
European Journal of Engineering Education

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ceee20

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**To cite this article:** Xin Ming, Jan van der Veen & Miles MacLeod (02 Sep 2024): Competencies in interdisciplinary engineering education: constructing perspectives on interdisciplinarity in a Q-sort study, European Journal of Engineering Education, DOI: 10.1080/03043797.2024.2397419

**To link to this article:** https://doi.org/10.1080/03043797.2024.2397419



Published online: 02 Sep 2024.

EUROPEAN JOURNAL OF ENGINEERING EDUCATION
https://doi.org/10.1080/03043797.2024.2397419



# Competencies in interdisciplinary engineering education: constructing perspectives on interdisciplinarity in a Q-sort study

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**ABSTRACT**

Interdisciplinary engineering education (IEE) is gaining traction as engineering practices increasingly acknowledge the need to transcend traditional boundaries given the complexities of globalised systems. IEE, however, faces challenges that underscore uncertainties and different perceptions about what interdisciplinarity means for engineering education, what it requires, and how current educational practices should change accordingly. This study addresses these concerns by taking competencies as indicators. Analysing new angles interdisciplinary approaches bring to traditional engineering competencies, we first propose six IEE-related competency categories. We then use the Q-sort methodology to investigate how interdisciplinarity is envisioned within overall engineering educational goals. Findings highlight three distinct perspectives, seeing IEE respectively as social-holistic, technical problem-solving, and reflective pragmatic. Each perspective embodies specific values and conceptions about the role and implications of interdisciplinarity for engineering education. The multifaceted understandings of and approaches to realise IEE suggest the need for nuanced strategies and continuous dialogues in education.

**ARTICLE HISTORY**
Received 23 November 2023
Accepted 21 August 2024

**KEYWORDS**
Interdisciplinarity; interdisciplinary engineering education; competency; Q-sort; generic competencies; engineering competencies

## 1. Introduction

In a contemporary world of complex challenges and globalised systems, elements previously considered as outside the traditional engineering domains are becoming increasingly unavoidable in engineers' professional life. With ambitions to develop abilities to understand, employ and incorporate broad perspectives, knowledge and skills, engineering educational initiatives go beyond conventional disciplinary domains and reach to multiple and more flexible types of expertise. This trend entails the development of interdisciplinary engineering education (IEE), an approach towards reforming and even potentially revolutionising the education of engineers for the future (Roy and Roy 2021).

Rendering engineering education interdisciplinary is, nevertheless, not easy. In the rapidly changing educational enterprise, both what specific engineering domains require from students and what interdisciplinarity entails defies unanimous answers. As review studies report, IEE practices face the challenge of clarifying and aligning learning goals and assessments (Borrego and Cutler

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2010; Van den Beemt et al. 2020). Despite literature, policies and initiatives promoting interdisciplinary education, different visions and understandings compete for defining interdisciplinarity and determining how it should be realised in engineering education. To address the challenges IEE faces, investigations into such different conceptualizations, especially the positioning of interdisciplinarity in perceptions and practices of engineering education, are crucial.

What interdisciplinarity means, however, is often abstract and not always straightforward. Agents who engage in engineering education may not always have explicit theories on the role of interdisciplinarity. In this article, we apply competencies as indicator to discover understandings regarding IEE and explore how interdisciplinarity is embedded into the overarching landscape of engineering educational goals. As such, this study pursues the following research question: What kinds of underlying perspectives are disclosed by prioritising certain competencies in engineering education in view of interdisciplinarity? To answer this question we undertake two steps of investigation. First, we analyse what competencies are pertinent to IEE. Second, we investigate different visions in prioritising certain competencies among broad potential competencies that engineers might acquire in interdisciplinary contexts.

In the next section, we analyse and categorise IEE-related competencies as identified in the field. We then use the resulting framework in a Q-sort study to identify different perspectives on IEE.

## 2. Conceptual framework: competencies in IEE

A prominent approach to educational design and evaluation in outcome-based education focuses on the development of competencies, which entails the demonstration of knowledge, skills, attitudes, values and behaviours (Gervais 2016; Morcke, Dornan, and Eika 2013). Competencies, in this sense, indicate those personal qualities that drive performances and underpin certain level of behaviours, representing specific areas of the general competence or ability to function and perform tasks (MacLean and Scott 2011; Moore, Cheng, and Dainty 2002). For the highly profession-oriented engineering education, competencies are therefore useful indicators to devise education that prepares students for practical situations. Competencies also serve as a fruitful compass to interpret learning goals, outcomes and objectives, helping identify what students are expected to develop through education. Hence, IEE necessarily concerns how interdisciplinarity modifies the competencies addressed in traditional engineering education and introduces new ones.

Interdisciplinary approaches towards complex problems generally favour strategies geared towards synthesising knowledge and methods based in different disciplines that are commonly seen as separate (Lattuca et al. 2017). What interdisciplinarity entails in terms of competency development can nonetheless be various. The syntheses may occur in different ways, from individual intellectual development to teamwork (Borrego and Newswander 2010), involving various types of disciplinary expertise as well as generic cognitive and social capacities. Accordingly, we devise six relational categories to capture IEE-related competencies, differentiating them in terms of their relevance to interdisciplinarity. Following this, we draw out representative items from each category and assemble a broad inventory of competencies to operationalise empirical investigations into how individuals group and rank IEE competencies in relative importance when it comes to training engineers and designing curricula.

### *2.1 Conceptualising IEE competencies*

Comprehensively drawing up competencies pertinent to IEE starts with sketching new angles interdisciplinarity brings into engineering education competencies and limits of current competency frameworks for IEE. Engineering education has generally acknowledged two types of competencies: *disciplinary competencies* involving specific engineering content, especially deep understandings of disciplinary knowledge and mastery of skills; and *generic competencies* concerning general work performance in professional settings and daily challenges, not distinctive for any discipline but generally practiced across particular vocational and life contexts (Boelt, Kolmos, and Holgaard 2022; Miranda et al. 2021; Woollacott 2009; Young and Chapman 2010).

In a traditional sense, engineering is considered part of the technical realm that applies and industrialises natural sciences. Disciplinary competencies then equal technical competencies, consisting of technical knowledge and technology-oriented abilities – understanding, applying and creating technologies and technology-based solutions (Miranda et al. 2021; Sánchez Carracedo et al. 2018). Such technical expertise for practical problem-solving and design are predominantly considered as the epistemological core of the engineering discipline and are emphasised in most descriptions of engineering practices (Trevelyan 2010; Winberg et al. 2020). For disciplinary competencies, interdisciplinarity primarily implies expanding the scope of content engineering curricula incorporate (Figure 1), extending disciplinary content beyond traditional engineering and even to non-technical elements (Barnard et al. 2013). The expansion brings together different disciplinary perspectives and bridges the epistemological distance between disciplines (Choi and Pak 2008).

The outstretch of disciplinary competencies beyond domain-specific technical traditions therefore has two tiers: non-domain-specific technical elements and non-technical disciplinary elements. The former concerns elements affiliated with disciplines that are generally considered as cognitively more proximate to the assumed technical core of engineering. Accordingly, interdisciplinarity indicates the inclusion of fundamental natural sciences, underlying mainstream engineering knowledge and ingrained in specific engineering domains (Reich and Shai 2012). This tier may also imply the instrumental use of mathematics and physics, or connections between different engineering domains such as mechatronics or robotics. Relevant disciplines are often integrated in broad STEM (science, technology, engineering and mathematics) education (Martín-Páez et al. 2019) together with engineering.

