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Citation for the original published paper (version of record):
O'Connell, M., Adawi, T., Wallin, P. et al (2025). Engineering students and professionals as co-learners: epistemic practices and positioning. European Journal of Engineering Education: 1-19.
http://dx.doi.org/10.1080/03043797.2025.2566697

European Journal of Engineering Education

ISSN: 0304-3797 (Print) 1469-5898 (Online) Journal homepage: www.tandfonline.com/journals/ceee20

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To cite this article: Michael T. O'Connell, Tom Adawi, Patric Wallin & Christian Stöhr (02 Oct 2025): Engineering students and professionals as co-learners: epistemic practices and positioning, European Journal of Engineering Education, DOI: 10.1080/03043797.2025.2566697

To link to this article: https://doi.org/10.1080/03043797.2025.2566697

Published online: 02 Oct 2025.

EUROPEAN JOURNAL OF ENGINEERING EDUCATION
https://doi.org/10.1080/03043797.2025.2566697

Engineering students and professionals as co-learners: epistemic practices and positioning

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ABSTRACT

A significant turning point in the discourse on interdisciplinarity is marked by the growing interest in non-disciplinary perspectives. This paper explores the potential of a model for engineering education where students and non-academic stakeholders are co-learners in project-based learning. The context is an interdisciplinary project-based course on battery technology open to both engineering students and engineering professionals. Interviews were used to explore what epistemic practices groups of students and professionals mobilise, and how they position each other and the project. A key finding is that students and professionals were positioned in complementary ways, with the latter perceived as valuable sources of industrial knowledge and the former as sources of academic knowledge. Additionally, group composition was found to have an effect on their epistemic practices. Based on our findings, we discuss three models for involving non-academic actors in engineering education.

ARTICLE HISTORY
Received 7 February 2024
Accepted 22 September 2025

KEYWORDS
Interdisciplinarity; transdisciplinarity; project-based learning; interdisciplinarity plus; professionals as co-learners

1. Introduction

Interdisciplinarity is a key concept for rethinking and reshaping engineering education (Feng et al. 2023; Van den Beemt et al. 2020) and, more broadly, higher education (Jacob 2015; Schijf, van der Werf, and Jansen 2023). The driving force behind interdisciplinary education is the recognition that many problems, such as climate change and social injustice, cannot be meaningfully addressed within disciplinary boundaries (Jacob 2015). But challenging the disciplinary hegemony comes at a cost:

> Contrary to the whiggish optimism of most literature on interdisciplinarity, and thanks to the blunt lessons offered by experience, we have learned that interdisciplinary collaboration is, to put it frankly, *really bloody difficult.* (de Ruiter, Wittingslow, and Chiu 2023, 15, emphasis original)

Interdisciplinary learning environments are therefore designed to prepare students to work across disciplinary boundaries, tackling problems that call for the use of theories and techniques from more than one academic discipline (Ashby and Exter 2019).

That way of theorising and researching interdisciplinarity has, however, been criticised for marginalising *non-academic* perspectives, marking a critical turn in contemporary discourse on interdisciplinarity (Frodeman and Mitcham 2007). In the wake of such criticism, we are witnessing the

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emergence of a broader conceptualisation of interdisciplinarity. Frodeman and Mitcham (2007) argue eloquently for a new form of interdisciplinarity 'that moves beyond the academy into dialogue with the public and private sectors' (506). In their view, interdisciplinarity 'needs to do more than simply reach across campus' (513). Similarly, Lattuca and colleagues argue that an appreciation of non-disciplinary perspectives is a crucial component of interdisciplinary competence (Lattuca, Knight, and Bergom 2013). This broader understanding of interdisciplinarity – traversing not only the divide between academic disciplines, but also the one between academia and society – is sometimes referred to as 'interdisciplinarity plus' (Repko and Szostak 2017).

Consistent with the notion of interdisciplinarity plus, there have been calls to involve non-academic stakeholders as *co-learners* in higher education (Mercer-Mapstone et al. 2017), including engineering education (Visscher et al. 2022). Sagheb and colleagues have recently advocated a project-based model where stakeholders from industry are embedded within student teams (Sagheb, Walkup, and Smith 2022). Although the idea behind their embedding model is arguably to capitalise on differences in perspectives and practices between external stakeholders and students, we are not aware of any prior research attempting to pinpoint such differences (if any) in the context of project-based learning. Indeed, as Gallagher and Savage (2023) note in their recent review article on challenge-based learning in higher education, the role of extra-academic actors remains largely under-explored: there is 'little detail as to what their input was' (1144).

To address this gap in the literature, we report on a qualitative study that examines how groups of engineering students and engineering professionals engage in interdisciplinary project-based learning (iPBL). The project forms the backbone of a course on battery technology that is open to both engineering students and engineering professionals. A central part of the design of the study is the use of three types of groups: (1) students only, (2) professionals only, and (3) a mix of students and professionals. Our analytical interest here is twofold. First, we are interested in what the different types of groups do to develop or acquire new knowledge: what *epistemic practices* (Knorr Cetina 1999) they engage in. Second, in this process of creating knowledge, we are also interested in how students and professionals discursively attach value and significance to – that is, how they *position* (Green et al. 2020) – themselves, each other, and the project. Accordingly, the study was guided by two research questions:

RQ1: What epistemic practices do the three types of groups employ – and how are these epistemic practices enacted – in interdisciplinary project-based learning?

