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Boundary crossing skills: unlocking interdisciplinary learning mechanisms in higher education

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ABSTRACT

In engineering education, the integration of disciplinary, societal, and ecological perspectives is facilitated by boundary crossing. This competency is cultivated through boundary-crossing learning mechanisms and is considered essential for students in interdisciplinary challenges in complex learning environments. However, limited research exists on students' perceptions of their own learning processes when developing the complex skill of boundary crossing. This paper, therefore, investigates boundary-crossing learning mechanisms, sub-mechanisms, and frictions that drive learning. The authors qualitatively analysed 720 reflection documents from 180 students in a 2nd-year interdisciplinary engineering master's course. The study reveals a progression from recognising strengths to calibrating expectations, identifying weaknesses, and positioning within meaningful activities. Identity (I) Concepts were used to examine frictions in this process, showing students engaged with themes such as self-knowledge, interdisciplinary teamwork, relationship building, and approaches to culture, structure, and planning. These insights may inform the design of interdisciplinary engineering education as transformational learning journeys.

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Interdisciplinary learning; boundary crossing; transformation

Introduction

In recent years, complex societal challenges have gained importance in higher engineering education. Increasingly, engineering curricula address climate change, sustainability, and other significant societal challenges. These topics also bring many epistemological complexities, perspectives, and personal and professional development issues to the learning environment. Those diverse perspectives are often addressed through inter- and transdisciplinary learning and the integration of disparate knowledge. Many authors argue that interdisciplinary work requires an open mindset, perspective-taking, empathy or other characteristics (Habbal et al. 2024; Lattuca 2019; Borrego et al. 2013). Integrating these different perspectives and knowledge bases concerning societal and sustainability challenges and situations has consequently become a prerequisite for learning in higher engineering education (Trevelyan 2019).

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The what and why of boundary crossing

Boundary crossing, as a philosophy, has emerged from the idea that disciplines can be delineated (Akkerman and Bakker 2011; Klaassen 2020; Oonk et al. 2022; Vereijken et al. 2023); they have their own culture, with their ideas and embedded in related practices (Popov et al. 2022). These disciplines tend to share a view on how knowledge is constructed (Becher and Trowler 2001), with a standard set of problems, theories, concepts and problem-solving methodologies (Popov et al. 2022). 'Inter' disciplines, from this perspective, are a space-filling activity (Szöllösi-Brenig 2019), supported by boundary-crossing activities between two disciplines with a shared problem space (Akkerman and Bakker 2011).

Boundary work is practised by people working in a particular discipline or profession. They conceptualise their specialisation by showing what the discipline or profession does and does not accommodate (Fortuin et al. 2020; Oonk et al. 2022). This boundary work helps to determine robust and coherent mental models from which constructive reasoning emerges in particular circumstances and contexts. However, the professional engineer is encouraged to become a boundary spanner. Boundary spanners cross the divide and prompt the questioning of another discipline while establishing and maintaining inter-organisational relations (Ersoy and van Bueren 2020). In the presented case study, boundary spanning takes place within the interdisciplinary team and towards stakeholders from industry and academia who are involved in the educational process.

Through inter- and transdisciplinary learning, among other approaches, students gain the opportunity to cross boundaries. Forming a professional identity and addressing a range of challenges in an interdisciplinary context is tightly bound up, amongst others, with (1) the ability to access diverse epistemological knowledge basis within an interdisciplinary team and knowledge systems of different stakeholders (academics and professionals) (Boon and Van Baalen 2019), and (2) the ability to define problem spaces that stimulate methodological plurality, making optimal use of the different 'knowledge' of participants in interdisciplinary teams (Lury 2021). (3) Lastly, the ability to cross disciplinary boundaries (Oonk et al. 2022).

An important reason is that boundary crossing theory supposes the most significant learning and innovation potential is available in the 'in-between' space of disciplines and professional environments (Carson 2019; Markauskaite and Goodyear 2019). Hordern (2017), based on Bernstein's social theory of knowledge, further argues that boundary crossing is a horizontal activity focused on skills that pragmatically bridge the gaps between the disciplines in context. The different natures (boundedness and permeability) of the disciplines, stakeholders, peers, and context determine how this complex gap is bridged, shared, and transformed, turning knowledge from both academic knowledge bases and external practices into knowledge bases that solve complex societal problems (Barnett 2017). Indeed, knowing the ways of a discipline requires critically questioning, valuing, and revaluing different disciplines (Eriksson et al. 2014) and re-contextualising disciplinary knowledge for different contexts (Hordern 2017).

In this 'in-between' problem space (at the boundary), four boundary-crossing learning mechanisms can be observed depending on how well students conceive, understand and have learned to practice their dominant discipline (Akkerman and Bakker 2011; Popov et al. 2022). Learning mechanisms are identified as opportunities for learning at the boundaries between different practices, exploring the limits of their own competences, revisiting their own realities, expanding horizons and co-creating new knowledge (Oonk et al. 2022). Vereijken et al. (2023) additionally emphasise the hierarchical nature of these four mechanisms, which should eventually stimulate students to transform their professional identities.

These four boundary-crossing learning mechanisms are defined as follows by Akkerman and Bakker (2011) and Oonk et al. (2022):

(a) *Identification:* Students gain (new) insight into their disciplinary perspective on the issue at hand and how other disciplines/professions/cultures (s) approach this issue (i.e. othering);

additionally, they explore their competencies, revisit their assumptions and expand their horizons. The focus is mostly on gaining insight into diverse practices.

(b) *Coordination*: Students learn from the use or search for procedures, means, communicative connections and objects to collaborate between disciplines/professions/cultures.

(c) *Reflection*: Students see their discipline through the eyes of another discipline, professional or cultural lens, through peers or stakeholders, which leads to new insights (i.e. learning perspective taking; cf., Repko, Newell, and Szostak 2011, 16–18).

(d) *Transformation*: Students develop new ways of doing and thinking that have characteristics of one discipline and other(s) (i.e. a hybrid position), or new professional and cultural perspectives, which are (partially) integrated and combined into a new professional identity in the making.

Reflection reports typically represent the internal dialogue triggered by boundary-crossing learning mechanisms and the use of objects or unfamiliar territory to facilitate these reflections. However, the internal dialogue does not coincide with boundary-crossing learning mechanisms. Vygotsky (1978) states, inner conflicts and contradictions arise only when 'I-conceptions' or roles, during a transition towards new systems of relationships with the self and others, incite change. These I or Identity conceptions emerge in terms of discrepancies, experienced conflicts or internal frictions between (1) workplace and university, (2) in terms of discrepancies between personal identity and taught (discipline) and experienced situations, and (3) personal beliefs-skills and expectations from external peers and stakeholders differing from our own (Alsup 2006; Amenduni and Ligorio 2017). Once they show up in reflection stories, they confirm the students' awareness and, therewith, the potential for learning. The (boundary-crossing) learning mechanisms are assumed to represent the situational conditions for crossing a boundary. However, only when these situations give rise to inner conflicts do we assume these to incite learning that becomes tangible in reflection reports. Reflective (inner and outer) dialogue should thus question assumptions by addressing emerging conflicting beliefs, values, and cultural and professional norms at each level of the boundary-crossing learning mechanism and at different 'I-conception' conflict levels. Studying this interplay reveals how the inner dialogue and learning mechanisms interact, leading to boundary crossing.

The reason for this study

In the sustainable and interdisciplinary context of higher engineering education discussed in this study, (re) contextualisation is characterised by the extent to which boundary crossing learning mechanisms stimulate divergent thinking and an open mindset towards other people, disciplines, plural methodologies, theories, and solutions. However, more insight is needed to identify what happens to the individual in a boundary-crossing situation over a 10-week period in education.

Therefore, we decided to focus on boundary crossing learning mechanisms and sub-mechanisms in one of the four categories in students' reflection reports as a primary step in uncovering or clarifying boundary crossing learning mechanisms taking place within individual students in an interdisciplinary higher education context.

The main research question is: 'What type of boundary crossing learning mechanisms and sub-mechanisms cause students to experience learning in interdisciplinary higher education contexts according to their reflection reports?'

This paper is a descriptive and qualitative analysis of reflections (on action) of over 180 students made during (three personal logs) and at the end (a final individual reflection) of a 2nd-year engineering master's course. In this interdisciplinary engineering master's course, student teams from diverse cultural and disciplinary backgrounds work on a company case, which usually comprises an overarching sustainable development goal (SDG). The teams' disciplines depend on the company's needs and case brief, varying from narrow to broad interdisciplinarity (Kolmos et al. 2024), including the natural sciences, engineering, policy and management, archaeology, and business.

Teams are coached weekly by company or governmental coaches and academic experts; often, they (the teams) work on-site within or sometimes beyond Europe.

The reflection reports focus implicitly on the growth and application of boundary-crossing behaviours and personal leadership skills. However, no learning goals or assignments in the course were explicitly mentioned or related to boundary crossing competences prior to the analysis of the available data.

A sizeable part of these 720 documents is qualitatively and iteratively analysed via a first and a second round of coding. Eventually, the results are expected to expand knowledge of boundary-crossing learning mechanisms, through data longitudinally collected over a 10-week course on sustainability challenges in an interdisciplinary higher engineering education context. Furthermore, identifying transformative friction through I-Concepts is expected to provide guidelines for designing boundary-crossing learning mechanisms for transformative learning in higher education engineering contexts. Practically, it will provide a framework or tools to guide students in interdisciplinary learning contexts, helping them master diverse or divergent thinking, compositional methodological plurality, and take the initiative to achieve better results in addressing sustainability challenges across disciplines and professions.

Boundaries in interdisciplinary learning

The interdisciplinary and professional situations require students to enter unfamiliar territory, face the challenge of combining different experiences in hybrid situations, and achieve novel goals (Veltman, van Keulen, and Voogt 2024). In an interdisciplinary environment, these furthermore tend to be identified as cultural boundaries between disciplinary discourses, structural boundaries embedded in academia, and professional boundaries between industry and academia (Bandola–Gill 2024). We may add cultural boundaries between students, staff, and companies' international backgrounds. These boundaries are represented in the master course, where structural and professional boundaries between academic disciplines and academia and professionals are minimised, as shown in the context section. The integration of professional and academic expertise is stimulated through extensive company and academic involvement in each assignment. Cultural boundaries are explored in the interdisciplinary team discourse, which includes varying disciplinary and cultural backgrounds. Learning in this study can be broadly defined within the constructivist paradigms of learning. Learners construct their understanding through experiences and social interaction, integrating new information with their existing knowledge through critical reflection (Gogus 2012). Ideally, this reflective dialogue and social interaction lead to transformative change. This change emerges via questioning assumptions and critically questioning shifts in epistemological interpretations of knowledge (Kitchenham 2012). Ultimately, this results in expansive learning through continuous interaction between the context and the learner, bringing about collaborative transformation of systems (Engström and Sannino 2010).

Why study reflection reports

Reflection reports are presumed to give a glimpse into the sense-making activities of students during each of the four boundary-crossing (learning mechanisms) steps. The internal dialogue with ourselves and other individuals is a continuous sense-making activity providing coherence and continuity to reality and the self (Amenduni and Ligorio 2017). Reflection reports may also provide insight into the occurrences or incidents taking place during a course that may cause boundary-crossing. Boundary-crossing is assumed to occur when information-sharing across a geographical, cultural or professional boundary takes place (Akkerman and Bakker 2011). Boundary awareness is about understanding these similarities and contradictions and negotiating multiple meanings (Akkerman and Bakker 2011). Boundary objects can be determined as events with a common goal that bring together people (peers and stakeholders) and resources to address challenges or opportunities.