The latter particularly refers to disciplinary perspectives regarding humanity and society. Although human and social elements are increasingly acknowledged as indispensable contexts of engineering, relevant disciplines are perceived as epistemically more distant from engineering and less represented in current engineering curricula. Towards more meaningful engagements with critical world problems, scholars have advocated for the incorporation of expertise from such disciplines in engineering education (Baillie and Armstrong 2013). New developments in

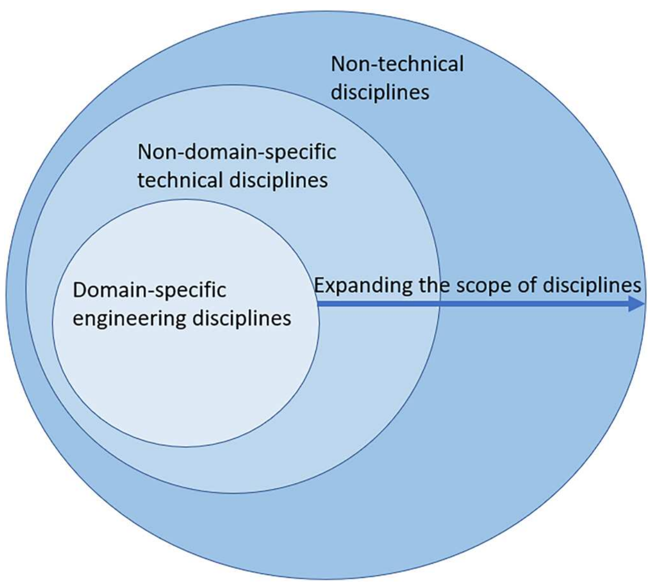


**Figure 1.** IEE expands the scope of disciplinary competencies in engineering education.

engineering fields, from human-centered design to human computer interaction, also expedite engineering education to embrace elements from humanities and social sciences, such as psychology and stakeholder approaches (Mohedas et al. 2020).

Generic competencies with few disciplinary features, on the other side, are broad in engineering education, ranging from social skills for teamwork to cognitive capacities towards personal learning and development. Such competencies are largely framed by the call of industrial employment (Winberg et al. 2020). Because engineering practices inherently embody socio-technical complexities (Trevelyan 2019), different emphases on these complexities can lead to different interpretations of generic competencies. Confining engineering as specific for certain technical domains, generic competencies only need to suffice for an isolated technical context (Matturro, Raschetti, and Fontán 2019; Walther et al. 2011). How generic competencies are framed and developed, then, presumes both a homogenous social environment and a straightforward link with engineering techniques and technologies.

An interdisciplinary approach calls for new generic competencies along different dimensions (Figure 2). First, IEE practices can break through particular technical contexts, not specifying any disciplinary context. Such education implicitly embraces interdisciplinarity by focusing the development of generic competencies on a general academic and professional level. Engineering, then, is orientated towards open-ended, ever-developing complex systems, where disciplinary knowledge is embedded in broad skills that can transfer across different settings (Gutiérrez Ortiz, Fitzpatrick, and Byrne 2021). Correspondingly, generic competencies address professional settings beyond engineering and personal development across contexts.

Furthermore, when IEE deliberately stresses applying and integrating different disciplines in tackling complex systems, generic competencies gain explicit interdisciplinary characteristics. Engineering then goes beyond the mere use of technical knowledge or social interaction in homogeneous teams. Rather, educators will place more emphasis on the involvement of diverse disciplinary perspectives, expertise, stakeholders and relevant groups. For example, interdisciplinary contexts require teamwork competencies differently. Engineering students need to learn to operate across disciplinary boundaries, which in curricula can be trained by bringing students into collaboration with students or academics outside their engineering field as well as extra-academic actors (Gallagher and Savage 2023). The general sense of reflection and (meta-)cognitive skills is also converted

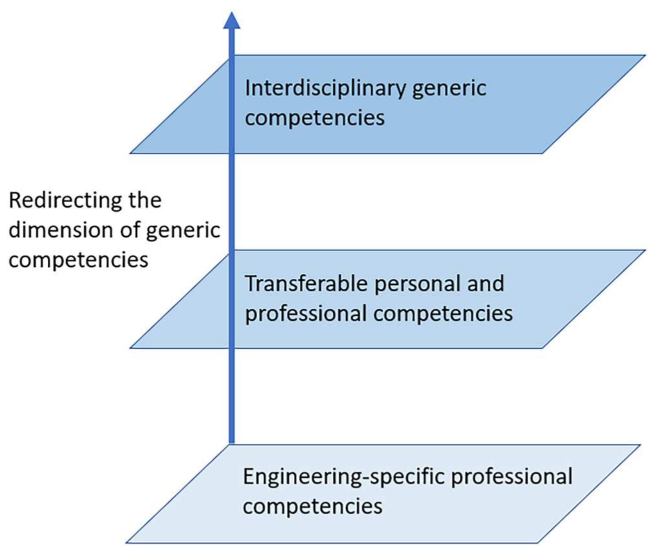


**Figure 2.** IEE directs generic competencies onto different levels in engineering education.

to an interdisciplinary level, underscoring competencies such as awareness and recognition of specific disciplinary perspectives (Claus and Wiese 2019; Lattuca, Knight, and Bergom 2013).

## 2.2 Categorising IEE competencies

It is admittedly debatable whether IEE competencies can be analysed into categories. Primarily, competencies are mutually dependent as one competency cannot be practiced or developed isolated from others (Sturm et al. 2020). Education thus must take into account interrelations between generic attributions and disciplinary expertise (Barrie 2006). Moreover, how interdisciplinarity remodels engineering competencies, both disciplinary and generic ones, is more a matter of degree or emphasis than category. Nevertheless, relative perceived importance and differential emphasis amongst educators when it comes to competencies is unavoidable given limited resources (Chan and Fong 2018; Passow 2012). Clustering competencies in terms of value or importance helps conceptualise education and curricular development (May and Terkowsky 2016). Therefore, given our goal of investigating how interdisciplinarity is incorporated into educational visions, we organise our analysis around categories that try to capture distinctions made in the educational literature itself.

In order to identify a broad range of competencies ascribed to modern engineering education, we refer to accreditation criteria for engineering programmes, that address engineering educational competencies by assigning learning outcomes regarding knowledge, understanding, skills and abilities that prepare students for the engineering profession. Formulated by authoritative organisations and operated on international scales, major criteria include ABET (Accreditation Board for Engineering and Technology),[1] ENAEE (The European Network for Accreditation of Engineering Education)[2] and CDIO (Conceiving–Designing-Implementing-Operating Initiative).[3] These criteria, with different applications and roles in connecting educational institutions, policies and engineering industries, all inscribe certain demands and expectations for competency development, revealing representative understandings regarding engineering competencies. Following the analysis about how competencies differently relate to interdisciplinarity, we propose six categories of IEE competencies that classify the prescribed competencies. By doing so, we embed competencies particularly related to interdisciplinarity in an overall system of engineering competencies.

### 2.2.1. Domain-specific engineering disciplinary competencies

Specific technological work, technical knowledge and skills are often considered as the scope of engineering and core of engineering competencies (Pleasants and Olson 2019; Trevelyan 2010). In the major engineering educational accreditation criteria, engineering specialisation and fundamental principles are at the forefront of learning outcomes, treated as prerequisite for creating engineering solutions, which is considered as the heart of engineering practice (Passow and Passow 2017). The creation of engineering solutions is further actualised through design and manufacturing, enabled by skills including modelling, data analysis, experimentation and using engineering tools.

### 2.2.2. Non-domain-specific technical disciplinary competencies

General STEM elements are closely related to the assumed domain-specific disciplinary core in engineering education. Mathematics, physics, other basic natural sciences and oftentimes computation are largely well embedded in engineering curricula, seen as cornerstones of engineering knowledge and practices. To foster interdisciplinary learning, education may highlight the distance between such disciplinary input and the engineering specialisation (Costa et al. 2019; Gero 2017). Similarly, different engineering domains sometimes come together to form IEE in an overarching, non-specialised context of technologies or design projects (Harrison, Ewen Macpherson, and Williams 2007).