RQ2: How do the students and professionals position themselves, each other, and the project?

We consider this double analytical focus to be important since differences in epistemic practices and perspectives between students and professionals can be construed as *learning opportunities* – opportunities for broadening perspectives and the repertoire of practices (or challenging practices and perspectives deemed suboptimal). Perhaps even more important is to understand how the epistemic practices mobilised by mixed groups relate to those employed by groups of students only and professionals only. As such, our findings hold relevance for engineering educators who are keen to better understand the potential (and pitfalls) of involving engineering professionals as *co-learners* in project-based courses.

2. Related literature

The use of the term 'interdisciplinarity plus' (Repko and Szostak 2017) to conceptualise the empirical setting for this paper requires some explanation. Research attending to collaboration between students and non-academic actors is growing, and it is often conducted under the banner of 'transdisciplinarity' (e.g. Davis and Caldwell 2023; McCrory et al. 2021). There are, however, two distinct schools of thought associated with the term transdisciplinarity: Mode 1 and Mode 2. Proponents of Mode 1 transdisciplinarity seek to integrate knowledge across disciplines, while proponents of Mode 2 transdisciplinarity are more concerned with the development of socially robust knowledge (Scholz and Steiner

2015). Our empirical setting – on the academic side – is interdisciplinary rather than Mode 1 transdisciplinary, and 'interdisciplinarity plus' is then a convenient way to label approaches that straddle interdisciplinarity and Mode 2 transdisciplinarity. This is illustrated in Figure 1.

Regardless of how this strand of research is labelled, there are well-documented benefits emerging when students work with non-academic actors. In their review article, Gallagher and Savage (2023) found that 'student collaboration with […] extra-academic actors deepened student knowledge […], motivated and engaged students […], and supported industry-specific training' (1144). Such benefits are to some extent attributed to a central assumption behind transdisciplinary approaches to education: different actors bring different perspectives and practices to the collaboration. As Scholz and Steiner (2015) have pointed out, transdisciplinary approaches acknowledge the 'incompleteness of different forms of epistemics' (527) when it comes to tackling complex problems. Our study directly addresses this key assumption.

It is worth noting that the term 'collaboration' in the above cited passage by Gallagher and Savage (2023) is left unspecified and unproblematic, despite the fact the term could mean different things in practice. It could, for example, mean that non-academic actors take on the role as mentors, clients, or collaborators (e.g. Bakırlıoğlu and McMahon 2021; Holmén, Adawi, and Holmberg 2021; Piccardo et al. 2022; Sagheb, Walkup, and Smith 2022). An interesting yet less explored possibility is that non-academic actors take on the role as *co-learners* in higher education (Mercer-Mapstone et al. 2017). Here, the non-academic actor's goal is learning-oriented and there is a possibility of failing a course. While they might be capable of drawing on non-academic knowledge, their role within courses and projects is the same as that of the students. These different models for involving non-academic actors in higher education are illustrated in Figure 1, and we will return to these models in the discussion.

While we were unable to identify prior studies with professionals enrolled and participating as co-learners with students in a project-based course, we did find some studies that bear some relevance to this paper. Nyarko and Petcovic (2023) investigated the teamwork skills of groups taking part in a hydrogeology field course. The course contained a mixture of lectures and group work in the field. One of the groups had a member that was employed, while all other participants were students or recent graduates. Communication was the most commonly used teamwork skill, but the group with an employed member communicated more often.

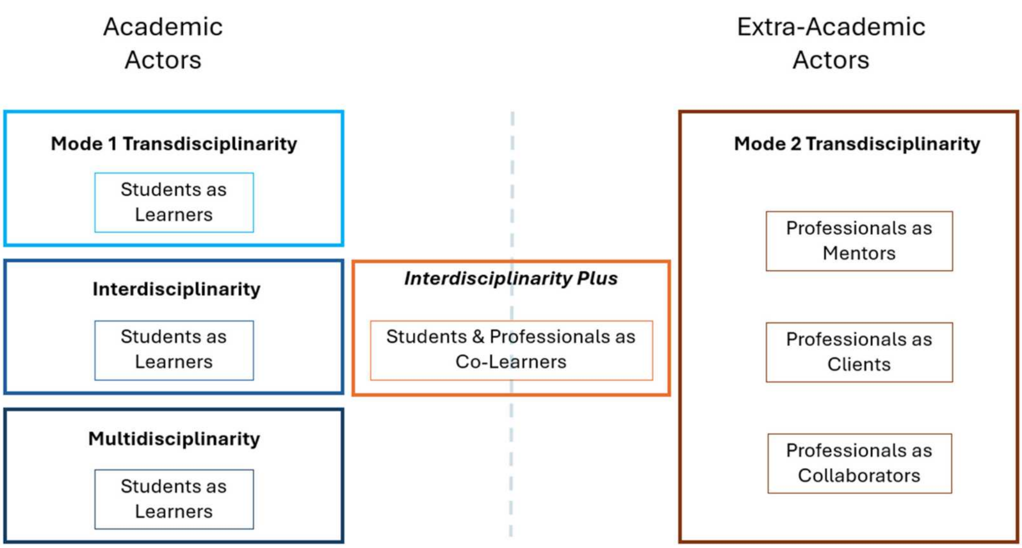

Figure 1. Positioning 'interdisciplinarity plus' as an educational approach and models for involving extra-academic actors in higher education.

