic lens would focus on a diversity of knowledge within the project. The make-up of the student groups is less important than the variety of disciplinary knowledge that they are exposed to. These are of course intended as means for teachers to be able to identify where their conceptualization sits on a theoretical plane, and their position within the typology can change as they develop and deliver their interdisciplinary courses.

However, when deliberating on which mode they align with, it is crucial for teachers to recognize that educational interventions unfold within specific socio-cultural contexts that shape their design, implementation, and impact. With this understanding, we now turn to one important facet of this broader issue.

Disciplines do not always meet as equals. It is, for example, well-documented that "hard" disciplines (i.e., the natural sciences and engineering) tend to dominate decision-making in interdisciplinary collaboration, while "soft" disciplines (i.e., the humanities and social sciences) are often marginalized (Gardner, 2013). As Miller et al. (2008) put it, interdisciplinary collaboration often "ends up entitling a single discipline or epistemology, incorporating others in a support or service role" (p. 46). We therefore recommend that, when using the typology for professional development purposes, teachers are encouraged to reflect on the power dynamic that emerges when students from diverse disciplines and epistemic traditions collaborate. Critically engaging with writings on epistemic justice in engineering education (e.g., Vargas-Ordonez & Rodríguez-Simmonds, 2025) can help deepen such reflections.

It is worth emphasizing that the typology is not intended to provide a definitive answer to what interdisciplinary education is, nor to anesthetize teachers' own theoretical engagement with the question. Instead, it is meant to invite reflection and conversation, serving as a springboard for further exploration.

6.2 | Future directions for research

Most theoretical analyses of the concept of interdisciplinarity in the engineering education literature seem to rely on how theorists in other fields define the concept, and such analyses also seem to strive for unity, for a single definition (e.g., van den Beemt et al., 2020). Our typology speaks to a re-orientation of such efforts to theorize interdisciplinary engineering education and is a call for pluralism. We therefore see three main avenues for future research. First, further empirical studies need to be conducted to further refine and expand the typology. Qualitative data can help strengthen and expand upon its various elements and quantitative data can provide insights into their prevalence among engineering teachers.

Second, our data was collected within the Nordic region from universities with a strong emphasis on project- and problem-based learning. One avenue for future research is to explore how engineering teachers outside the Nordic

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region whose universities might have less emphasis on project- and problem-based learning conceptualize the nature of interdisciplinary education. Such studies can help refine our typology and strengthen its transferability.

Finally, there is room for studies attending to how engineering educators' conceptions of interdisciplinary education shape their educational practice. Related to this, future research would also do well to explore how engineering educators develop their views on interdisciplinary education—what intellectual resources they draw from, and how they negotiate different theoretical positions and identities in relation to what is seen as relevant to engineering education.

6.3 | Limitations

While the theoretical nature of this study increases the transferability of its insights, some caution is warranted in interpreting and applying the developed typology. First, the study's Nordic setting, with its distinctive educational structures and cultural attitudes toward collaboration, may not directly translate to higher education contexts elsewhere. Additionally, we acknowledge that individual educational trajectories, backgrounds and experiences also play an essential role in shaping how interdisciplinarity is understood and enacted, which was explored only to varying degrees but was not examined systematically in this study. Similarly, we did not explore how the teachers developed their beliefs on interdisciplinarity, whether it was through formal institutional courses or practical experiences. However, keeping these contextual delimitations in mind, the participating universities reflect wider trends in engineering education, particularly the growing emphasis on interdisciplinarity and sustainability, which supports the dependability and transferability of our findings to similar contexts. Second, interviews were conducted in English, which was not the first language of most of the participants, and this may have constrained the depth or nuance of their responses. Finally, although thematic analysis allowed for an in-depth exploration of teachers' perspectives and was validated through iteration and discussion among the authors, the coding and interpretation remain prone to researchers' bias and subjectivity. Future investigations with larger, more diverse samples would help corroborate and extend the insights offered here.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are not publicly available because the interviews contain information that could compromise participant privacy and participants did not consent to public data sharing. Anonymized excerpts relevant to the study's findings are included within the article.

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