The requirements of goal setting and information sharing for problem solving instigate that boundary crossing should lead to productive and reflective dialogue amongst and within participants (Amenduni and Ligorio 2017).

When does boundary crossing theoretically occur

When designing education for boundary-crossing, one tends to expect that students will learn to cross a boundary when they go through specific steps. However, what happens in students' learning process while going about their tasks still needs to be clarified, as different learning results may emerge from the same situation (Oonk, Gulikers, and Mulder 2019). Both Metsutoglu and Oonk show that students do not automatically learn to cross boundaries, and the boundary crossing learning mechanisms need to be better understood (Mesutoglu et al. 2024; Oonk, Gulikers, and Mulder 2019).

The difficulty in boundary crossing can be questionably ascribed to the fact that novices in a new field of study with little knowledge of the disciplines involved are confronted with a high level of cognitive uncertainty, which might characterise a lack of confidence, low levels of resolution or determination, helplessness, erratic decision making, minimum knowledge, understanding, skills, or negative emotions (Phan 2021). However, it might also be due to a range of values or beliefs that inhibit the crossing of boundaries, such as ineffective cultural values (Bennett 2017), personal values (Klaassen 2020) or professional values (Trede and Jackson 2021), which are inadequately trained or practised. Bennet's developmental model of intercultural sensitivity shows, for example, the principle that people develop their competencies in congruence with how they perceive 'otherness', which, in this case, is represented by the other discipline, culture or professional context. It is not only recognising the 'otherness' that drives one towards a better understanding of oneself or one's discipline but also understanding oneself before one can be open to otherness. The growth occurs in beliefs/perceptions from communicative competence in one's home culture to communicative competence across cultures. Thus, for students, being open to multiple perspectives and integrating new ways of doing things into their knowledge base, while involving multiple disciplines, professional stakeholders and cultural diversity, is no simple feat.

With the Identity-concepts, we argue that Identity integration – a process of bringing together various aspects of oneself into a coherent whole – and the sense of self-continuity and wholeness that emerges as a result of these processes (Mitchell et al. 2021) are necessary for learning from the boundary crossing experience. Identity conflicts reflect a discrepancy between 'values, beliefs, norms and demands inherent in individual and group identities' and emerge when individuals feel they must adapt their behaviour to satisfy identity-based expectations. (Carminati and Héliot 2022). Identity refers to the self in a professional role versus the individual values/emotions of the self. Professional identity development comes about when continuous experience and interaction with the material and social world occur (Alsup 2006; Dewey 1938), and when learning in one situation becomes an instrument in dealing effectively with the next situation. Consistent experiences and perceived conflict allow students to enact new and adapted behaviour towards emerging professional and integrated identities, increasing their sense of personal growth, maturity and self-awareness at an earlier stage in education (Carminati and Héliot 2022). These behaviours that they are now expected to develop after completing their engineering master's programme are addressed at an earlier point in engineering education.

Identity Conflicts in this context are captured via so called Identity Concepts or I-Concepts and can positively or negatively diverge from presupposed values and assumptions. The I-Concepts are defined as (1) differences in values/emotional frictions between workplace and academic expectations (workplace/university); (2) Differences in personal experiences, values and emotions based on personal/cultural background and the taught experiences at university; and finally (3) the personal beliefs, expectations, values and emotions versus the values/emotions/beliefs and expectation of peers and stakeholders to act a certain way in a particular role (Alsup 2006; Amenduni and

Ligorio 2017; Vygotsky 1978). We presume identity development takes place as a self-reflective and continuous interaction between the individual and its context, in which the individual is the unit of analysis and is measured through coding reflections. These conflicts trigger accommodation to adapt to the new contextual information or assimilation, in which contextual information is re-interpreted or ignored to deal with 'internal conflict'. (Van Der Gaag, Gmelin, and De Ruiter 2025).

Methodology

Course context of the study

In the studied course, students are evaluated and graded on the content presented with their deliverables in three review sessions. The process evaluation comprises a group part and an individual part. After each review session and one additional moment, students conduct a peer feedback session and individually write three personal logs and a reflection report at the end (Figure 1).

These reports are not graded and the learning from the reflection is emphasised. However, the assignments do need to be handed in; otherwise, they do not receive a final grade. Learning objectives related to the reflection reports are:

(1) *Collaboration and communication in an interdisciplinary team;* Demonstrate behavioural competencies and skills relevant for interdisciplinary teamwork and effective communication with different stakeholders.
(2) *Self-adjustment and reflection capabilities;* To carry out regular reflections on professional and personal development, and be able to improve upon those reflections.

In the first reflection report, students are asked to formulate an initial growth goal, identify what they need to develop, and specify the professional values they would like to develop. The first personal log report is written after the problem definition phase, the second after seeking active stakeholder collaboration, and the third prior to the final deliverable product. The last individual reflection report is written when finalising the course. The personal log and the final reflection are written as an individual reflection report. At each reflection moment, students provide each other with 360-degree peer feedback via the buddy check tool and oral feedback sessions on their leadership skills and functioning in the group before handing in the personal log report. Leadership skills, such as innovative attitude, results-oriented, interdisciplinary integration and collaboration, critical thinking, communication and reflection on individual performance were part of the feedback tool and

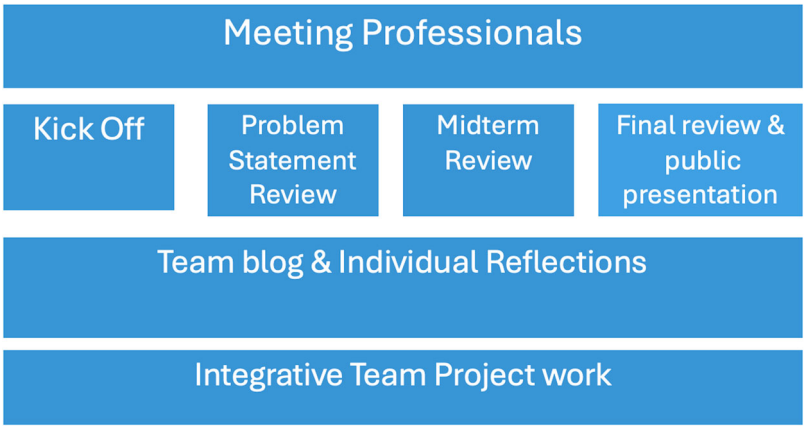

Figure 1. Course structure.

feedback sessions, which student applied without guidance (Klaassen and De Bruin 2022). They close the course with an individual final reflection based on three aspects (to what extent did they achieve their personal goals defined at the beginning of the course (in the motivation letter), leadership skills and functioning in the group), explored during the course in their personal log and their personal growth within the team and interaction with stakeholders throughout the course. The size of the reflections ranged from one (A4) to four pages depending on students' inspiration. The minimum requested was 500 words. Note that the students are neither trained in boundary crossing skills nor made aware of the concept of boundary crossing in any way. Furthermore, we emphasise we have retrospectively studied the occurrences of boundary crossing in this course to capture students implicit understanding and perception of boundary crossing learning mechanisms.

Data collection: reflection reports

In this study, 180 students wrote three personal logs during the 10-week course in weeks three, five and seven (henceforward called moment 1, moment 2, and moment 3). At the end of the course in week 10 (moment 4), students write one individual and final reflection. The total number of documents amounts to 720. Understanding how students approached interdisciplinary learning and transitioned through the boundary-crossing stages has been identified through qualitative coding of the available reports. All 180 students have been asked to consent to the anonymous use of their logs. They could opt out of participating in this study, which only three have done so far. These records have been removed from the data set.

Data analysis: coding process

Coding is initially realised by two coders (researchers) who first established agreement on the code definitions and later achieved agreement on differences in their coding for the first 40 documents. After calibration, the researchers proceeded alone with the coding and only consulted each other when in doubt. The first round of coding focused on identifying boundary-crossing learning mechanisms. The second and third-level codings have delved deeper into identifying the underlying incentives/mechanisms through time personal logs at moments 1, 2, 3, and I-Concept frictions at each boundary-crossing level in the final reflection at moment 4.

In the first level of coding, boundary-crossing learning mechanisms were coded in the personal logs based on one of the four boundary-crossing stages mentioned in the introduction (identification, reflection, coordination, and transformation). These were coded as mutually exclusive categories. Figure 2 shows an overview of the percentage each coder (moment 1, moment 2, moment 3) has given to the initial 40 documents. The code 'project statements', such as 'our meeting was planned on Wednesday' is further excluded from the analysis as they do not contribute to answering the research question. If occasionally text fell outside the scope of the boundary crossing code, we excluded these excerpts (raw data fragments) from the analysis.

This first level of coding agreement is represented in Figure 2 of the initial 40 documents, which showed 90% agreement on Moment 1 personal logs, 89% agreement on Moment 2 personal logs, 85% agreement on the third Moment personal logs, and 85% agreement on the final individual reflection. The 40 documents were coded by two coders separately. Successively, an agreement percentage was established and revisited in discussion to avoid any chance or random categorisation. These agreement percentages have thus been established before calibrating on the differences between the two coders. Differences were then explored in follow-up conversations until 100% agreement was reached on the boundary-crossing learning mechanism excerpts identification, coordination, reflection and transformation.

The second round of coding the text is within the excerpts identified in the first round of coding in personal logs of moments 1,2,3, and were a level deeper with the in-vivo method on emergent categories based on participant voices (Saldana 2016). Note this coding is realised for each boundary

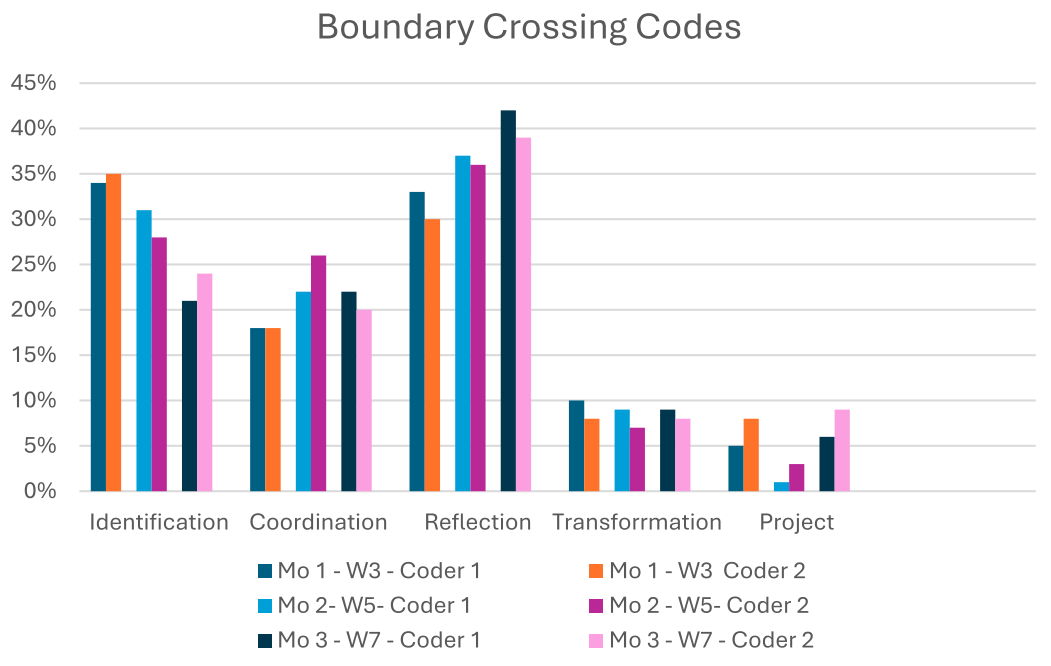

Figure 2. Calibrating codes between coders; an overview of the percentage each coder (moment 1/moment 2/moment 3) has given to the initial 40 documents.

crossing category (rows) and each moment (columns), resulting in a matrix-structured table. The code book of the in vivo coding is included in the annexe. More specifically, the second-level inductive in-vivo coding was on emerging values, such as opinions, and reflective observations (cultural, personal, professional, and other) at the different **moments** throughout the course. We call these sub-mechanisms that trigger learning in a boundary crossing category. For example, initially the excerpt was coded as identification and then in the second round as ambition in moment 1. Thus, 2nd-level codes are captured via the words of the participants in a specific category of boundary-crossing and at a particular moment in time in the software Atlasti. The emerging codes have been established through reaching a consensual agreement on the interpretation of the 1st 40 documents between coders 1 and 2. After this, a single coder takes over and only calibrates with the second coder when in doubt.