Bakırlıoğlu and McMahon (2021) examined a programme that saw students take part in a three-month design project within industry, which included four 'masterclasses' to deliver fundamental knowledge, as well as assignments and workshops to help support their learning. The students collaborated with industry partners for the projects. Sometimes this was on an equal relationship and at other times the partners took a mentor role. Despite not operating as co-learners, both the students and industry partners were found to benefit from the programme.

Atman et al. (2007) investigated how student groups and groups of professionals engaged in a project and found that the professionals spent more time and went through more iterations on tasks. However, there was no significant difference in the quality of the groups' end products.

Bjursell (2015) investigated how students and professionals positioned each other in the context of a course with high school students and entrepreneurs. Both cohorts saw the advantages the other brought and felt that they had complementary skills and knowledge. The students were seen as a source of technical knowledge, while the entrepreneurs were seen as having valuable knowledge of the business world and providing a potential network.

In the context of engineering education, a clearly important group of non-academic actors are industrial stakeholders (Shah and Gillen 2023; Valentine, Marinelli, and Male 2021). Sagheb, Walkup, and Smith (2022) argue that industry-academic partnerships can enrich student learning experiences and advocate a model where industry partners are embedded within student teams in project-based courses. In their model, the industry people act as mentors, giving feedback on student design solutions. In this paper, we analyse opportunities and challenges of a model for engineering education where industrial engineers are co-learners, rather than mentors or clients, in an interdisciplinary project-based course.

Cunningham and Kelly (2017) provide a theoretical motivation for our study when they distinguish between 'epistemic practices of engineering' and 'epistemic practices of engineering in education'. This suggests that academia and industry may have their own idiosyncrasies in terms of epistemic practices, which raises a number of interesting questions for empirical inquiry: How do the epistemic practices of engineering students and professional engineers compare? What happens when these practices meet, and what learning opportunities does this open up for students?

3. Methodology and methods

The present study adopts a qualitative approach to answer the research questions. Qualitative research enables an in-depth and contextual understanding of participants' perspectives and practices (Merriam and Tisdell 2015). The study is based on semi-structured interviews with engineering students and engineering professionals who attended an interdisciplinary project-based course on battery technology as part of a ten-year educational initiative titled Tracks, which fosters interdisciplinary group-projects across programme boundaries, grounded in real-world problems (Enelund and Henricson Briggs 2020) at Chalmers University of Technology in Sweden.

3.1. Empirical setting and participants

The course offered 7.5 ECTs and had a diverse curriculum taught by a team of experts. The curriculum covered a broad range of battery topics, from their chemical and physical properties to their production, management, sustainability, and recycling. The course was four months in duration, with four 'class days', one of which included the groups presenting their projects, where all participants attended lectures from 8 am to 5 pm. Additionally, there was three tutorial sessions and one lab session that saw participants make and test a battery. Course participants were required to complete three individual tasks (one after each of the first three days of classes), an individual lab report, and a group project.

The group project concluded with each group presenting their work to the class in a seminar format. While groups could choose their own topics for the final project, they had to include one of the following: a review on a topic of battery research, a review of a specific battery technology, a presentation of their lab results (if possible), or another topic of their choice if the teacher agreed. The projects also had to have some relevance to the course topics. Due to the project requirements and the course topics, the group projects were inherently interdisciplinary. The groups were formed approximately two months before the seminar.

Altogether there were 30 participants enrolled on the course, 10 of whom were professionals. Using a list of groups and their members, individuals from all three group types (student-only, professional-only, and mixed) were invited by email to participate in interviews, and care was taken to ensure that all group types were represented. To this end, six groups were represented in the interviews: two student groups (S1 and S2), two mixed groups (M1 and M2), and two professional groups (P1 and P2). The interviews included one participant from each of the student and professional groups. Two professionals were interviewed from Group M1, one student and one professional were interviewed from Group M2. In total, three students and five professionals were interviewed. The size and composition of each of these groups is shown in Table 1.

As can be seen in Table 1, the diversity of academic disciplines varied across the groups in this study, with some groups being more homogonous than others. The student groups proved to be the most homogonous, with members having bachelors in the same discipline (but from different universities) and attending the same or similar master's programmes. The professional and mixed groups had a larger mix of disciplines, with members only occasionally sharing a discipline from their bachelor's or master's degrees. All group members' core qualifications were in STEM disciplines and so the groups should be considered narrow in terms of interdisciplinarity. All the student participants were enrolled in master's degree courses. All professionals had at least a master's degree or equivalent. All the professionals in the groups listed were employed during the course and worked in either management or research and development roles. The majority of the participants in the groups, and the course, were males. Only two participants in the groups included in this study were female.

3.2. Data collection

When developing the interview protocol, we drew on theories related to collaborative learning, specifically social regulation of learning (SoRL), to better describe and identify epistemic practices. Epistemic practices are the 'ways that members of a group propose, communicate, evaluate, and legitimise knowledge' (Kelly and Licona 2018, 140) and we theorised that processes or episodes related to SoRL would help reveal such practices. SoRL is one of the two core processes of collaborative learning, the other being the co-construction of knowledge (Järvelä and Hadwin 2013; Volet, Summers, and Thurman 2009). Regulation of learning is the taking control of processes related to metacognition, cognition, behaviour, emotion, and motivation through iterations of activities such as planning, monitoring, evaluating, and changing (Hadwin, Järvelä, and Miller 2017; Pintrich

Table 1. Size and composition for each group type represented in the interviews.