### 2.2.3. Non-technical disciplinary competencies

In engineering education, non-technical elements from humanities and social sciences are often regarded as generic common sense and contextual constraints to be aware of when creating technical solutions (Passow and Passow 2017). One example is ethics, an established discipline in the humanities but mostly mentioned as a non-cognitive skill for cultivating professional responsibility (Kohlbeck et al. 2021) that engineering students should recognise, appreciate and reflect upon. Despite long-lasting advocacy in favour of integrating systemic and in-depth knowledge, specific methodologies, and experts pertaining to humanities and social sciences, engineering education does not commonly include such non-technical disciplines (Donald et al. 2017). Nevertheless, the importance of non-technical elements offers IEE significant opportunities. For example, social studies have helped engineering education reconceptualize technologies as sociotechnical systems (Sørensen 2009). And Hynes and Swenson (2013) introduced six non-technical disciplines that should interest engineering programmes: psychology, sociology, communications (although addressed as professional skills), law, economics and philosophy/ethics.

### 2.2.4. Engineering-specific professional competencies

Generic competencies are sometimes formulated as specific to the engineering professions. Assuming a homogeneous technical context of engineering, problem-solving means devising technical solutions, teamwork implies working with fellow engineers, and communication particularly refers to technical reporting, of domain-specific content and to homogeneous audience (Selwyn and Renaud-Assemat 2020). The designated engineering contexts also transform non-technical disciplines into generic competencies for engineers, such as ethics into professional responsibility. Economics and business disciplines are also seen as a source of generic innovation and entrepreneurship skills, pointing to the impact and commercial value of technical implementations (Charosky et al. 2022; Male, Bush, and Chapman 2011). As some scholars argue, such professional competencies and the underlying approach to problem-solving are less generic as they have to be integrated with specific engineering disciplinary content (Winberg et al. 2020).

### 2.2.5. Transferable personal and professional competencies

Unlike in category IV, generic competencies are sometimes relevant across various life situations and domains, hence transferable in broader contexts (Nägele and Stalder 2016). Such transferable competencies are applicable to a much broader range of professions and settings than engineering alone, and are increasingly valued by industrial employers (Ahern et al. 2019; Boelt, Kolmos, and Holgaard 2022). Related to personal development, some examples of such competencies are self-reflection,[4] life-long learning and higher-order thinking (system thinking, creative thinking and critical thinking as the CDIO criterion puts). We also include professional skills generally for solving real-life complex problems like planning tasks and managing projects, which matter throughout all professional settings and necessarily transcend disciplinary contexts.

### 2.2.6. Interdisciplinary generic competencies

Engineering education accreditation criteria suggest that curricula should make 'multidisciplinary connections' (CDIO) and address 'multidisciplinary contexts' for engineering understanding and analysis (EANEE).[5] However, what multidisciplinarity means for IEE and the implications on competency development remain unsaid. Current discussions about interdisciplinary education have explicated three major aspects of competencies at stake for interdisciplinarity. First, the social contexts of engineering transcend homogenous groups, therefore evoking new demands for competencies of communication and collaboration following the emphases on heterogenous actors with diverse social and disciplinary backgrounds (Brassler and Dettmers 2017; Claus and Wiese 2019). Second, interdisciplinarity stresses cognitive competencies in integration – the ability to connect, engage and integrate knowledge, methods and other elements of different disciplines (Boix Mansilla and

Duraising 2007; Clark and Wallace 2015; Claus and Wiese 2019; Lattuca, Knight, and Bergom 2013). Third, the presence of different disciplinary perspectives calls for competencies addressing awareness of, reflection on, and the ability to analyse disciplines, both those of others and one's own (Boix Mansilla and Duraising 2007; Claus and Wiese 2019; Lattuca, Knight, and Bergom 2013).

## 3. Method: Q methodology for identifying conceptualizations of IEE

Based on our categorisation of competencies pertinent to IEE, we applied the Q methodology to explore attitudes and outlooks regarding interpretations of interdisciplinarity and their relative importance in engineering education. By capturing structures that rank relevant competencies differently, our analyses led to clusters of opinions with participants sharing similar opinions. Each cluster represents a distinct pattern of preferences valuing some competencies over others, revealing specific expectations towards and conceptualizations of IEE. Here we first introduce the Q methodology and then describe the design and analyses of this study.

### *3.1 Q methodology*

Q methodology is a well-used approach for investigating and describing subjectivities, including opinions, perceptions and attitudes. It collects data in the form of sorts (Q-sorts), compiled by participants who are asked to rank a set of items or statements on a predetermined diagram of normal distribution scaling from total negativity (disagreement, unattractiveness, unimportance) to total positivity (agreement, attractiveness, importance) (Cross 2004; Stephenson 1964). Figure 3 shows the grid used in this study. To analyse Q-sorts, a by-person factor analysis is used, seeking intercorrelations between individual sorts and generating factors that represent typical patterns among the sorts. Sorts grouped in the same factor have similar compositions and embody comparable perceptions and structures of opinions. Tracing sorts back to participants may illuminate further

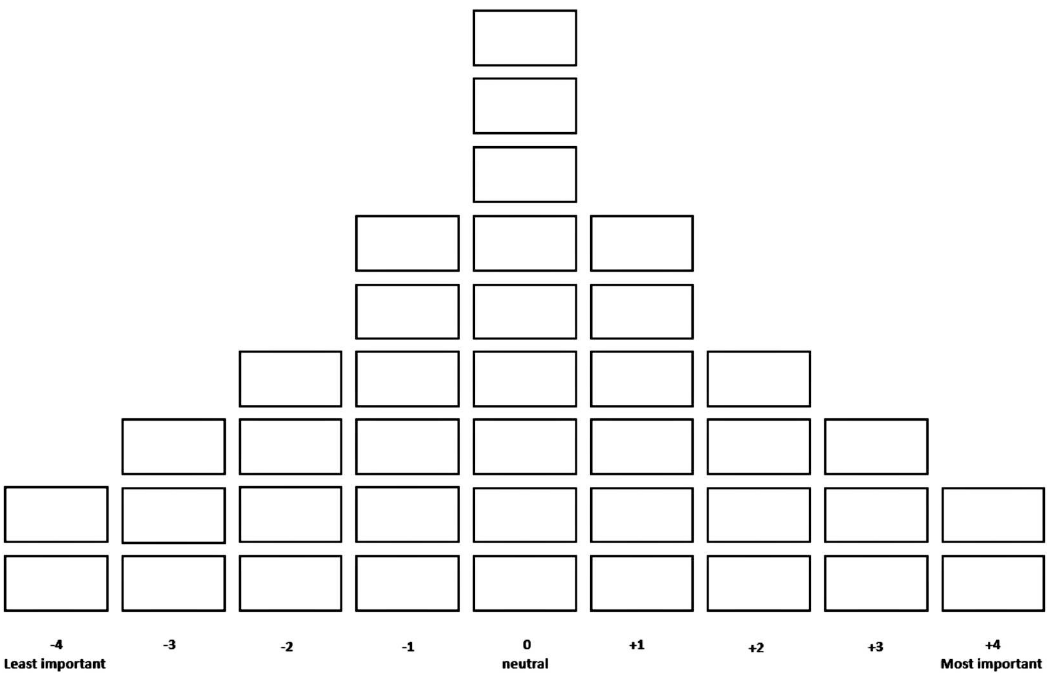


**Figure 3.** The Q-sort grid used for this study.

correlations between subjectivities and participants' other features. Besides Q-sorts, Q methodology often employs interviews to facilitate the sensemaking of the resulting patterns, inviting participants to elaborate on their considerations during sorting.