Thematic coding in the third round is on I concepts

The third round of coding focused on the individual reflections created at the end of the master course. This process demonstrated the interplay between boundary-crossing learning mechanisms and I-conceptual frictions, as described in the theoretical background, allowing for both deductive and thematic coding. Coders have calibrated their thoughts jointly, coding the first ten individual reflection reports (moment 4 after 10 weeks), to establish a joint reference frame (coding book in the annexe) and insight into what is happening in the educational context in terms of process and learned skills, behaviour, and strategies that are effectively guiding what is being learned in the course.

To analyse how transformation comes about, we looked at the conflicts these students described through the lens of Identity (I)-Concepts. The Identity (I)-concept that emerges from discrepancies in perceived boundaries gives rise presumably to experienced conflicts between (1) workplace and university environment, (2) in terms of discrepancies between personal identity and taught (discipline)

and experienced situations, and (3) personal beliefs-skills and expectations from external peers and stakeholders differing from our own (Alsup 2006; Amenduni and Ligorio 2017).

Document volume

After the coding agreement and calibration took place on the initial 40 documents, the remainder of the documents has been coded by only one researcher, until saturation is achieved either in the inductively emerging in-vivo codes or the deductive I-conceptually thematically coded text (Urquhart 2013). Saturation is achieved when new information does not emerge from the inductively coded text or where excerpts deductively coded are extensively covering the data, leading to more of the same results (Saunders et al. 2018)

Note 62 reflection documents have not been handed in during the first moment, where students are not fully aware of the implications of lacking documents (no grade). They receive a serious warning after week three (moment 1). Other missing documents are lacking due to illness or circumstances (Table 1).

Table 1. Number of documents coded.

Reflection Moments	Number of Documents Coded	Not coded	Total number of documents
Moment 1 – Week thee Personal logs	130	±1	131
Moment 2 – Week five Personal logs	128	±50	178
Moment 3 – Week seven Personal Logs	124	±50	174
Moment 4 – Week ten Final (ind) Reflection	105	±70	175
total	487	171	658

Quantitative analysis of personal logs

The first level of coding is used as categorisation, the clustering of boundary crossing categories. In total, we have 676 excerpts on Identification, 453 excerpts on Coordination, 661 excerpts on reflection and 102 on Transformation. In total, there are 1892 excerpts on 487 coded documents.

Below we will share the number of excerpts at the second level in-vivo coding; these are the emergent codes at different moments (personal logs). These excerpts were equally coded in one category only. Coders convened on the best code through conversation when in disagreement.

Figure 3 shows the codes that emerged at second-level coding and the number of times/excerpts that have occurred. In the text below, the highest number of excerpts for each category is in boldface.

In Moment 1, we found 689 excerpts on Identification, coordination and reflection.

Identification – moment 1 (week three)

The emerging codes in the personal logs of week three – Moment 1 for the boundary crossing category Identification (689 excerpts in total) are ambition (144 excerpts) and **observation and feedback** (182 excerpts). Showing that observation and feedback are the most important activities in identifying one's values with respect to the disciplines and individual competencies.

Coordination – moment 1 (week three)

The emerging codes in the personal logs of week three – Moment 1 for the boundary crossing category Coordination are Identification of assumptions (11 excerpts), external activities and interactions (49), external trust (5), formal and informal communications (7), **tasks and responsibilities** (72). Showing agreement on tasks and responsibilities is most critical in moment 1 for the boundary crossing category coordinating.

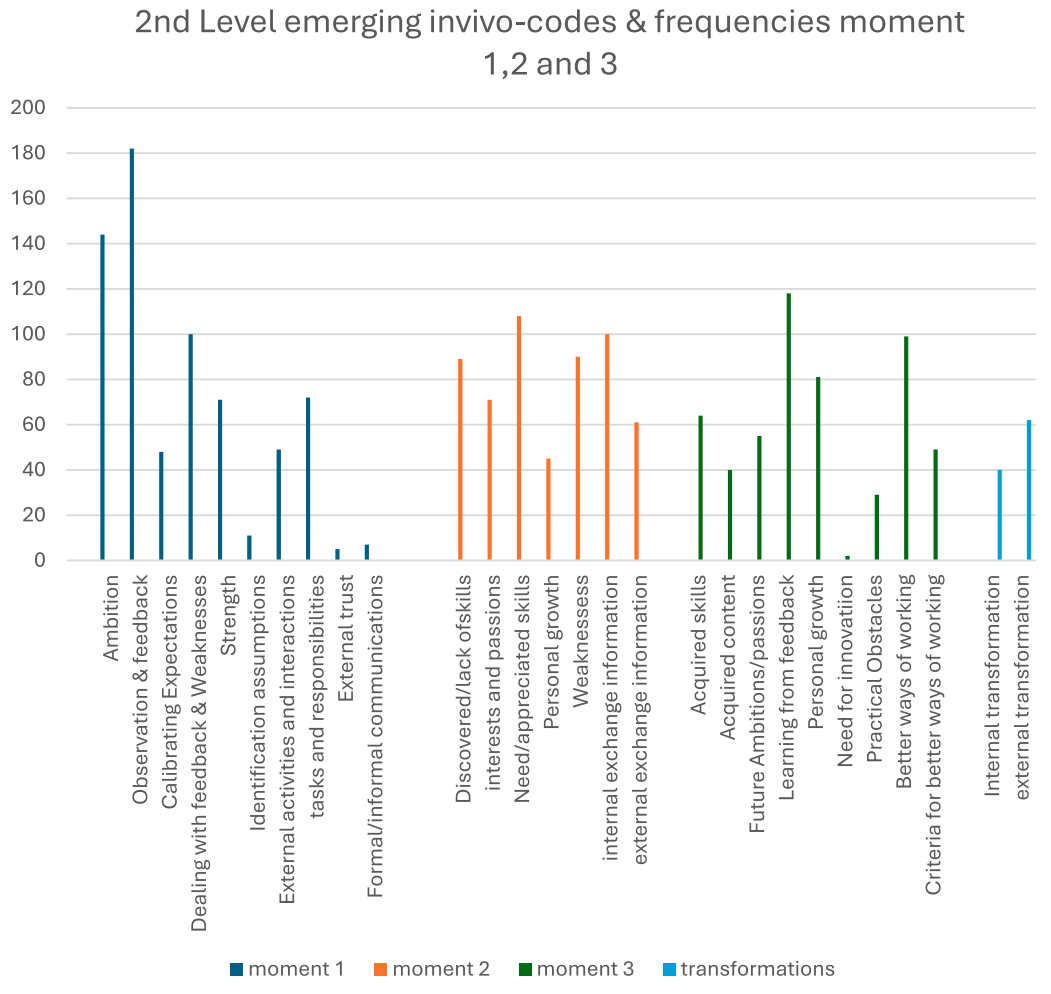

Figure 3. Number of excerpts on second level in-vivo Codes at moment 1 – week three, moment 2 – week five and moment 3 – week seven.

Reflection – moment 1 (week three)

The emerging codes of the personal logs of Moment 1 for the boundary crossing category Reflection are calibrating expectations (48 excerpts), **dealing with feedback** (100 excerpts) and strength (71 excerpts). Dealing with feedback is the most important for taking up the feedback of others.

In Moment 2, we found 564 excerpts on Identification, coordination and reflection.

Identification – moment 2 (week five)

The emerging codes in the personal logs of Moment 2, for the boundary crossing category Identification are '**discovered or identification of lack of skills (89 excerpts)'** and 'interest and passions' (71).

Coordination – moment 2 (week five)

The emerging codes in the personal logs of Moment 2, for the boundary crossing category coordination, are the **informal exchange of information** (100) and formal exchange of information (61), which are distinct emerging categories used to monitor and manage team procedures.

Reflection – moment 2 (week five)

The emerging codes in the personal logs of Moment 2, for the boundary crossing category Reflection are **Needed and appreciated skills** (108), Personal Growth (45), and Weaknesses (90). These emergent codes particularly show the vital role of the discovery of one's competencies through feedback from peers and external stakeholders.

In Moment 3, we found 537 excerpts on Identification, coordination and reflection.

Identification – moment 3 (week seven)

The emerging codes for the boundary crossing category Identification focus on **acquired skills** (64), acquired content (40), future passions and ambitions (55), practical obstacles (29) and a need for innovation (2); signifying that gaining insight into students' disciplinary perspectives, competences and assumptions is at stake.

Coordination – moment 3 (week seven)

The emerging codes in the personal logs of Moment 3, for the boundary crossing category Coordination**,** are the **uncovering of effective activities** (99) and criteria (49) that lead to better ways of working together.

Reflection – moment 3 (week seven)

The emerging codes in the personal logs of Moment 3, for the boundary crossing category Reflection, are **learning from feedback** (118) and Personal Growth again (81).

Transformation 1, 2, and 3

In Moments 1, 2 and 3, 102 excerpts on transformation are identified across all the moments. *These are divided* into internally (40) or externally (62) induced or triggered during the process.

Individual Reflections Reports: Boundary Crossing and Frictions (I Concepts)

In Moment 4 (week ten), the final Individual Reflection reports, we found related to boundary crossing at the first round of coding: Identification 216 excerpts; Coordination 141 excerpts; Reflection 138 excerpts and only 27 excerpts on Transformation (rows 2). Furthermore, these have been analysed in terms of I-Concepts in a third round of coding (column Table 2). We assumed the individual reflection reports would reveal the 'transformative friction' causing boundary crossing as students reflected on the 10-week course. This coding round gave an insight into which values, opinions, and observations postulating I-conceptual (or conflicts) that play a role in boundary–crossing that is more prominent. Note, however, that not all excerpts fit into the I-conceptual (thematic) categories. 28 excerpts in the identification category have not been coded and 22 in the reflection category. These will not be included in the discussion for clarity sake.

In Table 2, we can see the distribution of the excerpts. For identification, we find that learning is caused mainly through differences in taught and real-life experience and personal identity (N = 110). Coordination lays bare the predominant friction between work life and university as a source of learning (N = 68). Reflection, as can be expected, is most dominant in the friction between personal

Table 2. Number of excerpts on I-Concepts frictions at boundary crossing levels in individual reflections.