	S1	S2	M1	M2	P1	P2
Students	3	3	2	1	–	–
Professionals	–	–	2	2	3	3
Disciplines	ME	AE, ME	SS, AE, EPE	ME, SES, NA	ME, CEAP, MS, MSMT	QAM, ISCE, CE

Note. The following abbreviations are used for the disciplines: mobility engineering (ME), automotive engineering (AE), sustainable systems (SS), electric power engineering (EPE), mechanical engineering (MechE), sustainable energy systems (SES), naval architecture (NA), chemical engineering with applied physics (CEAP), materials science (MS), materials sciences and manufacturing technology (MSMT), quality and operations management (QOM), innovative and sustainable chemical engineering (ISCE), chemical engineering (CE). For most participants this represents the discipline of their master's degree, however for the participant with a PhD we included both the master's and doctorate's disciplines.

2004; Zimmerman 2015). SoRL is comprised of three distinct, yet often interlinked, modes: self-regulation of learning (SRL), co-regulation of learning (CoRL), and socially-shared regulation of learning (SSRL), with the difference between them being the subject and object of regulation. SRL sees the individual regulate themselves towards the group's goal, while CoRL occurs when one or more individuals regulate others, and SSRL is the group's regulation of itself (Hadwin, Järvelä, and Miller 2017).

Therefore, most of the interview questions focused on the groups' activities at the beginning, middle, and end of their projects, in keeping with Zimmerman's (2008) three phases of SRL (forethought, performance, and evaluation or reflection). The questions incorporated several aspects of regulation of learning, including motivation, planning, goal setting, monitoring, and evaluation. Questions also addressed the groups' organisation, and how they resolved potential challenges and disagreements. Additionally, participants were also asked to compare their method of working with their previous experiences in industry or university and to identify any major differences in epistemic practices between these two realms. Finally, in terms of positioning, participants were asked if they felt they learnt from the project as well as from others in the group, or if they felt they helped others learn.

The interviews were semi-structured, meaning that the questions outlined above formed the backbone of the interviews while allowing new aspects to surface. All interviews were held over Zoom and were one-on-one (except for the interview with the professionals in Group M1, as they requested to be interviewed together). Online interviews were chosen for their convenience, and they offer interviewees the possibility to participate from familiar surroundings (de Villiers, Farooq, and Molinari 2022). There is a potential risk that holding interviews online might be an issue as there is the potential for participants to be unfamiliar and/or uncomfortable with the technology being used (de Villiers, Farooq, and Molinari 2022). However, this was not deemed an issue as all the participants had held their group meetings online and appeared comfortable in the medium. The interviews lasted between 20 and 60 minutes. All interviews were conducted by the first author, audio-recorded, transcribed, and anonymised.

3.3. Data analysis

The interview transcripts were subjected to thematic analysis (Braun and Clarke 2013). While our thematic analysis was inductive and iterative in nature, the initial identification and interpretation of data segments were guided by predefined theoretical constructs – notably epistemic practices and positioning. These constructs acted as *sensitising concepts* (Blumer 1954) and informed a theory-driven starting point, but the coding process was open to emerging patterns within these broader categories. Thus, our approach can be characterised as theory-informed thematic analysis that allowed for the inductive development of subthemes and variations within conceptually defined domains. This process involved repeated readings of the interview transcripts to identify passages related to epistemic practices (RQ 1) and positionings (RQ 2). These passages were systematically coded to capture their meanings, and the codes were then sorted and sifted into themes. Themes are typically more abstract than codes, and the development of themes from codes draws on the idea of *semantic proximity* (Braun and Clarke 2022), where codes that are close in meaning are clustered to form a coherent theme. This clustering process was done iteratively through several rounds of refinement to maximise proximity within themes and distinction between themes.

Epistemic practices, as outlined above, are those related to how groups set-up and engage in knowledge creation, or learning. When analysing the data, we considered the theoretical point by Cunningham and Kelly (2017, 148) that there is a difference between the 'epistemic practices of engineering' and 'epistemic practices of engineering in education'. Therefore, the epistemic practices of professional engineers and engineering students might not be the same. Example indicators in the coding process include references to regulatory processes such as planning, monitoring and evaluation or collaborative processes such as organising work and sharing information.

Positioning refers to the ways individuals locate themselves and others within a social context, thereby defining dynamic roles, responsibilities, and relationships (Davies and Harré 1990). It is understood as something that can be applied to both people and objects (Berge and Danielsson 2013). In the context of interdisciplinary engineering education, positioning can illuminate how different stakeholders, such as students and professionals, negotiate their identities, expertise, and contributions within a learning environment. Positioning was identified in two ways: through direct statements, or by comparing practices of students and professionals. Indicators for this analytical dimension can include, for example, describing a person as an expert, contrasting the project from other previous projects, or expressing value statements about participants or project activities.