Combining qualitative evidence and quantitative analysis, Q methodology is recognised for its robustness in exploring opinions and attitudes, allowing active configurations by participants regardless of the topic (Watts and Stenner 2012). It is fruitfully used in fields where human subjectivity is at stake, including in educational research (Lundberg, de Leeuw, and Aliani 2020). For example, scholars have used the Q methodology to investigate educators' attitudes in using certain learning interventions (Alotaibi, Agha, and Masuadi 2022) and perspectives on key elements for improving certain competencies (Márquez-Álvarez et al. 2021).

### 3.2 Study design

To detect patterns of emphasising and prioritising IEE-related competencies, we assembled 39 competencies from the six categories for participants to sort (see Appendix). This list is neither definite nor exhaustive, but is meant to representatively cover a broad landscape of competencies that spans from a technical and domain-specific focus to particular competencies in interdisciplinary integration.

22 participants performed the sorting task (Table 1). 15 of them were engineering educators from 2 faculties (referred to as A and B) who have authorities in (re-)designing engineering courses and curricula; the other 7 were alumni who currently work as engineers in the industry. We invited educators based on their roles in educational policy-making, teaching and programmes' educational committees that oversee educational quality and design. Practitioners were recommended by participating educators. All participants work for or have studied in engineering programmes that are not specially labelled as interdisciplinary, at a Dutch technology-oriented university which stresses interdisciplinarity in policies and includes interdisciplinary project-based education in bachelor and masters programmes. Hence participants are generally aware of and often directly involved with IEE.

Every sorting session started with a sensitising talk about IEE (analysed separately and reported elsewhere), setting the context for the hands-on task. We then asked participants to place the 39

**Table 1.** Participant information and allocation of Q-sorts on the identified factors.

| Participant number | Role | Faculty affiliation | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|---|---|
| 1 | Educator (policy maker) | A | −.00 | .57* | .49 |
| 2 | Educator (policy maker) | A | −.21 | .81* | .10 |
| 3 | Educator (teacher) | A | .26 | .77* | −.00 |
| 4 | Educator (teacher) | A | .33* | −.02 | .25 |
| 5 | Educator (teacher, policy maker) | B | .19 | .01 | .47* |
| 6 | Educator (teacher) | B | .74* | −.13 | .22 |
| 7 | Educator (teacher) | B | .53* | .06 | .35 |
| 8 | Educator (teacher) | B | .24 | .02 | .53* |
| 9 | Educator (policy maker) | B | .74* | −.04 | .00 |
| 10 | Educator (teacher, policy maker) | B | .80* | .02 | .23 |
| 11 | Educator (teacher) | B | .27 | .06 | .32* |
| 12 | Educator (teacher) | B | −.20 | .74* | .23 |
| 13 | Educator (teacher) | B | .11 | .31 | .65* |
| 14 | Educator (teacher) | B | .37* | −.00 | .07 |
| 15 | Educator (teacher, policy maker) | A | .27 | .43* | .30 |
| 16 | Practitioner | N/A | .54* | .30 | .42 |
| 17 | Practitioner | N/A | .33* | .28 | −.25 |
| 18 | Practitioner | N/A | .14 | .27 | .60* |
| 19 | Practitioner | N/A | .71* | .16 | −.06 |
| 20 | Practitioner | N/A | −.08 | .19 | .47* |
| 21 | Practitioner | N/A | .15 | .28* | .16 |
| 22 | Practitioner | N/A | .59* | .33 | .25 |

*Note.* Significant loading at $p < 0.001$ is indicated with * cards of competencies on the grid, from the least important to the most for IEE, considering what IEE should emphasise especially given the current engineering educational practices. Participants were only give the cards and grid, without information about the categories used for deriving the competencies. By doing so, we tried to avoid influences on participants from the predefined framework, which was only applied later for data analysis.

Participants could place the cards in ways they preferred, although they were offered the advice to first make three stacks (negative, neutral, positive). After sorting, we briefly interviewed participants, asking about their experience and reasonings in completing the task. On average 15-minute-each, these post-sort interviews included questions: (1) whether the sorting was difficult; (2) why they placed the competencies on the two extreme ends (±4, ± 3); and (3) if other cards should be added. The study is approved by university's ethics committee.

### *3.3 Data analysis*

To analyse Q-sort data, we used open-source software Ken-Q Analysis v.1.0.8.[6] Following the advice of using the scree test and eigenvalues to determine the number of factors to include (Watts and Stenner 2012), we retained 3 factors and arrived at three clusters of Q-sorts, each representing a distinctive perspective about IEE competencies. To interpret the factors, we further examined their similarities and differences by observing consensus items and comparing their general structures. We specifically analysed the pattern of each factor, as represented in its typical composition (generated as composite or average Q-sort) and distinguishing items. Post-sort interviews, though not specifically transcribed or coded, were analysed using the three questions to further guide our interpretation, serving as references and explanations. The following section reports our findings.

## 4. Results

Applying Q methodology to study how interdisciplinarity is perceived in relative importance alongside more traditional engineering educational goals, we identified three factors that indicate the intrinsic diversity in participants' views, accounting for 43% of the variance of all the sorts. All 22 sorts are loaded on one of the factors, without insignificant or confounded ones (see Table 1). We labelled the factors as perspectives that embody distinctive views and values about IEE. To illustrate each perspective, we consult the post-sort conversations and cite participants from the corresponding factor group. After explaining the perspectives with their distinguishing aspects, we compare them and highlight some overlapping aspects.

### *4.1 Factor 1 social-holistic perspective*

Factor 1 (eigenvalue 5.39, 24% explained variance) comprises 10 sorts, and Figure 4 illustrates its typical composition. It represents a perspective of IEE that prioritises disciplinary and generic competencies stressing interdisciplinarity over the traditionally central technical aspects. The social aspects of working in interdisciplinary contexts (collaboration +4**,[7] effective communication +2**, initiating exchange +2**) are especially highlighted, appreciating IEE's social nature. As participants said, 'for me interdisciplinarity is really about interacting with others from other fields, or other stakeholders from the society. You can be trained in this and you need to be trained in this'; 'you can do all these [technical things] right but you have to communicate [with others], otherwise they don't work'.

The de-emphasis on technical knowledge and specific engineering skills also distinguishes this perspective. Competencies traditionally honoured as fundamental or key engineering expertise (mathematics – 4**, computing and programming – 4**, physics – 3**, measurement – 3**, modelling – 2**) rank rather low as they already fill most engineering curricula, being 'the default things you