I Concepts	Work – University friction	Personal beliefs/-taught experience	Identity – beliefs and learning from peers/ stakeholders	Total
BC learning Mechanisms				
Identification	53 excerpts	110 excerpts	25 excerpts	188
Coordination	68 excerpts	30 excerpts	43 excerpts	141
Reflection	2 excerpts	29 excerpts	85 excerpts	116
Transformation	7 excerpts	6 excerpts	14 excerpts	27
Total	130	175	167	472

beliefs and those of others involved, providing feedback as a source of learning (85). Finally, transformation might come about predominantly through friction in this same area, personal beliefs and peer and stakeholder feedback/opinions (n = 14). However, we need to observe that transformation in individual reflections is a serendipitous occurrence through feedback on personal behaviour, as behaviour is perceived as (in)appropriate in the team context, and the person is being pressured to change. Another mentioned reason is through observations of the individual, who has gone through an experience, and successively decides that things should be done differently. In both cases, these numbers are very small and have caused relatively few individual transformations. Moreover, these transformations are not related to the goals of the course.

Results: boundary crossing learning mechanisms and emerging codes over time

In the following paragraphs, the qualitative results of the boundary crossing excerpts from the personal logs at each moment (weeks three, five, and seven) will be shared. All the names used in quotes/fragments in this document are fictive and unrelated to real persons. Initially, we did not anticipate any sequence or build-up of the Boundary crossing learning mechanisms identification, coordination, reflection and transformation. However, we noticed that the emerging in-vivo codes can be taken as sub-learning mechanisms identifying longitudinal growth throughout one of the four singular boundary crossing learning mechanisms. We furthermore note that in moment 4, topics mentioned within the I-concepts of one of the four boundary crossing learning mechanisms indicate the topics of friction experienced by the students and, more importantly, caused them to accommodate or assimilate their behaviour or 'learn', instigating identity formation.

Identification

The reflection logs dealt with goal setting and first impressions about positioning oneself in terms of personal and professional values. Included are quotes to see the shift in focus across each level of boundary crossing and are shifting focus through the phases of learning: problem definition (moment 1), progress (initial solution pathways) (moment 2), and final review (concept/prototyping deliverable) (moment 3). Each subparagraph includes a brief statement on the emergent codes, an example quote, including words that led (amongst many) to determine the in-Vivo code. Note that the Identification code is strongly present in the first moment. In Figure 5, an overview can be found.

Moment 1 (week three) – ambitions, observations, and feedback

In the first moment, the boundary-crossing learning sub-mechanism surfaced, particularly with formulating students' individual learning goals (Ambitions), such as gaining self-confidence in voicing opinions, as shown in Table 2/Figure 4. They have expressed their ambitions in terms of skills or situations to be overcome. The other code is from the first observations and feedback during the first two weeks of the course, and is, for example, the difference in opinions. Observation and feedback that trigger students to identify how they differ from their peers, professional contexts or disciplinary contexts and are one of the most prominent catalysers of learning.

Quote moment 1 student Johny observation and feedback

"My main goal when I joined this course was to be able to apply the knowledge, I gained during my first year of studying "Y". Mainly, to feel how the interdisciplinary approach works in real-life projects, what might go well and what might go wrong when working in a team with diverse disciplines and backgrounds or perhaps goals. Although the project is at an early stage, the diversity in the team was apparent from the language we used and the strength that team members had shown in their fields."

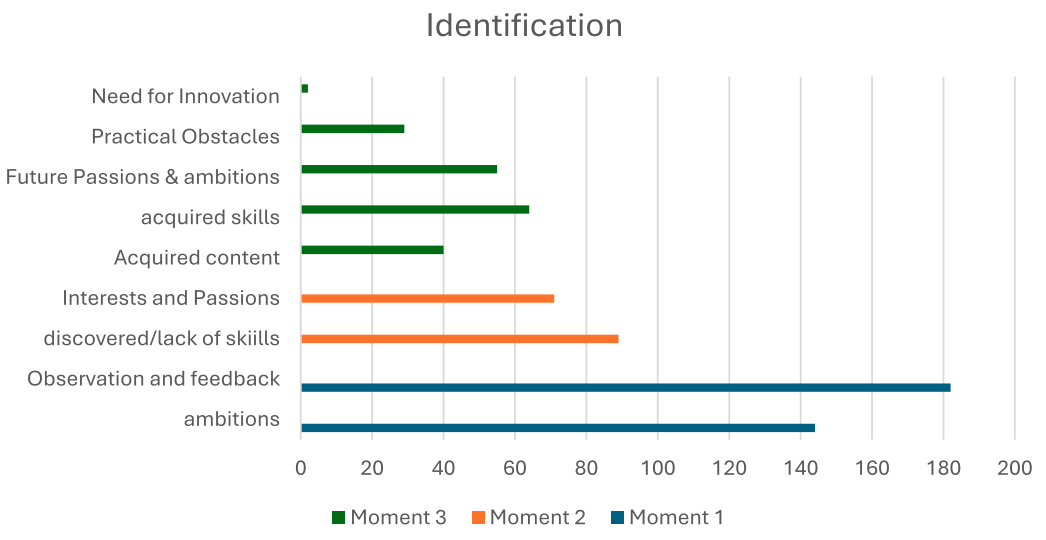

Figure 4. In-vivo codes Identification across moments.

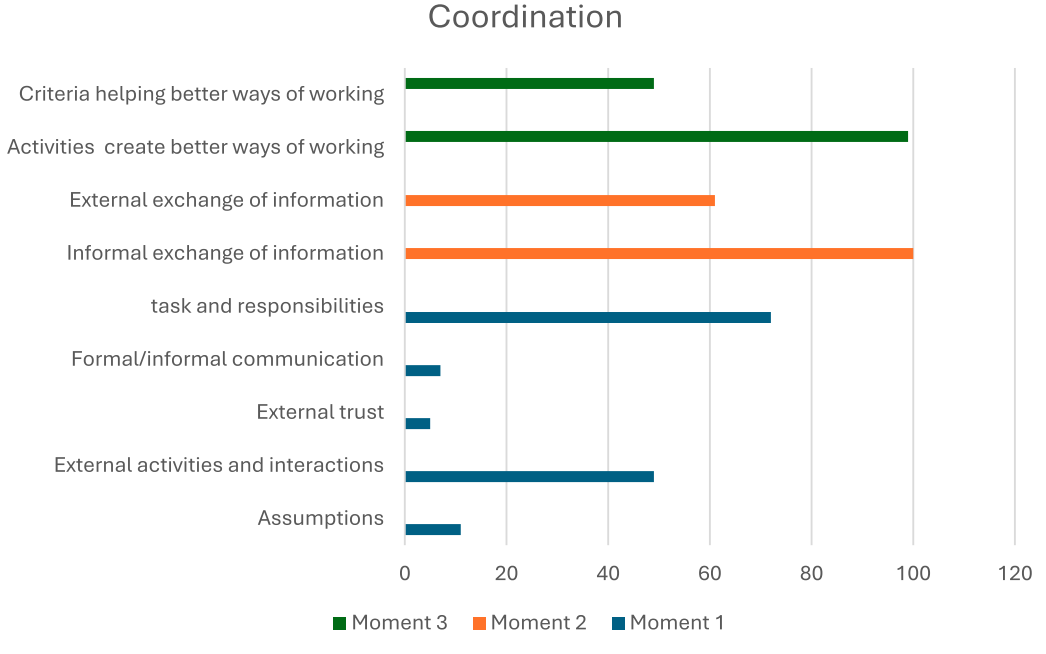

Figure 5. In-vivo codes coordination across moments.

Moment 2 (week five) – skills development

Most of the identification issues at moment 2, listed in figures four and five, involved discovered skills or a lack thereof, such as learning to model or a lack of communication skills. The other in-vivo code that emerged was interests and passion, stemming from new experiences of friction with the team or its immediate environment, such as getting to know the working culture or identifying new challenges for myself.

Quote moment 2 student Yvette – skills development

"A 'new' struggle is the navigation between personal and professional relationships. Because we are together 24/7 and also are having 'fun activities', it is sometimes hard to switch back to the professional setting. I think we are managing this struggle for now, but it sometimes it a little hard."

Moment 3 (week seven) – new ambitions and acquired skills

Interestingly, in the third measurement moment, listed in Figures four and five, we find a strong focus on acquired content that might be applied at this Moment and in the future. These learnings are taken from the bachelor's education that is applied in this course, towards the realisation of shortcomings of the individual or the team due to practical obstacles encountered in the course and the need for innovation in this course.

Quote measurement moment 3. Student Suraya – new ambitions – acquired skills

"I see myself improving in the goals I assigned to myself in the first personal log. First, several times I applied the knowledge from both my bachelor's and my master's. It's nice to see the knowledge unfold and explain it to other team members. This was mainly during the technology investigation, but even now, during the coding of the supply chain model, I value the time spent in my bachelor's for several projects so as to make it easier for me now to code. Then I also worked on improving my writing skills. Initially, I wrote an expensive text with a detailed explanation of why we chose each technology.

Finally, I am happy with my improvement in the presentations. I also presented in the midterm review, and according to the viewers, I did well. That was one of the most important things for me to improve because it has a positive effect on explaining my work to others."

The transition in the boundary crossing learning mechanism *identification* during the course goes from personal ambitions and seeing the first skills needed towards a build-up of new skills and discovery of new passions and interests, consolidating in awareness of knowledge learned in the practicality and applicability of university-taught theory. Moreover, ideas about the necessity for innovation and the obstacles encountered in achieving these innovative ambitions are expressed in moment 3.

Moment 4 (week ten) identification

In the final individual reflection on boundary crossing learning mechanism identification, students expressed having gained (new) insight into their disciplinary perspective on the problem they solved with their team. Furthermore, they learned how other disciplines/professions/cultures approached this problem; additionally, they have explored their competencies and revisited their assumptions.

The learning came about particularly through work/university frictions they signalled, and personal experiences vs. taught experiences in their studies. To a lesser extent, personal beliefs vs. stakeholder expectations play a role at this level of boundary crossing.

Work/university friction. We find that friction caused by differences in the work and university culture has given rise to learning about the work culture. Students are surprised by the work culture and find it different from what they were taught at university and expected. They are compelled to reassess their assumptions about the work culture and learn about the values that truly matter in the industry. Students perceived that accountability and responsibility in the working culture was high on the agenda. Other topics that were mentioned concerned: mutual respect, empathising with the company's goals and values and keeping an open/transparent attitude. Complaining was not part of the work environment's vocabulary. On a more negative note, the work

environment sometimes felt untransparent, and the behaviour was perceived as unacceptable. It helped students to determine what their position was/is. What were their strengths and weaknesses in this context, and whether they wanted to contribute to a similar company after graduation or discover that they had different values (Table 3).

Personal/taught experiences. Many students notably learned much new content from their peers and the company on the topic of the challenge they studied, which had not been addressed in their disciplinary field of study, such as a business plan, stakeholder, risk and market analysis, rules and regulations, inventory management, and so on. Communicating about and explaining their studies to others was essential to sharing and integrating knowledge. Language proficiency in English and Dutch, oral and writing skills, was needed for effective communication. Similar to the acquisitions of various software tools, such as PPT and Trello, but also MATLAB, Simulink, etc. Self-knowledge mainly emerged through becoming aware of individual capabilities and what one could or could not contribute to the teamwork.

Quote moment 4 student Ali – Personal versus taught experience

In my point of view, and after analysing the results I gained during the multiple rounds of reviews, I could play as a good link (connection) between the technicalities of the project and the management, and institutional aspects of it. For instance, together with my other colleague (from the same studies), we wrote the institutional analysis chapter of the report which further helped with the evolution of the methodology and the generation of alternative solutions. I can thoroughly state that I could play a significant role in the whole methodology section of our project. Furthermore, my background and specialisation in energy system engineering were a great help with the evolution of our framework (the final product of our project).