To ensure reliability, the first author conducted the analysis, with the other authors periodically checking the codes against the original transcripts and discussing potential discrepancies. Only minor refinements were done during the different steps of the coding process, mainly referring to questions of phrasing to increase understandability of the code and themes. Overall, the discussions and refinements contributed to strengthen the trustworthiness of the applied methodological process.

4. Findings

This section expounds on themes that were developed for the two research questions based on the data. The themes constructed for RQ1 shed light on the similarities and differences in the enactment of epistemic practices between the three types of groups. The themes constructed for RQ2 focus on how students and professionals position their partnership and the project. For clarity, we reiterate that the nomenclature we used to identify the groups were S1 and S2 for the student groups, M1 and M2 for the mixed groups, and P1 and P2 for the professional groups.

4.1. Epistemic practices employed by groups (RQ1)

Based on our analysis of the interviews, we see epistemic practices contributing to five themes: (1) co-constructing a project focus, (2) coordinating actions, (3) monitoring progress and quality, (4) supporting learning within groups, and (5) building group cohesion and interdisciplinary capacity. An overview of these themes is provided in Table 2, and when an entry is specific to only one group their name is attached to it.

4.1.1. Co-constructing a project focus

The interviews show clear differences in how the three types of groups co-constructed the focus or topic for their project. Members from the two professional groups described comprehensive processes that typically involved a range of practices, such as researching, meeting, and discussing. Moreover, the professionals stated that their groups were keen to choose topics that reflected big issues or practical challenges within industry.

> We thought it was a good idea to try to see: okay, what's the challenges we have in industry right now. (P1 professional)

> We took the thermal runaway analysis because it seems like this is something that you hear and it's a big issue, at least in the industry. So that's why we took it. (P2 professional)

Members of the two student groups devoted considerably less time and effort on co-constructing a project focus. In Group S1, the topic was simply determined when one member proposed an idea, which the other members found agreeable. Similarly, in Group S2, a single student suggested a potentially interesting topic, and after a brief discussion, the group concurred. Thus, the topics that the student groups agreed on were based on single proposals from individual group members.

The two mixed groups chose a different route, pooling multiple proposals and thus considering the interests and knowledge of all group members from the start. For Group M1, this meant a topic

Table 2. The five epistemic practices identified and their enactment by group type (RQ1).

Epistemic practice (*what* aspect)	Enactment of the epistemic practice (*how* aspect)		
	Student groups	Mixed groups	Professional groups
Co-constructing a project focus	Based on single proposal Based on shared interest in proposed topic	Based on pooling of multiple proposals Based on range of individual interests, experiences, and resources	Based on selection from multiple proposals Based on ideology: • Reflect industry issues • Teach students (P1)
Coordinating actions	Meetings for synchronous coordination: review and decide on action plan Less time restrictions: available to meet on weekdays, weekends and in person or online Shared online document for asynchronous coordination	Meetings for synchronous coordination: review and decide on action plan More time restrictions: only available to meet on weekends and online Shared online document for asynchronous coordination	Meetings for synchronous coordination: review and decide on action plan More time restrictions: only available to meet on weekends and online Shared online document for asynchronous coordination
Monitoring progress and quality	Synchronous monitoring of progress in meetings Asynchronous monitoring of progress (contribution) through online document No quality checks (S2) Surface quality checks (S1)	Synchronous monitoring of progress in meetings Surface quality checks (M2) Deep quality checks (M1)	Synchronous monitoring of progress in meetings Deep quality checks
Supporting learning within groups	Support on request by reading up on the issue (S2) Actively checking if support is needed (S2) Teaching and knowledge sharing by all group members (S1) Creating a shared understanding	Support on request by reading up on the issue (M1) Teaching and knowledge sharing by all group members (M1) Explanations by professionals only (M2) Creating a shared understanding	Support on request by reading up on the issue (P2) Teaching and knowledge sharing by all group members (P1) Creating a shared understanding
Building group cohesion and interdisciplinary capacity	Familiar with each other Narrower disciplinary background as group	Unfamiliar with each other Broader disciplinary background as group No reported attempt to get to know each other (M2) Meeting to get to know each other (M1)	Familiar with each other (P1) Unfamiliar with each other (P2) Broader disciplinary background as group Familiar with project management methods

Note. When an entry is specific to a group their name is attached to it.

that all group members had some basic knowledge of. Based on the interviews, it appears that professionals and students thereby incorporated knowledge from industry or their discipline. Group M2's project topic was formed to utilise all group members' interests or specialties. The professional in Group M2 commented that they deliberately chose a topic that allowed them to utilise their industry resources. However, in contrast to the two professional groups, the topics formulated by groups M1 and M2 were not chosen to highlight industry challenges.

4.1.2. Coordinating actions

The interviews reveal that meetings were utilised by all groups to coordinate actions synchronously, and all groups used a shared document for asynchronous contributions of the group members. Almost all interviewees reported that their first meeting was used to select a topic, formulate a plan, and delimit the scope of the project. Although the frequency of meetings varied, most groups met at least four times. Notably, Group S2 only met twice throughout the project, but they maintained communication to provide assistance as needed.

All groups, except for one, followed a similar way of structuring their meetings throughout their projects. This involved practices such as reviewing their progress since the previous meeting, determining what should be done next and splitting tasks among the members. There were slight variations of this structure – the interviewee from Group P1 described that they would spend a number of hours working in cycles of collaborative and independent work, reconvening periodically. Notably, they were the only group to report that they worked together on comprehensive tasks during the meetings. In contrast, other groups only indicated collaboratively solving minor tasks, such as updating presentation slides (Group M1) or searching together for a way to help a member facing difficulties.