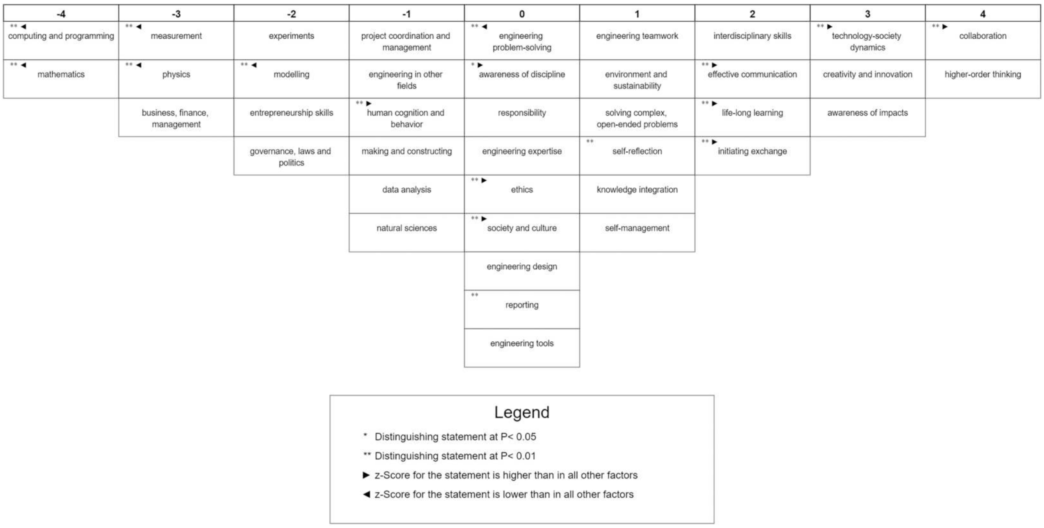


**Figure 4.** Composite Q-sort of factor 1 (the social-holistic perspective).

learn in this day'. The relevant importance of such technical expertise hence drops in interdisciplinary contexts. Engineering students, as some participants clarify, do need basic technical knowledge and skills, but mastering them is not needed: 'You need to understand mathematics. … if you are working in the field of engineering, you don't need to actually understand complex mathematical problems'. Rather, students would be limited if their education focused on technical specialisation, which are 'monodisciplinary things' and 'mono-skills'. The technical core assumed for engineering is, as participants suggest, 'not for everybody' and no longer considered a prerequisite. Engineers who are 'not great at physics and programming … [and students who] stay away from some of those monodisciplinary things … can still be extremely successful'. Technical traditions such as 'data analysis, mathematics, physics, you can learn by yourself … anytime, anywhere', and 'can find people who do that'. Without such 'very disciplinary stuff … you can also be fine in an interdisciplinary environment'.

In contrast, some non-technical disciplines gain more favour in this perspective. In particular, understanding technology-society dynamics (+3**) is stressed. As one participant explained, engineering issues are techno-social in nature. The societal side, 'the impact of it [engineering solutions], the effect it has on society' is 'more why you're doing something' and thus more important. Several other non-technical fields (human cognition and behaviour – 1**, ethics 0**, society and culture 0**) are also rated significantly higher than many technical disciplinary competencies and than by other factors. Attention on disciplines that are rather absent in common engineering education reveals the perspective on interdisciplinarity of factor 1 as holistic, broadening engineering from the technical realm to social domains. Holism in the valuation of disciplinary competencies is also revealed in the relatively high ranks of initiating exchange with other disciplines (+2**) as well as awareness of both impacts of engineering solutions (+3) and relevance, contributions and limits of different disciplines (0*).

### *4.2 Factor 2 technical problem-solving perspective*

Containing 6 sorts, factor 2 (eigenvalue 2.8, 13% explained variance), as represented in the composite sort (Figure 5), stresses engineering as problem-solving in nature: 'I think engineering is designed to solve problems'. Its emphasis on devising solutions for complex, open-ended problems without fixed scheme (+4**) is notable, but it also highly rates problem-solving within an engineering framework (engineering problem-solving, + 4).

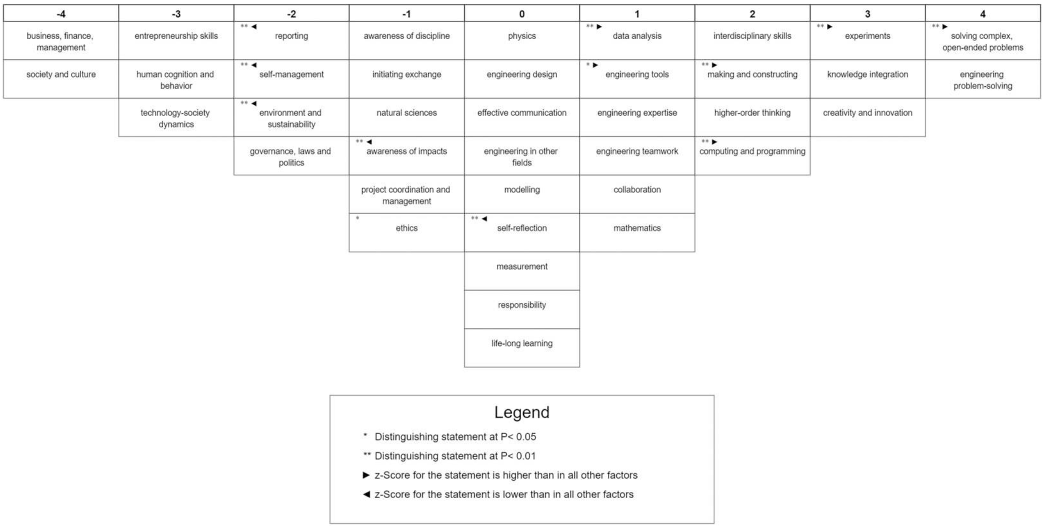


**Figure 5.** Composite Q-sort of factor 2 (the technical problem-solving perspective).

More than others, this perspective prioritises technical skills (e.g. computing and programming +2**, data analysis +1**, engineering tools +1*) in IEE as in more traditional engineering education. Especially, hands-on practices, such as conducting experiments (+3**) and constructing prototypes (+2**), are considered crucial in applying knowledge to problem-solving. 'Not all problems are like ones from the book … [Students] should be able to break [complex problems] down into simpler problems, which *are* in the book, solve these, and assemble them to a larger context … When you're doing this you need to be able to verify your answers. Verification comes from experimentation'. Only 'when you actually make something … you are going to notice different issues … [and] come over different obstacles'. While scientific knowledge provides basics, hands-on practices are the most required for 'being able to design'.

Factor 2 implies a perspective on IEE with a technical focus of problem-solving. Non-technical disciplines score low, seen as peripheral 'things further away from the purpose [of engineering]' and 'not so much the core of our [engineering] program'. They are the first to be downgraded in the ranking task: 'It would be nice if they were included but … you can't do everything'. Some participants completely rule out non-technical disciplines from the scope of engineering education, interdisciplinary or not: 'It doesn't have to be part of an *engineering* study'; 'if it's for education in *engineering*, it's not so important'. The generic awareness of engineering's impacts (−1**) referring to non-technical systems is also less valued. However, non-technical elements are not irrelevant for engineering practices; they are what engineers 'run into, you need to deal with' and 'are important obviously when you design a project'. But for these, engineers 'can have other people … instead of having to know it yourself'. While engineering concerns non-technical aspects, they are, as the problem-solving perspective frames, not any priority in engineering education. They are 'important, but as an engineer you first need to develop all these fundamental aspects', namely, the technical, hands-on competencies.

Unlike the holistic perspective's emphasis on interpersonal elements, the problem-solving perspective focuses interdisciplinarity on cognitive competencies, highlighting the skills to apply and integrate different disciplinary perspectives (knowledge integration +3, interdisciplinary skills +2). For some participants, interdisciplinarity just means integrating knowledge: 'You need to be able to integrate knowledge if you want to be interdisciplinary'. In contrast, social aspects as the holistic perspective values are less crucial (collaboration +1, effective communication 0): 'If [communication] doesn't really go that well, it takes just a little while and it will probably be alright'.