Personal beliefs/external peers. A precondition, however, seems to be 'good team collaboration', a trusting and open atmosphere with equal dedication. Equally, having awareness or self-knowledge about effective or inhibiting behaviour also proved very valuable. Thus, learning to recognise areas of personal growth.

Coordination

Coordination is more prominent in the second and third moments (week five and seven) as shown in Figure 5, when students have become aware of the necessity for communication and organising principles. External activities and Interaction are a driving force in the first moment in shaping the collaborations. The effectiveness of the collaboration is largely driven by the informal exchange of information in the second and third moments, through activities that are or should be undertaken to create better ways of working together. In the following sections, we will briefly indicate the experiences at moments 1, 2, and 3 with an illustrative 'quote'.

Table 3. Identification and I-Concept frictions.

Boundary Crossing Learning Mechanism: Identification			
I-concepts Frictions	Work vs University friction	Personal Identity vs taught experiences	Personal beliefs/skills vs expectations from external peers and stakeholders
	Working culture Interdisciplinary value in industry Real-life situations Finding one's position Networking	Content Communication Teamwork collaboration Self-Knowledge	Personal Growth Professional core values Trust and safety Self-management

Moment 1 (week three) – assumptions, trust, and mutual respect

In moment one on Coordination, we find the focus is first and foremost on clarifying assumptions, building trust and mutual respect, responsibilities, and discussing task divisions and formal and informal communications.

> Quote moment 1, student Ishan – assumptions, trust and mutual respect.
>
> *"My individual peer review reflection made me notice that so far, I have been working correctly and fitting into the work dynamic of the team. There was an initial lack of organisation within the team, mainly due to members not being present during the meetings for different reasons, but now I acknowledge that we seem to be on the right track, and there is a general sense of better organisation while working all together. It is interesting to notice how the individual profiles of each one combine, and how we are able to divide work and delegate it according to each individual abilities and areas of knowledge."*

Moment 2 (week five) – team boundaries

Moment two is about setting criteria or boundaries for what helps or supports the team's efforts. These are internal within the team and external towards the company and other stakeholders. Supported by active formal and informal exchange of information.

> Quote moment 2, Student Zara – Team Boundaries
>
> "*This course, in my opinion, is a fantastic tool for professional growth. In order to be able to communicate the results to the others in a style that is simple for them to grasp, we must first work as a team and complete individual duties that have been assigned to us. This is significant since they lack the time to elaborate as much as each researcher did during the research. Second, there are times when we work in pairs. In more mathematical activities, where two minds are more productive than one, this is also advantageous. In addition, we managed to go to the office last Thursday, which gave us the opportunity to see how the company works and spent more time with experts on the subject we are working on."*

Moment 3 (week seven) – growing the team

In moment 3, the emerging focus in the reflection was on activities that worked for the team to get a better result.

> Quote moment 3, student Jamal – Growing the team
>
> "*Along the way, the team including myself build a strong trust foundation between members, this is evident by the pleasant working environment we have as a team. This strong foundation helps us to get the job done efficiently and more enjoyable. This is because of the commitment of all the team members as well as the trust in their opinions in their field of expertise. Therefore, our team including myself do appreciate and embraces the fact that we come from diverse background, and we use this fact as a competitive advantage for our team to produce a more inclusive solution for our problem at hand."*

We find that coordination initially focuses on dividing tasks and responsibilities, then on building an informal exchange of information within the team, and finally on activities to create better ways of working together. An important aspect observed in individual reflections is how to plan and share information more professionally with the company and within the team, as well as becoming aware of the interdependence of team members for mutual success.

Moment 4 (week 10) – coordination – final reflection

According to the definition of the boundary-crossing learning mechanism provided in the introduction, students learn from using or searching for procedures, means, communicative connections, and objects to collaborate between disciplines/professions/cultures. An important issue observed in individual reflections is how to plan and share information more professionally with the company and

within the team, as well as how to become aware of the interdependence of team members for their mutual success. In this boundary-crossing learning mechanism, team organisation/collaboration methods/safety and relational issues are mostly at the heart of the coordination activities and are felt to be prerequisites for successful operations and learning. The I-concept, where friction was identified for growth, primarily occurred in the work/university difference and, to a lesser extent, involved personal beliefs versus expectations from stakeholders and peers (Table 4).

Work and university differences are mostly related to structured work (scrum, work rhythm, planning meetings, preparing relevant, to-the-point, and consistent information/presentations on progress, sharing information while maintaining professional decorum, asking questions, and seeking feedback). Scrum was a new format of working for many students and had not been encountered before. While the 8-hour-a-day office hours principle is well known, it was hard for some to follow. The awareness that meeting planning had to be far in advance, as time is precious, did not occur to students prior to the course. The same goes for the need to present relevant and focused information, which some found difficult in a collaborative setting with a company. Students realised that asking focused questions about the decisions that had to be made at a given moment. They had to unlearn asking random, irrelevant questions. Students had to become accustomed to solving problems for an official engineering company, such as an airplane manufacturer, a semiconductor company, or an energy powerhouse, rather than a random student project. This made them aware of the necessity of careful preparation and planning.

Personal identity – taught experiences

Contrary to what is taught in university, students realised that having the same frame of reference helped coordinate teamwork. Other issues frequently mentioned by students that they were not aware of at the start of the course included knowing each other's strengths and weaknesses, the need to learn content from peers, and active expectation management. Soft skills such as respecting each other's cultural and disciplinary backgrounds, recognising interdependence within teamwork, helping each other, and having compatible personalities are important for effective interdisciplinary team collaboration. According to their insights on coordination, having team core values, a shared focus, and a clear scope simplifies the apparent complications of complex decision-making.

Quote moment 4, Student Kushu – Personal Identity – taught experience

I am fortunate enough to have worked with the team as I had an opportunity to learn and develop both on a personal and professional level. We had a big discussion about who had to be the captain as everyone wanted to lead the team. This shows our commitment towards the project. In the early stages of the project, XX supplied a set of data that was disorganised and quite random. We had to go through the process of organising and cleaning the data. We also had to go through the complete production process individually during this phase. Because everyone had diverse backgrounds, we ran into several difficulties as a group on several occasions. When one of us was caught up in an uncertain situation, we alternated helping the other. It was enlightening how the interdisciplinary component encouraged us to consider ideas from various angles. The key takeaway here is that we knew what we were doing and why we did that as a team. On a side note, working together with this team was a wonderful experience. It was a great opportunity for me to learn and comprehend their way of thinking and preferences

Table 4. Coordination and I-Concept frictions.

	Boundary Crossing Learning Mechanism Coordination		
I-concepts	Work vs University friction	Personal Identity vs taught experiences	Personal beliefs/skills vs expectations from external peers and stakeholders
Frictions	Team atmosphere Planning and preparedness Information Sharing Stakeholder Networking Good relationship with stakeholders/ network	Focus & Scope Core Values Shared reference frame & expectations	Giving and receiving constructive feedback Decision making Taking joint responsibility for results Ways of working – task distribution

Personal beliefs – peers/stakeholders

The importance of voicing opinions (especially for the timid) while remaining respectful helped manage expectations and work more efficiently and productively. These identified frictions were immediately followed by learning to take on shared responsibilities and by providing critical feedback to team members who were lacking. These skills were necessary for effective planning, workload distribution, and maintaining the high quality of the work. Furthermore, the relevance of building relationships within the team and with external stakeholders, of dealing with difficult personalities and conflicting situations, and of maintaining professional attitudes and contact proved to be valuable insights.

Quote Moment 4, Student Moira – Personal Beliefs vs Peers/Stakeholders

Working with a company such as XX, I realised that innovation in big companies is not easy. This is due to the different interests and priorities of involved stakeholders. This led to difficulty in choosing which perspective should be used to address the business challenge. What I appreciated about working with XX, is the freedom they gave us to innovate. Although our final product might not seem to be technically sophisticated. but from our understanding of the business context and the current problems, we believe we have taken the right decision in choosing what to focus on and develop further.

Reflection

The boundary-crossing learning mechanism definition of Reflection was that students see their discipline through the eyes of another (discipline), or receive feedback from peers, and external stakeholders/academic stakeholders, which leads to new insights (Figure 6). Students become aware of their weaknesses and the skills they need to develop to be effective within the team, and they indicate what exactly they learn from the feedback. This Reflection definition is interpreted more broadly as becoming aware and receiving feedback from both a disciplinary perspective and a personal perspective on individual behaviour. The reason is that prior to the reflection reports, students received peer feedback from one another on individual performance and weekly feedback from their coach on content and process.

Moment 1 (week three) – calibrating expectations

In the first moment, the reflection focused on calibrating expectations amongst interdisciplinary ways of working, personal vs team development, and external versus team expectations. Interdisciplinary ways of working involve getting to know one another (various disciplines/cultures/languages/environments/values) by establishing trust, accountability, enthusiasm, and strength to achieve the team goal. This is achieved by sharing knowledge/values/opinions/and ideas while enhancing tolerance and flexibility in thinking. Strongly principled ideas create friction between personal and team goals, compelling students to address feedback on their weaknesses. This critique or self-revelation is a shocking discovery for some. Students also acutely feel the need to clearly state their wishes and set boundaries with external partners, and they feel at a loss when the necessary expertise is not available within their teams.

Quote moment 1**,** Student Wouter – calibrating expectations

"After two weeks of working in this amasing interdisciplinary project I could gain many new soft and hard skills. Most of all the main advantage of being in this project so far has been the fact that I never had the opportunity to work with students from other faculties and backgrounds on the same project. However, in this course we all get this perfect chance of working with students who have for sure different perspectives and approaches towards certain problems either technical or non-technical. Furthermore, the significant point about my team is also the culture and gender diversity. I now have the chance to work on an industrial project with people from the Netherlands, China, India, and Portugal which has so far given me a nice insight of how different people think or react about diverse topics or matters. Moreover, I feel that participating in this project is completely improving my tolerance and flexibility for thinking (accepting or refusing) different ideas. Within this team we all get a chance to state our opinions and points of view and discuss on them freely in a polite manner for sure."

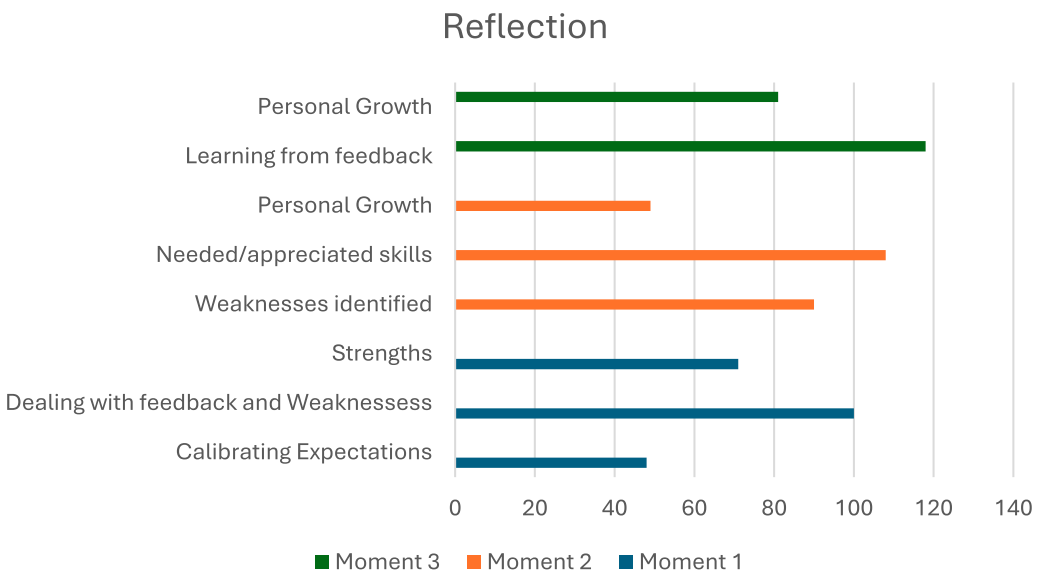

Figure 6. In-vivo codes boundary crossing mechanism; reflection.