Based on the empirical material, the inclusion of a professional to a group appears to have had a direct impact on the groups' availability for meetings. Professionals consistently reported more time constrictions as they were balancing work, family life, and study. As a consequence, all professional and mixed groups held their meetings on weekends only and online. While students also reported time constraints due to thesis writing or work placements, the student-only groups had more flexibility in their options for meeting. Indeed, the interview from Group S1 revealed that they met weekdays and weekends, both in person and online.

4.1.3. Monitoring progress and quality

Interviews showed that all groups monitored the *progress* of their work, but there were some differences in how this practice was carried out. With the exception of Group S2, it appears that all groups used meetings to regularly monitor progress. Participants explained that all members would present and discuss the progress relating to their assigned tasks, and the groups would then plan work for the next meeting. Group P1 included an additional layer of monitoring as they not only assigned tasks on a weekly basis but would cycle between individual and collaborative work during their meetings (as mentioned above).

Only the student groups (S1 and S2) reported monitoring their progress asynchronously through the shared document. The interviewees stated that group members that were seen to be falling behind in their work or not contributing would be sent 'reminders' by the others in the group. It is noteworthy that the student groups monitored the shared document for progress only. The respondent from S1 disclosed that they did not comment on the content of the work 'because the work was not complete until the time we met'.

How groups monitored the *quality* of their work also varied. Group M2 would discuss content that had been added since the previous meeting and provide feedback such as 'maybe this graph is not good enough … maybe we need to make it better' (M2 student). Group M2 members would also ask questions about the data or slides, e.g. 'what kind of inference we got from this data? Does it make sense?' (M2 student). They determined their project's quality by comparing it with their goals from the beginning:

> It was more or less like, have we met what we had described in the proposal for the topic and it felt like we had achieved like this is what we wanted to check and this is what we found out. (M2 student)

Interviewees from groups P1, P2 and M1 described how they would conduct more in-depth reviews of the quality of their work during their meetings. This included, for example, double-checking references and statistics, and re-ensuring the content was correct.

The quality checks of student groups were less in-depth. Similar to the other groups, Group S1 had weekly presentations, whereby the feedback provided was appreciative and included 'constructive criticism', 'rather than just pointing out the mistakes'. This use of feedback is in contrast to Group M2, where the professional noted holding back from giving critical feedback on the final presentation due to unfamiliarity with their teammates. The interviewee from Group S2 stated that although they did not perform any 'quality analysis', the group believed their project was at the level of a 'master thesis or PhD students', primarily due to the quality of sources they used for data and information. Given the group's lack of regular meetings, the empirical material suggests that they only reviewed the actual content of each other's work during their final meeting.

4.1.4. Supporting learning within groups

From the analysis, it is clear the groups engaged in various epistemic practices that supported members' learning, including helping group members with their tasks or understanding. This support primarily took two forms: providing help when a member requested it and providing knowledge or instruction to the group (without help being requested). This typically occurred during meetings, though sometimes members or groups would share knowledge or provide help through messaging or emails. All help and support came from within the groups themselves as no group felt the need to reach out to the teacher for help on their projects. The few that did contact the teacher did so to clarify the requirements for the presentation.

Different approaches were taken by groups when called upon to provide help. Interview participants from groups S2, M1, and P2 reported that if a team member was having difficulties, the others would read articles to better understand the problem so they could help. To compensate for the only two 'official' meetings over the course of the project, Group S2 took a proactive approach to identifying individuals that needed help by messaging each other periodically. They would then have dedicated discussions with the group member that needed help.

The interviews also suggest that groups facilitated learning through knowledge sharing or providing instructions. Group S1 took an active approach to supporting each other by sharing knowledge while individuals worked on their own tasks. Participants mentioned that if someone found a research paper or relevant information, they would share it with the appropriate team member. Similarly, a professional from Group M1 reported if they 'found something interesting' they would send it to the group. Most groups (S1, M1, M2, and P1) provided support as needed through knowledge sharing or instruction. In the interviews, participants from these groups reported that those with expertise in a particular subject or area would explain concepts to the group. In Group M1, the interviewees mentioned that all members would assume a teaching role if they possessed relevant knowledge. However, this was not the case in Group M2, where only the professional reported sharing their knowledge from industry with the others.

Furthermore, the analysis indicates that knowledge sharing within groups sometimes involved generic skills rather than strictly academic content. For instance, a student in Group S1 provided advice to the rest of the group on how to deliver better presentations. This is in stark contrast to Group M2, where the experienced professional member reported they explicitly held back on advising the group on presentations.

As previously mentioned, the interviews showed that all groups split the work among themselves to some extent. One participant noted that while this practice is efficient for progress, it may not support comprehensive learning:

> You do that and you do that […] Quick and efficient. Maybe not the best way to learn every step of the things, but time efficient. (M2 professional)

Recognising the limitations of primarily working on individual tasks, participants from groups P2 and S2 described their efforts to ensure mutual understanding of each other's work. For Group S2, this involved reading each section or slide and asking if there were any doubts or uncertainties during their final meeting. Despite not always mentioning specific measures to ensure everyone learned all aspects of the project, the majority of participants (groups S1, S2, P1 P2, M2) reported gaining knowledge about the tasks and parts of the projects they did not directly work on.