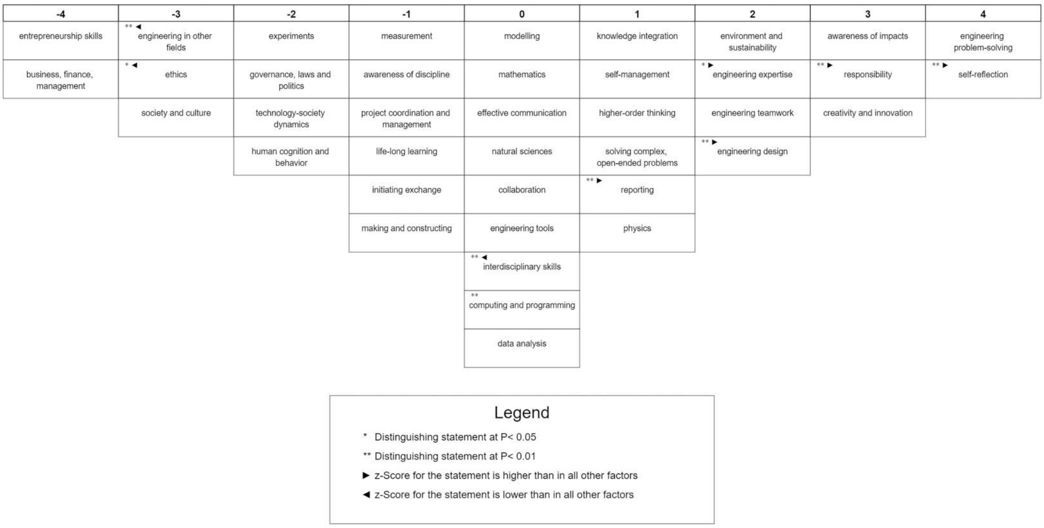


**Figure 6.** Composite Q-sort of factor 3 (the reflective pragmatic perspective).

### *4.3 Factor 3 reflective pragmatic perspective*

The other 6 sorts are loaded on factor 3 (eigenvalue 1.28, 6% explained variance, Figure 6). Distinctively, competencies explicitly referring to interdisciplinarity receive little emphasis in this perspective of IEE. It especially takes little notice of the interdisciplinary skills of applying different disciplinary perspectives (0**), which other factors value more. Instead, it emphasises some generic competencies, both transferable and more engineering-bound. Self-reflection (+4**) is one of the highest rated. Participants sometimes characterised self-reflection as a mindset, vital for many important aspects of engineering work, including teamwork, responsibility, awareness of engineering impacts, and interdisciplinarity: 'Awareness of discipline [has] a lot to do with self-reflection'.

This perspective also stresses responsibility (+3**) and awareness of impacts (+3) engineering has on non-technical systems, especially environment and sustainability (+2*). Unlike the holistic perspective that integrates non-technical disciplines in IEE, in factor 3 those disciplines are treated as personal interests and specialisations that 'some [engineers] are very good at … and really do'. Meanwhile, 'the awareness of impact itself is more for everybody' and should be essential in education. Among the non-technical aspects, environmental and sustainable issues stand out due to their societal urgency that is often neglected in engineering curricula:

> I really missed sustainability and environment in my education. Then I do feel it's a bit outdated, like, Okay, we explain it to you like we always did, instead of thinking what we need in five years when *you*'re working.

IEE, accordingly, could utilise such 'very integrative theme[s]' like sustainability to overarchingly address various knowledge and skills.

As factor 2, factor 3 underscores engineering's specific problem-solving nature (engineering problem-solving +4). For some, this defines engineering: 'Engineering is solving a problem, in a systematical way. Others might not come to the same solution but at least understand your process'. Solving problems, however, does not necessarily centre the mastering of technical skills (computing and programing 0**, making and constructing – 1, experiments – 2, engineering in other fields – 3**) as factor 2 suggests but is pragmatic: 'It doesn't really matter what you do … if you do data analysis or modelling. But you have to know how I'm solving problems'. The pragmatism is also visible in the balance between technical disciplinary competencies and generic competencies. While domain-specific engineering expertise (+2*) and engineering design (+2**) are the foundationally important ‘core competences’ that ‘makes you a good engineer’, generic capacities like self-reflection and self-management (+1*) distinguish students: ‘These make you an excellent engineer, an excellent human being maybe’.

### 4.4 Comparing the perspectives

Our analysis identified three perspectives of IEE, represented by three factors, each with a distinctive pattern of prioritised competencies. Comparing them further illustrates the varying ideas about what IEE is and should concentrate on (Figure 7). Nevertheless, several items are similarly ranked by all. In particular, two generic competencies – creativity and innovation, higher-order thinking[8] – are agreed upon as very important. Although not explicitly related to interdisciplinarity, they are ‘affecting your point of view and behavior’ and ‘really make a difference’, enabling engineers to develop and keep up with critical techno-social issues.

Despite this consensus, several differences stand out given the three perspectives’ preferences and visions of IEE. First, different generic competencies stand out when conceptualising IEE. While the holistic perspective explicitly addresses interdisciplinarity as essentially social and emphasises discipline-crossing interpersonal skills, the problem-solving perspective prioritises the cognitive skill of integration and underplays the social aspects. The pragmatic perspective weakens the prominence of disciplines in IEE and stresses interdisciplinarity by a generic sense of self-reflection and responsibility. Second, the attention on disciplinary competencies differs between perspectives. While the perspectives embodied in factors 2 and 3 understate non-technical disciplines, factor 1’s holistic perspective is rather moderate towards this category, valuing some even more than specific

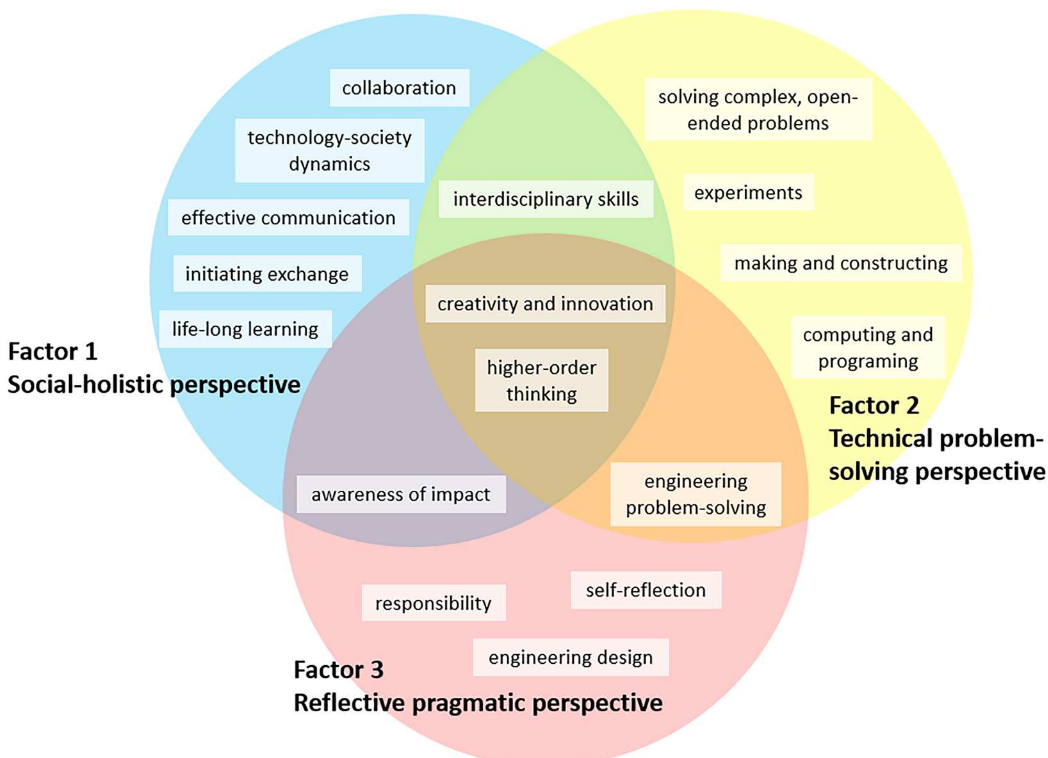


**Figure 7.** Important distinguishing and consensus items between and among the factors/perspectives.

technical domains. Third, the perspectives show different balances between IEE's disciplinary and generic aspects. While the holistic perspective strongly favours generic competencies over disciplinary (especially technical) ones and the problem-solving perspective mostly prioritises technical skills, the pragmatic perspective combines basic technical know-how and societal consciousness with elevating developmental generic competencies.