Moment 2 (Week five) – needed and appreciated skills

The second measure-moment was about the improved skills and behaviours that have grown over the weeks. Students point out that they have seen the improvements happening either to themselves or the team. Similarly, the weaknesses felt as obstacles to effective functioning in team collaboration are identified, observed and given back to team members. They also indicate, the needed skills, to function in a professional environment.

Quote moment 2, Student Zhang– Needed and or appreciated skills

"Yet, the diverse background we have was a critical element to uncover the challenge and get to the important aspects of the problem at hand from the different perspectives we have. The engineering perspective focused on the technical details and how to assemble things together, and the complex system engineering focused on the interconnectedness of the subsystems as well as specifying and engineering the requirements. The consumer behaviour perspective has also broadened our perspective on how to sell our ideas during the project as well as how to sell them to the end customer at the end."

Moment 3 (week seven) – Learning from Feedback

In moment three of the boundary crossing learning mechanism, Reflection, the students mainly reflected on the positive feedback they received from their peers and companies. They were surprised and proud of how well the team functioned and what they had achieved in terms of results. They also appreciated what they had acquired in terms of skills, leadership (interdisciplinary) behaviour, and knowledge, all without being specific about what they had learned.

Quote moment 3, Student Francesco – Learning from Feedback

"*Another noticeable improvement is the approach I practice more in this course by piecemealing the deliverables and directing the effort to the top priority part accordingly. Moreover, technically I am also gaining a notable insight into the (technical engineering) industry, interior design and some psychological aspects which all played a perfect role in making my master's program (x) in practice which is about these interdisciplinary perspectives.*"

Altogether, the reflection is about learning from direct or indirect experiences and feedback, rather than stepping into the shoes of other disciplines and viewing from that perspective.

Quote moment 3, Student Mariah – Learning from Feedback

"The team since day one has emphasised on the work environment being a safe space for everyone to speak up. While this has been the case for my peers where they have been candid on the issues that affect them personally and thus, affecting their working potential. In the past weeks, I have been more comfortable with the group and have been able to block my inhibitions and speak up a lot within team meetings. Although, that doesn't change my introvertive nature but does help me in becoming or at least others perceiving that I'm an active part of the team."

Moment 4 (week 10) – reflection

According to the definition of the boundary-crossing learning mechanism provided in the introduction, students view their discipline through the eyes of another discipline, a professional, or a cultural lens, as well as through the perspectives of peers or stakeholders, which leads to new insights. In this boundary-crossing learning mechanism, it is mostly personal beliefs vs. peer/stakeholder beliefs that caused friction and induced personal leadership skills development (Table 5).

Work and University friction

Students emphasised that the trust the company placed in their competence, along with positive feedback on their work, felt like a reward in itself. It supported them in their confidence-building and the idea that they, as a team, would be able to do the job. Similarly, a lack of constructive support from the company coach created an adversarial effect.

Personal Identity – taught experiences

Personal growth occurred particularly when students were able to leverage the feedback received on behaviour relevant for team collaborations, stakeholder interactions or content/process contributions. Preconditions for understanding, accepting, and acting upon feedback depended mainly on the teams creating a safe space, trusting each other, and having joint responsibility for the results. Creating the safe space helped students to experiment with more effective behaviour and content contributions, accepting the many differences in expertise encountered in the collaboration.

Table 5. Reflection and I-Concept frictions.

Boundary Crossing Learning Mechanism; Reflection			
I-concepts Frictions	Work vs University friction	Personal Identity vs taught experiences	Personal beliefs/skills vs expectations from external peers and stakeholders
	Trust Positive feedback experienced as (a reward from the company)	Relationship building Leadership Learning from peers	(Personal) Leadership skills Helicopter view (connecting the dots) Punctuality – time management skills Adaptability Taking Initiative Conflict resolution Appreciating interdependence (added value interdisciplinarity) Positive vibe/fun

Personal beliefs – peers/stakeholders

To create a safe space, students needed to be responsible, deliver what they promised on time, and ask for help when needed (punctuality). Mutual agreement on the ways of working and being respectful of differences was another hurdle to take (conflict resolution). Timely sharing of information would help maintain a helicopter view and develop relevant and balanced task distributions. This development of a helicopter view meant everyone had to take the initiative and support the team collaboration. For some, this proved to be a severe mental burden. It was an eye-opener for many to enact the appropriate behaviour, requiring adaptability and flexibility to meet continuously changing circumstances and dealing with internal conflict on different values, perspectives.

Transformation in Moment 1, 2, and 3 (Week three, five, seven)

Finally, Transformation has a second level of in vivo coding that is not explicitly addressed from moment to moment. Coding is internally induced (40 excerpts) or externally induced (62 excerpts) across all the measured moments 1,2,3.

Internally induced transformations

The transformations particularly focused on becoming conscious of individual behaviour and the learning this caused. Most dominantly (N = 7), they were learning to listen to others and becoming more open-minded or less headstrong. '*A good leader does not impose his/her ideas but shares them and listens to all the proposals on the table*'. At almost the same level (n = 6) was the voicing of opinions, without being disrespectful. Learning this allows one to set boundaries, manage expectations, and work more efficiently and productively. These were immediately followed by Learning to take and share responsibilities in a team for planning, workload, and quality of work (n = 5).

Additionally, the importance of building relationships within the team and beyond, overcoming difficult personalities, handling conflicting situations, and maintaining professional contacts was emphasised (n = 5). Finally, reflections and feedback helped students become aware of their individual competencies – what they can and cannot do – while also learning new skills such as presentation, leadership, planning, and chairing a meeting. To a lesser extent, issues such as dealing with the Uncertainty (n = 3), letting go of dominant behaviour (n = 3), and collaboration (n = 4) were inciting transformation.

Externally induced transformations

Noticeably, the most occurring external transformations were from a conflict in belief opinion and feedback from mostly peers that led to another attitude (N = 34 excerpts out of 62). These can be categorised on a spectrum, from participants feeling inadequate and not daring to voice their opinions or ask questions, to (un)clear communication due to a lack of timidity or self-confidence. They learned to be more proactive and engaging, taking on more responsibility and learned to ask questions. There was also a substantial number that felt they took the lead and 'all the responsibility and control'.

Quote moment 3, student Moos – externally induced transformation.

#4 When they said I took a lot of initiative; I was quite wary and asked if they found that I put pressure of any kind on them. I'm familiar with pressuring myself and becoming a bit controlling/ spastic regarding the project deliverable. They didn't feel pressurised at all which is a relief. I guess that is a learning lesson for me, that you don't have to see a project as a big unachievable obstacle that requires all your attention and effort, but to keep it in proportion. It opens my eyes that this process perhaps is a fun learning experience and that I should enjoy this opportunity while I can. Although this is still tricky for me since I always feel extremely responsible, this is group work, and a great opportunity to explore what happens if I take on less responsibility. Or not exactly less responsibility but become less controlling about it. Learn to let go when something is a group decision, be open for feedback to keep learning. I think this comprises the paragraph of my first log: to let go and don't become controlling.

I want to end this log by explaining why this project is so good for me. Previous projects were all in a study context. Within groups, there is a high, very specific, information density. Like I mentioned in log 1, I have trouble keeping up. I start slower, and I find my knowledge is not comparable to that of my group (I have a bad memory). This makes me feel unsuitable for the project and subservient to others. However, during these last few weeks I've come to realise I can manage just fine. Apparently, I can tackle a problem definition and doing research just fine. And while I may not find the right words to say in an instant, my writing can be very concise and relay the right message given some time. That means I do have the understanding. I think the interdisciplinarity of the group and the whole project setup, allows me to develop my skills outside of my field of expertise. It makes me realise I'm more than the facts I don't remember, and that being smart is not the same as remembering a lot of things. This realisation actually makes me emotional because for so long, I've felt inadequate, and now I've finally found something to explore what I'm really capable of."

Moment 4 transformation

The boundary crossing learning mechanism transformation suggests students develop new ways of doing and thinking that have characteristics of one discipline and other(s) (i.e. a hybrid position), or new professional and cultural perspectives, which are (partially) integrated and combined into a new professional identity in the making. Note, however, in the boundary crossing learning mechanism and I-concept frictions, this only occurs in 27 excerpts of the individual reflection suggesting, student have already adapted their behaviour and do not find it worth mentioning again or the change is short lived and temporary (Table 6).

Work/university

It helped students determine their position regarding strengths/weaknesses and whether they wanted to contribute to such a company or had different values. Interviewing stakeholders, involving professionals from the company and networking for better results are seen as necessary to make progress, similar to keeping 'good' relationships with everyone. Dealing with uncertainty (lack of information/unexpected situations), keeping a positive attitude, being flexible, and feeling rewarded, trusted, and confident were equally mentioned as conditions for a successful result.

Personal Identity and taught experiences

Having an open and curious attitude, not assuming you know the answers for others, learning to ask questions from peers/external stakeholders to find out what they mean, learning about their roles and learning other disciplinary knowledge were subservient qualities to the best possible learning results.

Table 6. Transformation and I-Concept frictions.

Boundary Crossing Learning Mechanism: Transformation			
I-concepts Frictions	Work vs University friction	Personal Identity vs taught experiences	Personal beliefs/skills vs expectations from external peers and stakeholders
	Dealing with uncertainty dealing with an organised mess dealing with a lack of transparency/integrity planning expectancies not complaining different behaviours desired in a real-life setting calibrating expectancies	Not assuming answers for others Asking questions	Overcoming Timidity – gaining confidence Being overbearing, leaving no room for others Setting boundaries Learning to listen

Personal beliefs/expectations from peers

Transformations mainly focused on becoming conscious of individual behaviour and understanding the necessity of change. Learning to listen to others and becoming more open-minded or less headstrong was also quite important. These respondents learned that leadership is not dictating to others but listening to others, respecting other people's viewpoints, and not being the centre of the world. These listening skills and conscious behaviour also helped students become more solution-oriented, explore different solution pathways, deal with disagreement, set personal boundaries, and persevere when experiencing setbacks.

Quote Moment 4, Student Premzy – Personal beliefs vs expectations from peers

"Actually, I've learned to rather ask than just assume, because the latter can result in facing a sudden problem which could have been prevented by just asking in the first place. It is good to realise that a company has gained a lot of knowledge in their field, and now is the perfect opportunity for them to share that knowledge and for a student to learn from them."

Discussion

This research examined the boundary-crossing learning mechanisms in reflection reports of 180 students to describe their learning process in an interdisciplinary engineering context. The main research question we aimed to answer was: *What types of boundary-crossing learning (sub)-mechanisms lead students to experience learning in interdisciplinary contexts, according to their reflection reports?* By investigating this question, we aimed to gain a further understanding of what triggered student learning and what kind of learning experiences students find meaningful when crossing (disciplinary) boundaries.