4.1.5. Building group cohesion and interdisciplinary capacity

The empirical material indicates that the different group types experienced different levels of familiarity with each other. How group members managed this unfamiliarity varied between group types. Both student groups held what can be seen as both an advantage and disadvantage over the other group types. They were all enrolled in overlapping master's programmes, though they had completed their bachelor's degrees at different universities. This provided an advantage in terms of knowledge of and familiarity with each other, but also resulted in a potential lack of diversity in terms of disciplinary knowledge. Thus, familiarity with each other occurred at the expense of interdisciplinary capacity.

In contrast, the members of the mixed groups were largely unfamiliar with each other but possessed a broader range of skills and knowledge. How the two mixed groups handled this unfamiliarity differed drastically and had a profound effect on their collaborative efforts. Group M1 dedicated time getting to know each other after its formation, as indicated by the professional member:

> So in the first week I think […] we just met each other and introduced ourselves. (M1 professional)

Subsequently, interviews with members from Group M1 did not reveal any issues related to familiarity during the project. Conversely, the professional in Group M2 expressed regret that the group did not invest time in getting to know each other:

> Now we didn't talk much about what's your speciality […] what have you been working with previously and so on. (M2 professional)

This professional also described that they often withheld feedback and advice from the group, ultimately to the detriment of the group, as they were not familiar with the others and felt uncomfortable saying something.

The members of Group P1 were former colleagues, while those of Group P2 were unfamiliar with each other. Nonetheless, neither group mentioned issues related to unfamiliarity in the interviews. Both interviewees indicated that they simply applied project management methods as they would have on industry projects, suggesting a generally higher capacity to manage unfamiliarity compared to the mixed groups from the start.

4.2. Positioning by students and professionals (RQ2)

An overview of how students and professionals positioned their partnership and the project (RQ2) is presented in Table 3, and when an entry is specific to only one group their name is attached to it.

4.2.1. Positioning the partnership

The interviews revealed that students and professionals positioned each other (and themselves) in terms of knowledge, resources, and mindset. The empirical materials show that students and professionals perceived each other as bringing complementary assets to their projects. The perceived

Table 3. An overview of how students and professionals positioned their partnership and the project (RQ2).

Area of positioning	Positioning	
	Students	Professionals
The partnership	Positioned *professionals* as: • Having a forthright mindset • A source of industry knowledge and experiences • Having a professional network • Equal partners • Their occupation over qualificationPositioned themselves/other *students* as: • A source of academic knowledge and skills	Positioned themselves/other *professionals* as: • A source of industry knowledge and experiences • Having access to a professional network • Their occupation rather than qualificationPositioned *students* as: • Having an inquisitive mindset • A source of academic knowledge and skills • Equal partners
The project	Positioned the project/course in terms of its *value* as: • An interest-driven undertaking • A learning driven undertakingPositioned the project in terms of its *nature* (practices enacted) as: • Same as regular course projects	Positioned the project/course in terms of its *value* as: • An interest-driven undertaking • A career-driven undertaking • A learning driven undertakingPositioned the project in terms of its *nature* (practices enacted) as: • Different to regular industry projects (M1 & M2) • Same as regular industry projects (P1 & P2)

Note. When an entry is specific to a group their name is attached to it.

value of professionals' rich repositories of knowledge and experience from the battery industry was recognised by both students and other professionals. A student from one of the mixed groups reflected on the knowledge provided by the professionals:

> I got to learn stuff that I would not have normally been able to access. Like, this kind of information is not available in textbooks or anywhere like that. (M2 student)

Professionals (and a student on industry placement) would also utilise their industry colleagues as a resource for information to aid their course projects. Additionally, students noted that professionals were forthright when making points or asking questions in class. Students were positioned by the professionals as having an inquisitive mindset, with 'fresh and hungry ears and eyes' (M2 professional), often seeking more details or clarifications. Moreover, within mixed groups, students were regarded as equals and a source of academic knowledge and skills. For Group M1, this was reinforced by the students taking on tasks related to their theses or fields of study. While the professional in Group M2 noted the student's lack of real-world experience, they also appreciated the value of a team member who could provide academic resources and create a link between theory and practice:

> I think we were quite equal. It was, of course … the students have not been out in real life, but he was really skilled in finding things … what they have been trying in different universities and places like that and … 'I've found this here and there'. (M2 professional)

These academic skills were seen as complementary to the professionals' more practical experiences and skills:

> Me and the other guy from real life if you so call it … we were like … more I've done like this and hey, I have a contact … I can contact this and I can get some information. Yeah, we put it together. (M2 professional)

Interestingly, students positioned themselves in a similar way as academics, and the contrast between students and professionals was seen as positive by both – including students that were not in mixed groups:

> There were two different perspectives: one from an industry, and one from academia. So, when there are a lot of discussions happening during the lectures, and it was fun to look at both sides of it. (S1 student)

The positioning of group members in terms of discipline was partly dependant on whether they were a student or professional. While both professional and student interviewees from groups P1, P2 and M2 could recall their professional teammates' roles or specialties in industry, they were only vaguely or not at all aware of said teammates' academic disciplines. In essence the professionals were seen in terms of their careers rather than their qualifications:

> Their experiences kind of took them away from there. So, I could not tell what bachelors or master's they had. […] They were very into their careers at that time. (M2 student)

Conversely, the interviewees from groups S1, S2 and M1 (who were both professionals) were able to recall the academic disciplines of their student teammates at least at the master's degree level.