Interesting observations also arise when tracing the perspectives back to participants (see Table 1). Primarily, no obvious discrepancy is seen between how educators and practitioners sort IEE competencies; the distribution of both on the three factors is roughly even. However, the loadings of educators may hint some link between educators' faculty affiliations and their views on IEE, though not statistically decisive given the sample size. A contrast exists between educators from faculty A (4 out of 5 loaded on factor 2) and those from faculty B (only 1 out of 10 loaded on factor 2; 5 on factor 1). It is worth further exploration whether and how disciplinary cultures and organisational features matter in shaping perspectives on IEE.

## 5. Conclusion and discussion

If education entails competency development, current discussions about interdisciplinarity opens up the question of what competencies engineering students should develop. This study tries to identify competencies central to IEE. We first analysed how an interdisciplinary focus modifies the competencies traditionally addressed in engineering education and sketched a broad landscape of IEE-related competencies in six categories. Then we applied the Q methodology to empirically explore different views regarding prioritised IEE competencies and detected three distinctive perspectives.

### *5.1 Perspectives on IEE*

Unpacking the general notion of IEE into constellations of competencies, we identified different perspectives on IEE, regarding what interdisciplinarity means for engineering education and how education should develop towards genuine interdisciplinarity. This result implies coexistence of different paradigms in engineering education. Scholars have illustrated an ongoing paradigm shift in engineering education: Engineering, traditionally considered a deductive process of applying fundamental scientific principles to concrete applications, is increasingly understood as problem- and project-oriented holistic integrations of different disciplines, from sciences to humanities (Felder 2012; Fromm 2003). Our findings show that contending paradigms coexist even in the same educational context. Regardless of a probable paradigm transition, engineering education is no longer dominated by a single technical-centered deductive perspective.

Furthermore, the non-unanimous understandings of IEE reveal different meanings of interdisciplinarity, not only as relations between kinds of disciplinary knowledge (Klein 2010) but also as conditions it requires. While some conceptualise interdisciplinarity as teamwork (Fiore 2008), foregrounding its social dimension, some others model it as cognitive integration of individuals (Bernini and Woods 2014). Such presumptions on interdisciplinarity are certainly reconcilable but are not always recognised, leading to confusion or latent inconsistencies in visioning IEE (Van den Beemt et al. 2020).

The three perspectives respectively find echoes in theoretical discussions and empirical research from fields of both engineering education and interdisciplinarity. The stress on interdisciplinarity's social aspects and certain generic skills over specific knowledge, shown in the social-holistic perspective (factor 1), signifies disciplinary interaction dubbed as transdisciplinarity: reorganising knowledge to create new discourses towards concrete problems (Aneas 2015). Challenging the predominant assumption of engineering being technical and actively involving broad non-technical disciplines in engineering practices, it also accords with a long-standing appeal for holistic engineering education that undertakes whole systems and better incorporates nontechnical skills and human dimensions (Grasso and Burkins 2010).

The technical problem-solving perspective (factor 2) focuses IEE on the complexity in problem-solving settings, emphasising technical factors and marginalising non-technical elements. Affirming the presumed technical core of engineering, it underlines the indispensable role of disciplinary perspectives in modelling phenomena and approaching problems (Boon 2020). Interdisciplinarity, accordingly, relies on the integration of strong disciplinary bases, as often perceived by disciplinarily educated students (Zhang and Shen 2015). Its implications are observed in IEE practices to the effect that at times, interdisciplinarity which goes beyond technical domains is considered off-target, with non-technical elements considered subordinate to strictly technical disciplines in engineering education (Barnard et al. 2013).

The reflective pragmatic perspective (factor 3) characterises interdisciplinarity primarily as self-reflection and responsibility rather than explicit challenges to disciplinary structures. It stresses professional responsibility, rooted in disciplinary engineering expertise and design but connects individuals' social awareness with professional development (Canney and Bielefeldt 2015). The pragmaticism it signifies becomes salient especially compared to discussions about engineers' active responsibility, which recognises engineering as value-laden and interwoven with the society (Pesch 2015), and 'reflexive engineers', who apply 'an integrated ethical and systems-based approach to development' (Robbins 2007, 109).

### *5.2 Limitations*

Q methodology helped us in this case disclose subjectivities related to interdisciplinarity, engineering education and pertinent competencies. Reflection on our method use, especially the design and implementation of Q-sorts, further helps us clarify the insights, strength and also limits of this study.

First, our sample of Q-sort participants is limited and cannot be generalised to represent all IEE-related agents. Given the promotion of interdisciplinarity in their social-educational contexts, this study's participants are highly sensitised to and sometimes specialised in the topic of IEE. Actors at stake who are unfamiliar with or even object to interdisciplinarity are not likely included as participants. Therefore, the three identified perspectives do not represent all possible views on IEE competencies. Inviting a broader audience – in terms of region, stakeholder roles, engineering fields and industries, students – would further expand the scope. Factors and perspectives we detected are rather indicative of diverse co-existing understandings of IEE.

Second, our design of the sorting task obscured distinctions within engineering education. While the task was perceived as difficult by some participants because 'all these things are important', another attitude was also expressed when completing the sorts. Participants for instance expressed the need to sort differently, for example, for bachelor and master education, for various branches of engineering, and from a teacher's perspectives and a policy maker's perspective. Our approach of treating IEE as a general subject and collecting overall impressions and attitudes towards it may overshadow the differentiation and personalisation necessary for concrete educational contexts.

Third, meanings of specific competencies may be fine-tuned. As some participants pointed out, the sort items ranging from skills to attitudes and values are not always easily comparable, nor easy to incorporate altogether in practice: 'It's always tricky to include attitudes in our program'. Moreover, what a competency denotes may not be straightforward enough. Some participants commented on specific meanings and interpretations of some items. For example, project management may suggest making decisions and dealing with uncertainties. Self-management and -reflection may allude self-knowledge: knowing what one wants and developing accordingly. A non-commercial sense of creating impact is mentioned regarding the competency of entrepreneurship: IEE, as such, should 'let students know that everything is possible and they don't have to just be part of the system but can initiate something themselves … If you have a good idea you should be able to try it out'.

Last but definitely not least, any theoretical attempt to differentiate IEE-related competencies would implicitly influence participants in empirical investigations. Although we tried to limit bias by not communicating with participants about the predefined competency categories, the composition of Q-items employs a wide range, with ones that participants might have never considered before, thereby revealing our assumptions about IEE. Furthermore, perspectives elicited, reconstructed and interpreted though the Q-sort study are inevitably simplifications of participants' understandings, in which competencies are intertwined with diverse educational elements. Despite the post-sort interviews that began to explore such nuanced conceptualizations, in-depth qualitative studies, possibly based on phenomenology or phenomenography, that delve in perceptions and expectations regarding IEE will better complement our study to comprehensively elicit and sketch what interdisciplinarity entails in engineering education.