This article makes use of two theoretical lenses: the boundary crossing framework (identification, coordination, reflection, and transformation) and I-CONCEPTS. The boundary-crossing framework showed what the main topics are in the learning process, which are addressed in reflections. From a second round of inductive in-vivo coding focused on sub-mechanisms, we found students followed a sequence of discovering strong points, calibrating expectations, identifying weak points and finding a position and activities of value.

Shifting focus through time in Boundary crossing situations

Results show that observation and feedback are the most crucial triggers for the mechanism identification at the beginning of the course, the discovery of skills or a lack of skills in the middle of the course, and the acquisition of skills at the end. For coordination, we observed a strong focus on task and responsibility distribution at the beginning, followed by informal and formal exchanges of information in the middle, and activities that created improved ways of working towards the end. For reflection, we find that discovering strengths and weaknesses at the beginning, recognising needed and appreciated skills by peers and stakeholders in the middle, and learning from feedback at the end are among the most important triggers. Altogether, we observed a shifting focus within the Boundary-crossing learning mechanism over time in different moments. These demonstrated a shifting focus of students on what seemed relevant to them at a particular moment contributing to the refinement of the boundary crossing theory in educational settings. Identification focuses on the self, Coordination on the team and stakeholders, and Reflection focuses on relationships with others; finally, transformation is based on inner changes in response to the outside world.

In Table 7, we summarise the results for boundary crossing learning mechanisms. We saw that the learning mechanism 'identification' recognised individual positions and strengths as opposed to others. The mechanism seemed most solid and practical at the beginning, but later it diminished,

giving more weight to the 'reflection' mechanism, where different viewpoints are considered, providing a shift in focus towards our relationship with the world and others. Other and new environments will give us continuous direct and indirect feedback on our behaviour. At the coordination level, we observed a shift in focus from practical task division to more outward-oriented activities and information acquisition, which could benefit the team's positioning.

The boundary-crossing learning mechanism primarily occurs when conflicting beliefs about students' identities (beliefs/opinions) are challenged by peers or stakeholders. How we operate in the world may be the most essential trigger for transformative change: first, by observing differences; second, through informal and formal exchanges; and finally, by receiving feedback and learning from others.

Oonk et al. (2022) signalled a limited occurrence of transformation as a learning mechanism. In this study, we find it equally hard to establish the long-term impact of behavioural change supposedly induced in the Transformation boundary-crossing learning mechanism. However, transformation can also be seen as a continuous process in which the students participate in new forms of activity and resolve contradictions. The engagement in expansive learning can already be considered as a transformation in itself, without explicitly being identified as inducing changing behaviour. One can come to a transformed understanding through the activity in which we are engaged and unconsciously adapt new behaviour (with or without mediating objects/tools) (Tsui and Law 2007). This unconscious adaptation of behaviour, however, would be counterintuitive, as we said in the beginning, only through awareness of friction does one start to learn. Therefore, we do recommend more study on the transformation learning mechanism from a different perspective. How does it work when interdependent professionalisation of students, professionals and academics goes through a transformational process? How do we measure the transformation, and can we cater for this journey in the educational environment?

Table 7. Boundary crossing learning mechanisms observed throughout the course.

	Moment 1 – Week three	Moment 2 – week five	Moment 3 – week seven	Moment 4 w– eek ten
I AM IN THE WORLD				
IDENTIFICATION	Ambitions focused on goals Observation and feedback	Discovered skills – lack of skills Interests and Passions	Acquired Skills/Content, Future Ambitions/ Passions Practical obstacles and the need for innovation.	Frictions: Personal experience vs Taught experiences
US AND THEM: THE BIGGER PICTURE				
COORDINATION	Assumptions, External/Internal Trust, Task & Responsibilities, Formal/informal communication External Activities and Interactions	Internal/external exchange of information	Activities and Criteria helping to develop better ways of working	Work/University differences
I AND YOU: RELATING TO THE OTHER				
REFLECTION	Calibrating expectations: Dealing with feedback and weaknesses Uncovering Strengths	Improvement of skills – Behaviours: Weaknesses Needed and or appreciated skills Personal Growth	Learning from direct and indirect feedback Personal Growth	Personal beliefs and stakeholder/peers' beliefs
POSITIONALITY: THE PROFESSIONAL I IN THE WORLD				
TRANSFORMATION	Individual internally and externally induced transitions based on feedback and observations **at any moment** towards different behaviour patterns. Mostly came about through feedback from observations, organised and non-organised peer feedback and coaching feedback.			Learning from peers/ stakeholders

Shifting frictions in boundary crossing learning mechanisms

In this paper, we have assumed that individuals interact with a context, report their perceptions of discrepancies in values and norms in their reflections, and accordingly adapt their behaviour or maintain it (Van Der Gaag, Gmelin, and De Ruiter 2025). The I-concept frictions (listed in Figure 7) are shifting in terms of which topics trigger a specific boundary-crossing learning mechanism and the identity formation that accompanies this learning.

Identification is mainly triggered by differences in values between personal experiences and the taught experience at university. For example, knowing relevant content and effectively communicating about this content in practice demonstrates the relevance of what is being taught in academia.

Coordination is mainly triggered through differences in values and ways of working between the University and Work environments. Friction is not so much about the practical skills of planning and preparing, but rather about differences in relational or social norms and practices between work and university in planning, meeting preparation, and information sharing.

Reflection/Transformation is mainly triggered by the confrontation of personal beliefs with those of stakeholders and immediate peers in a working process. The focus is particularly on personal leadership and behavioural adaptability for reflections. Transformations are mainly relevant for behavioural change aimed at overcoming shortcomings in a situated role.

Based on the occurrence of Boundary Crossing Learning Mechanisms over time, we presume that students are initially mostly occupied with differences between university-acquired skills and knowledge and with how this can be applied in practice. Successively, there is room to discover differences in working relationships, working experiences, and what is taught at university. Finally, the key point

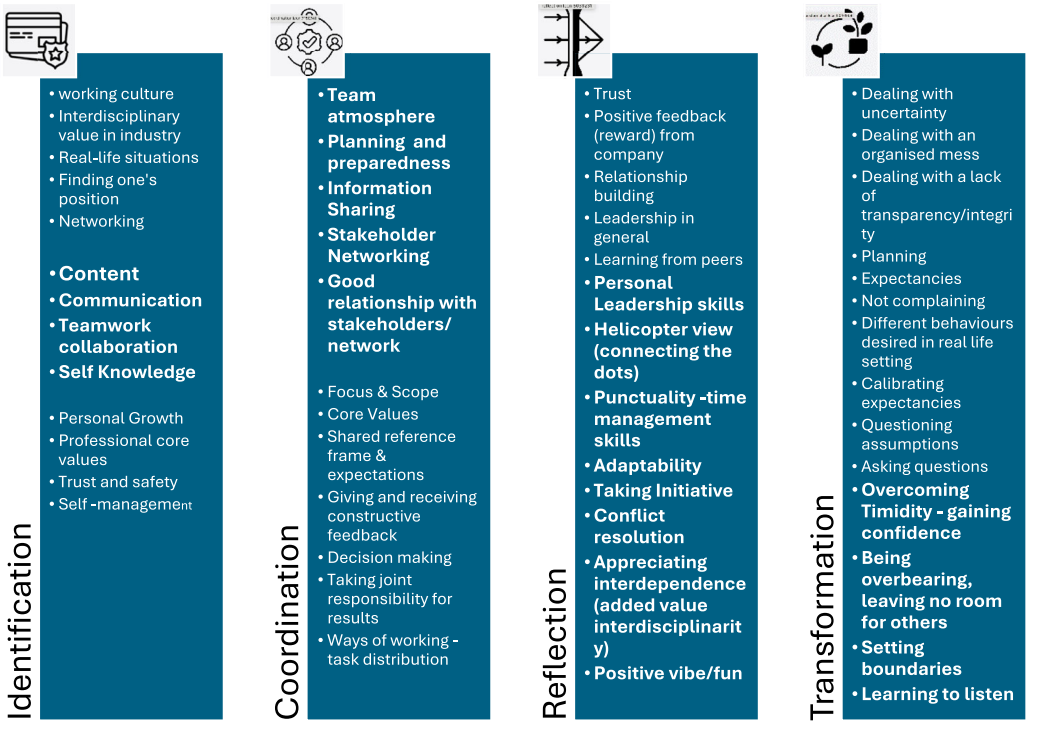

Figure 7. Topics identified in the I-Conceptual frictions categorised by learning mechanism.

of attention is individual behaviour and the adaptation to social conditions in this context. The latter coincides with or overlaps with the emergent focus in the sub-mechanisms mentioned in the previous paragraph, suggesting that Identity is co-constructed with the situated context, creating a more intertwined process that solicits a pattern of meanings emerging between the individual and the context, and possibly changing across contexts. This intertwining may obscure the observation of transformational learning and may require a different paradigmatic approach to identity, as a social phenomenon (Van Der Gaag, Gmelin, and De Ruiter 2025), where identity is inseparable from context and not an individual phenomenon in interaction with an independent context, as presented in this study.

Indeed, bridging knowledge cultures, between individual knowledge, community knowledge, specialised knowledge, organisational knowledge and holistic knowledge (Gunn et al. 2024), is an integral part of intrapersonal and dynamic identity building, summoning iterative steps in positionality, the uncovering of asymmetries and negotiations that support taking a stance at the individual and team level and the creation of the (professional) self in diverse contexts is a gradual and continuous process (Bouw et al. 2019).

Limitations

In this study, we have exhaustively examined a large volume of reflection reports and have presented a method for analysing boundary-crossing learning mechanisms across time and in relation to I-Concepts. While the boundary-crossing framework and I-CONCEPTS provided valuable insights, the reliance on self-reported reflections may have limited the depth and reliability of the data. Furthermore, the sequential patterns we identified could be shaped by our coding choices, suggesting the need for triangulation with additional methods such as observation or longitudinal tracking. Ideally, we would have involved coaches for interviews and created triangulations. However, previous studies have shown that the course is effective in terms of choosing challenges and acquiring professional and interdisciplinary skills (Bohm et al. 2020; Klaassen 2020; Klaassen and De Bruin 2022; Klaassen, Hellendoorn, and Bossen 2024). The focus on the student perspective on learning in this article has merit, as it draws on a large number of reflections and has supposedly a high impact on student teams' perfomance (Mell et al. 2022). According to fellow researchers, this helps to establish common denominators and patterns in student reflective behaviours and allows for a deeper understanding of the individual growth process and experience over time (Martin and Bombaerts 2024). Yet we note that the paradigmatic approach of Identity study may need to shift from the individual as an observational unit towards the study of the entire situation in which the individual is and an indivisible part of the social context that determines its behaviour.

Conclusion

This research examined boundary-crossing learning mechanisms in reflection reports of 180 students to describe their learning process in an interdisciplinary engineering context. The main research question we aimed to answer was: What types of boundary-crossing learning mechanisms and sub-mechanisms or activities cause students to experience learning in interdisciplinary contexts, according to their reflection reports? By investigating this question, we aimed to gain a deeper understanding of what triggered student learning in Interdisciplinary education, what kinds of learning experiences students found meaningful (in reflections) when crossing (disciplinary) boundaries (unknowingly) and how this contributed to identity formation or identity building. We found that within boundary-crossing learning mechanisms observed retrospectively (and not by design), there was a shifting focus of activities and topics that triggered identity formation over time. This shifting focus suggests Boundary crossing is a staged or developmental process that needs to be carefully designed in learner contexts, preferably including relevant prompts.

Learning Design elements and professional Identity

The concluding frameworks (Table 7 and Figure 7) identify and suggest essential elements for designing learning experiences that should be considered to help students critically address societal challenges in engineering. These learning design elements include, among others, observations, reflections, and evaluative moments with stakeholders and peers in spaces that are filled with tension. Spaces that are imbued with normative and epistemic significance and with shifting roles for participants, creating the need for negotiation and adaptive behaviour. They can be viewed as a necessary part of transformation, linked to personal values and real-life skills (Lake, Fernando, and Eardley 2016) and therefore contribute to the dimensionality of identity in interdisciplinary learning (Ming et al. 2025). These learning elements thus increase personal and professional growth by laying bare potential friction points that create learning opportunities in educational, interdisciplinary or possibly transdisciplinary contexts.

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Appendix

Appendix 1. Emerging codes

***a. Identification**n:* Students gain (new) insight into their disciplinary perspective on the issue at hand and how other disciplines/professions/cultures (s) approach this issue (i.e. othering); additionally, they explore their competencies, revisit their assumptions and expand their horizons. The focus is mostly on gaining insight into diverse practices.

b. ***Coordination***: Students learn from the use or search for procedures, means, communicative connections and objects to collaborate between disciplines/professions/cultures.

c. ***Reflection***: Students see their discipline through the eyes of another discipline, professional or cultural lens, through peers or stakeholders, which leads to new insights (i.e. learning perspective taking; cf., Repko, Newell, and Szostak 2011, 16–18).

d. ***Transformation***: Students develop new ways of doing and thinking that have characteristics of one discipline and other(s) (i.e. a hybrid position), or new professional and cultural perspectives, which are (partially) integrated and combined into a new professional identity in the making.

Emerging Codes – Moment 1-week 3

Code	*Descriptive*	*Examples*
Identification	*Students gain (new) insight into their disciplinary perspective on the issue at hand and how other disciplines/professions/cultures (s) approach this issue (i.e. othering); additionally, they explore their competencies, revisit their assumptions and expand their horizons.*	
Ambition	Ambitions: Any statement that includes an expression or wish to develop a skill or competency	Adaptability, communication, gaining self-confidence distribution of immediate and long-range needs, needs on the greater good above my own advancement, when necessary, Content knowledge acquisition of new topics, Voice opinions, time management and workload distribution skills, interdisciplinary skills, application of knowledge, teamwork, time management skills, setting boundaries, and gaining confidence
Observation & feedback	An act of self-reflection as a result of the observation of the behaviour of others or (general) feedback (not necessarily focused on	Self-reflection/evaluation, presentation skills/confidence. Having different opinions (interdisciplinary skills), perceiving the team process goes well, presentation skills, working

(*Continued*)

Continued.

Code	*Descriptive*	*Examples*
	one person), that brings about an activity, building of confidence or skills	with students with different backgrounds, role and task distribution, coordination, flexibility, online collaboration
Coordination	*Students learn from the use or search for procedures, means, communicative connections and objects to collaborate between disciplines/professions/cultures*	
External/internal trust	Internal trust – within the team, external trust towards stakeholder parties	Trust in team capabilities and creativity skills, freedom for the team to come up with new ideas – filtering and assessing ideas in iterative sessions
Formal/informal communications	The observation of the way in which implicit rules of behaviour on –how to communicate, which (professional) roles and responsibilities –are involved, and impact the author of the log/ reflection	Difference between formal and informal communication, roles and responsibilities with respect to stakeholder communications
Identification assumptions	Values and norms explication about the process, environment, content or product	Explicating – Clarifying assumptions of the company and the team while choosing a solution path/perspective-taking
Tasks and responsibilities	Defining the team members' responsibilities on; how to interact with one another. (usually agreed upon by the partners)	Mutual respect, free, equal and without judgement, behaviour and working responsibly. Division of tasks, yet also integration, working in pairs; we cannot do everything., Working space at the company or meeting rooms in the University
Reflection	*Students see their discipline through the eyes of another discipline, a professional or cultural lens, through peers or stakeholders, which leads to new insights*	
Calibrating Expectations	discovering, establishing, and expressing expectations needed to make the team (work) successful	Balance personal life and group work (well-being), team goals versus personal goals Building trust within the team, through accountability and enthusiasm, determining what one can contribute to the team Sustainability: establishing a core value/ambition in the project Working interdisciplinary; with other disciplines, honesty and with respect for each other
Dealing with feedback & Weaknesses	Author is framing implicit feedback about known or unknown weaknesses, by either denying, rejecting, accepting or taking action	Feedback: resistance seeking explanatory causes outside oneself Dealing with feedback – being frustrated about the peer feedback being unfair. Dealing with introversion, Developing confidence – overcoming stage fright
Strengths	Communicating (in the reflection) about personal strength based on personal beliefs or feedback from peers or other parties	Presentation skills Interdisciplinary skills; perspective taking/ different problem-solving approaches, tolerance and flexibility for different opinions/ Cultural values – learning about culture/gender Communication skills, relationship building with teammates, and getting things done. Planning – Structuring skills Creative ideas, planning and logistics,
External activities and interactions		

Emerging Codes Moment 2 – Week 5

Code	*Descriptor*	*Examples*
Identification		
Students gain (new) insight into their disciplinary perspective on the issue at hand and how other disciplines/professions/cultures (s) approach this issue (i.e. othering); additionally, they explore their competencies, revisit their assumptions and expand their horizons.		
I 2 Discovered/lack of skills		Research skills, Learning to model, Software implementation skills, Writing formal e-mails,

(*Continued*)

Continued.

Code	*Descriptor*	*Examples*
	Set of skills one discovers or already possesses, or skills that still need to be learned, skills one did not expect to use in this context.	Communication with different audiences (professional, experts) or Lack of communication skills – dealing with diversity, (Professional) Presentation skills – explaining hurdles – obstacles, Interview and networking skills, Dealing with conflicting personal and professional relations, Voicing opinions and speaking up Calibrating /monitoring if one is on the right track
12 Interests and passions	Finding out what is liked/disliked and might be pursued in the future	How to be, e.g. showing engagement – involvement, discovering what your passions are, sharpening personal ambitions/discovering passions, taking responsibility. Getting to know the working culture, getting to know the industry/ working in an interdisciplinary team, good communication and spirits, develop future thinking, identifying new challenges for myself,
Coordination		
Students learn from the use or search for procedures, means, communicative connections and objects to collaborate between disciplines/professions/cultures		
C 2 internal exchange information	What is needed in terms of team process to realise the next step in teamwork and project development?	brutal honesty/chemistry working vibe Sharing within the team information, more task division, roles & responsibilities and milestones are better determined Optimal work sharing/ working with a backup (together) creates better results We have challenging weekly goals, yet we achieve our weekly objectives as expected. Visualising frameworks to optimise the workflow and results Creating synergy between different team knowledges, strengths (multiple times) and ambition for innovation
C 2 external exchange information	What type of information is needed (in week 5) from the outside world to work on the problem effectively	Background information about the overall picture, scope, expectations, Design needs, getting a bigger picture overview of the trends going on in the field and the company. interdisciplinary exchange as a warning signal, Perspective-taking based on relevance for the problem at hand. Seeing live factories/field labs, etc, helps
Reflection		
Students see their discipline through the eyes of another discipline, a professional or cultural lens, through peers or stakeholders, which leads to new insights		
R2 Weaknesses	A confrontation with personal weaknesses that cause friction in the team or with self-leadership/competencies, etc.	Punctuality, transparent communication, language (lingua franca) obstacle, feelings of exclusion due to language barriers, struggling with taking initiative/proposing new ideas to the team, persuasively and effectively communicating ideas
R2 – Needed and/or appreciated skills	Showing awareness of what skills are needed or appreciated to realise the project results	Respect and appreciation for other team members Deep diving into research for a technical solution Realistic goal setting, positive attitude when confronted with unexpected challenges. Teamwork attitude, interdisciplinary skills, and using different perspectives for problem-solving Defining the scope and focus of the problem definition while calibrating with the company Leadership skills are an important skill. Communication, confidence and networking skills needed, as well as interview skills
R2 – Personal Growth	The skills that have been improved or are improving during the process of working on this project	Improving technical prowess and business analysis Better organisation of teamwork and tasks, online communication, team coordination – planning in advance, reporting and discussing doubts

(*Continued*)

Continued.

Code	*Descriptor*	*Examples*
		Steadily improving writing skills Improving on knowledge transmission to teammates impressive improvements made in team collaborations and content-wise Experiencing the stimulation of creative problem-solving by the company improved the team's innovative results

Emerging Codes – Moment 3 Week 7

Code	Descriptor	Example
Identification		
Students gain (new) insight into their disciplinary perspective on the issue at hand and how other disciplines/professions/cultures (s) approach this issue (i.e. othering); additionally, they explore their competencies, revisit their assumptions and expand their horizons		
Acquired skills	Looking back, what kind of skills have I learned	
Acquired content	Acquired content based on the reflection process that has taken place in the team or with external partners	
Future Ambitions/ Passions	Due to going through the process, I have developed the following passions /ambitions (either content-wise interests or behavioural)	
Practical Obstacles	Looking back at the barriers/obstacles that had to be overcome. Ideally related to a need for innovation, then coded both. However, it can also be merely a reflection on what obstacles were encountered and what they did to solve them. Which will mean it is only this Code.	
Need for innovation	This (interpretation is usually going in the direction of lessons learned and which skills, knowledge, or ways of working are needed for innovation in future activities (note this may also be a reflection (peers/stakeholder feedback) or a code at the transformation level, indicating really a change in doing things) this code	
Coordination		
Students learn from the use or search for procedures, means, communicative connections and objects to collaborate between disciplines/professions/cultures		
Better ways of working	Activities helping to create a better way of working, recommendations of process/task activities that should be undertaken to realise better ways of working	
Criteria for better ways of working	Criteria helping find better ways of working.Criteria are when the activities are good/bad	
Reflection		
Students see their discipline through the eyes of another discipline, a professional or cultural lens, through peers or stakeholders, which leads to new insights		
Learning from feedback	Learning From Feedback (peers or feedback from externals). Appreciating the feedback and what was directly learned from that. /note this might overlap with the previous codes	
Personal growth	Personal Growth: I have grown as a person due to to better understand oneself. (not learned skills)	

Transformation moments 1,2, and 3

> Students develop new ways of doing and thinking that have characteristics of one discipline and other(s) (i.e. a hybrid position), or new professional and cultural perspectives, which are (partially) integrated and combined into a new professional identity in the making.

Internal transformation: Students are triggered to learn from internal turmoil and the perceived need to act differently, integrating this into new/altered behaviour.

External transformation: Students are appealed to act differently/constructively via the environment (interpersonal contact/system) to make things work.

I-Concepts	Descriptors	
Work – University difference causing internal friction	Observed and mentioned the difference between the work culture of the company and the university culture, or other related professional organisations/people	Identification: observed differences Coordination: affecting work processes Reflection: received/given feedback, laying bare differences in work/university differences Transformation: inducing change in behaviour
Personal experience versus taught experience	Awareness and stating the difference between what was learned and experienced at university and what was personally learned and experienced.	Identification: observed differences Coordination: affecting 'work – collaboration' processes Reflection: received/given feedback, laying bare differences in personal vs taught experiences differences Transformation: inducing change in individual behaviour
Personal beliefs vs beliefs of peers/stakeholders and others	Expressed conflicting values/beliefs and norms between the individual and peers or stakeholders.	Identification: observed differences Coordination: affecting work/collaboration processes Reflection: received/given feedback, laying bare differences in beliefs/opinions between peers/stakeholders and self Transformation: inducing change in behaviour