### 5.3 Practical implications

Our findings about different perspectives regarding interdisciplinarity and competencies central for IEE can contribute to educational practices in several respects. Primarily, acknowledging and clarifying the differences can facilitate alignment between educational elements, from visions, learning goals, design, activities to assessments, preventing potential obstacles in creating and implementing education. Each perspective implies a preference on certain content and approach in education. For example, the social-holistic perspective may invite more non-technical input into discussions about technology, embedded in collaborative and communicative settings. The technical problem-solving perspective would concentrate on domain-specific knowledge and technical skills, topped with additional cognitive training for integrating other disciplinary elements. The reflective pragmatic perspective may inspire education to assemble relevant knowledge in an open-ended problem-solving context around concrete themes, highlighting reflection on indirect impacts and responsibility of engineering solutions. Educational design, therefore, could benefit from a curated consistency, either balancing between or choosing from different perspectives.

Furthermore, recognising different approaches towards IEE enables coherent educational policies and classroom practices. Interdisciplinary collaboration between disciplines and organisations can also benefit from acknowledging different understandings and expectations regarding interdisciplinarity in IEE. Besides, respecting differences in prioritising certain competencies may create opportunities for both consciously differentiating and synthesising different dimensions of interdisciplinarity and lead to more personalised or comprehensive IEE. As our study suggests, when discussing or engaging in IEE, it is worth considering how other educators, educational researchers, policy-makers and agents conceptualise interdisciplinarity, and ensuring that differences are recognised and understood upfront.

## Notes

1. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/#GC3.
2. https://www.enaee.eu/eur-ace-system/standards-and-guidelines/#standards-and-guidelines-for-accreditation-of-engineering-programmes.
3. http://www.cdio.org/content/cdio-standards-30; http://www.cdio.org/content/cdio-optional-standards-30.
4. Literature about interdisciplinary competencies sometimes coins self-reflection as an interdisciplinary competency (Claus and Wiese 2019; Lattuca, Knight, and Bergom 2013). But the pausing and stepping back implied by this general sense of 'introspective reflection' does not necessarily require disciplinary or interdisciplinary contexts. We therefore treat it as a transferable generic competency.
5. Although scholars often distinguish multidisciplinarity as a certain form of interdisciplinarity that entails only parallel existence of disciplines instead of their integration (e.g. Klein 2010), CDIO and EANEE do not explicitly explain what they mean with 'multidisciplinary' connections or contexts.
6. Available at https://shawnbanasick.github.io/ken-q-analysis/.
7. We use (*) to mark distinguishing items significant at $p<0.05$ and (**) at $p<0.01$.
8. Both consensus items do not distinguish between any pair of factors, non-significant at $p<0.05$.

## Disclosure statement

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

## Funding

This work was supported by 4TU.Centre for Engineering Education (the Netherlands).

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## Appendix

List of IEE-related competencies used for Q-sort.

| Competency category | Competency item | Description (operational definition) | Reference |
|---|---|---|---|
| Domain-specific engineering disciplinary competencies | Engineering expertise | Developing core knowledge and skills specific to one's own engineering field or discipline | ABET, ENAEE, CDIO |
| | Data analysis | Analysing and interpreting data | ABET, ENAEE |
| | Engineering design | Designing technical systems, components and processes | ABET, ENAEE, CDIO |
| | Modelling | Constructing models based on knowledge and data for estimation and analysis | (Passow and Passow 2017) |
| | Measurement | Measuring accurately and quantifying errors | (Passow and Passow 2017) |
| | Engineering tools | Using modern engineering techniques and tools | ABET (earlier version, see Passow 2012), ENAEE |
| | Making and constructing | Making artifacts through hands-on practice | (White et al. 2020) |
| | Experiments | Designing and conducting scientific experiments | ABET, ENAEE, CDIO |
| Non-domain-specific technical disciplinary competencies | Mathematics | Understanding mathematical principles | ABET, ENAEE, CDIO |
| | Physics | Understanding physical knowledge and principles | ABET, ENAEE, CDIO |
| | Natural sciences | Understanding fundamental aspects of natural phenomena, including chemistry, biology, earth and space sciences | ABET, ENAEE, CDIO |
| | Computing and programming | Computing and programming based on computer science and skills | ENAEE |
| | Engineering in other fields | Having engineering skills and technical knowledge from engineering fields other than one's specific field | (Harrison, Ewen Macpherson, and Williams 2007) |
| Non-technical disciplinary competencies | Human cognition and behaviour | Developing systematic understandings of human cognition, behaviour and performance | (Hynes and Swenson 2013) |
| | Governance, laws and politics | Understanding dynamics of governance, public policies, laws, regulations and politics | (Hynes and Swenson 2013) |
| | Society and culture | Understanding dynamics of social life, social change, communities and culture | (Hynes and Swenson 2013) |
| | Business, finance and management | Understanding economics, marketing, finance, business models and day-to-day management of organisations | (Male, Bush, and Chapman 2011) |
| | Environment and sustainability | Developing awareness and understanding regarding environment, environmental problems and sustainable solutions | (Guerra 2017) |
| | Ethics | Acquiring frameworks for understanding human morality, moral values and right and wrong | (Hynes and Swenson 2013) |
| | Technology-society dynamics | Understanding the mutual impact between and dynamics of technological innovation and society | (Sørensen 2009) |
| Engineering-specific professional competencies | Engineering teamwork | Functioning in engineering teams | ABET, ENAEE, CDIO |
| | Reporting | Reporting engineering solutions with technical reports, oral presentations and visuals | ABET, ENAEE, CDIO |
| | Engineering problem-solving | Systematically applying engineering skills and designs to create engineering solutions | ABET, ENAEE, CDIO |

(*Continued*)

Continued.

| Competency category | Competency item | Description (operational definition) | Reference |
|---|---|---|---|
| | Awareness of impacts | Being aware of impacts of engineering solutions in a global, economic, environmental and societal context | ABET, ENAEE, CDIO |
| | Responsibility | Recognising professional responsibilities in engineering solutions and making informed judgments | ABET, ENAEE, CDIO |
| | Entrepreneurship skills | Abilities to establish new viable businesses and design technologies to meet market-feasible conditions | (Male, Bush, and Chapman 2011) |
| | Creativity and innovation | Devising creative and innovative problem solutions through design and research | ENAEE |
| Transferable personal and professional competencies | Self-management | Establishing goals, planning tasks and meeting objectives timely | ABET |
| | Project coordination and management | Planning and organising work in projects by negotiating and coordinating efforts with coworkers | ENAEE |
| | Life-long learning | Learning continuously to keep up-to-date, acquiring and applying new knowledge as needed | ENAEE |
| | Solving complex, open-ended problems | Creating solutions to complex, open-ended practical tasks without a fixed problem-solving schema | ENAEE |
| | Higher-order thinking | Developing cognitive capacities towards better analytical thinking, critical thinking and systems thinking | CDIO |
| | Self-reflection | Stepping back and reflecting on current performances, solutions and processes | (Claus and Wiese 2019; Lattuca, Knight, and Bergom 2013) |
| Interdisciplinary generic competencies | Collaboration | Working together with diverse academic groups and stakeholders (e.g. communities and industries) | (Claus and Wiese 2019; Gallagher and Savage 2023) |
| | Effective communication | Communicating with stakeholders and target groups, adjusting to different audiences, translating and explaining between groups | (Claus and Wiese 2019) |
| | Awareness of discipline | Recognising discipline-based knowledge, concepts, methods and limitations | (Lattuca, Knight, and Bergom 2013) |
| | Initiating exchange | Making suggestions, initiating discussions, connections and exchange with other disciplinary perspectives | (Claus and Wiese 2019) |
| | Interdisciplinary skill | Thinking about and applying different disciplinary perspectives in solving complex problems | (Lattuca, Knight, and Bergom 2013) |
| | Knowledge integration | Actively integrating other disciplines' knowledge and developing new frameworks accordingly | (Claus and Wiese 2019) |

Note. Reference indicates whether the item is explicitly mentioned in the three referred engineering programme accreditation criteria; if not, the reference shows which literature has argued for this competency item in IEE.