Based on the analysis, all groups operated with a flat organisational structure, where there were no fixed roles, and the interviewees consistently suggested that all members contributed equally. However, in Group M1, the professionals tended to send meeting invites, start the meeting, and deliver the agenda, suggesting they naturally assumed a more leading role.

4.2.2. Positioning the project

The interviews also revealed a clear difference in how students and professionals positioned the project and course in terms of the *value* it held for them. While both professionals and students expressed that they started the course with personal learning goals and a focus on learning rather than simply passing, they differed in their motivations. Professionals generally had specific career-oriented reasons for joining the course:

> Yeah, it was mainly […] in my work. I'm starting, you know […] in a new area. So [I] was trying to get a deeper knowledge of what cells [are] and what is important to understand, I think … and also the company provide these opportunities. So that's […] what's [my] motivation: [a] new position and […] to at least try to understand what I'm working with. (P2 professional)

Students, on the other hand, generally chose the course as it aligned with their other studies and interests, or to learn about specific technologies or areas. There were, however, two exceptions: One was the professional from Group M1 who stated their main motivation was an interest in battery technology. The other was the student in Group M2 who was working and studying at the same time. Thus, they found the project both professionally and academically interesting.

Despite describing similar epistemic practices, how professionals positioned the *nature* of the project – that is, how they reflected on the epistemic practices they mobilised in their projects – depended on their group type. Interviews with the professionals in groups P1 and P2 indicated that they approached the project as they would in industry, referring to how they organised and managed themselves. In the mixed groups, however, the professionals characterised the project as different from the industry. Here the reasons given were not related to organisation and management. Instead, professionals in both groups M1 and M2 noted that the course project required them to take on unfamiliar tasks that in industry would typically be assigned to someone else with relevant expertise in that area. A difference between these mixed groups and at least one of the professionals in Group P1 is that part of their project fell within the professional's speciality. A professional in Group M1 also outlined that the difference between the course project and an industry project was reflected in how they felt as part of the group. Within industry projects, they felt more like individuals working towards a common goal, but in the project group they perceived themselves as an intricate part of the group. Nonetheless, they did add that the actual method of working on the project was similar in that tasks were assigned to individuals.

Professionals in both of the mixed groups commented on the academic nature of the project. The professionals in Group M1 saw the project as an academic exercise following a student 'work plan', and that they had to return to a student mindset, thus positioning themselves as students in the course rather than professionals. Similarly, the professional in Group M2 saw the group project as an opportunity for high quality content learning:

> We cannot have 40 people talking singularly with, of what they think is interesting. We put, we bunched them together 3 and 3. […] The quality is extremely much higher then. (Professional M2)

However, this professional found it difficult at first to handle the academic nature of the course, as it had been almost two decades since they completed their university studies.

Students more uniformly equated their projects to typical university projects. The student in Group S1 commented on feeling less pressure on this course compared to courses they usually took. Overall, despite the differences in how students and professionals positioned the nature of project, all groups appear to have followed a similar structure as outlined in the previous section. Differences were mainly related to their roles within their respective groups. Similarly, all interviewed participants reported being satisfied with what they had learned from the course and the project, and that their original learning goals had been fulfilled.

5. Discussion

This paper set out to explore how groups of engineering students and engineering professionals engage in iPBL, and how this co-learner model unfolds in the context of a course at a Swedish university. To this end, we have explored what epistemic practices three different types of groups (student, mixed, and professional) mobilise, and how students and professionals position each other, themselves, and the project.

A key assumption behind interdisciplinarity plus is that different types of actors bring different perspectives and practices to the collaboration (Scholz and Steiner 2015). Our findings both confirm and challenge this. On the one hand, our results are consistent with the assumption that students and professionals bring complementary perspectives to the collaboration. On the other hand, the empirical results also illustrate that all groups mobilised similar sets of epistemic practices regardless of their composition. That is to say, all groups engaged in cycles of planning, monitoring, and evaluation of their work and employed similar ways of coordinating their activities. Differences were found at the level of enactment (e.g. the frequency of work cycles) and in terms of motivation and goal setting, which we discuss in more detail in the following.

The importance of the planning and goal setting stage in iPBL is well documented (e.g. O'Connell et al. 2023). Here we can distinguish personal goals (learners' motivation) and the joint group goals of the project. Both students and professionals began the course and projects with distinct goals. The professionals' goals were predominantly career driven, whereas the students' goals were more interest driven. Notably, these differences in goal settings did not result in friction or issues regarding epistemic practices and collaboration at large. We posit that this is due to three reasons. First, learning, rather than simply passing the course, was the main driver for both professionals and students. Second, while the sources of their motivation differed, the goals can all be considered mastery goals (Pintrich 2000), which should show a greater disposition for regulation of learning as well as collaborative learning (Greisel et al. 2023). Third, while being at different stages in life and having different educational backgrounds, we argue that all participants in the 'narrow' interdisciplinarity groups are likely to share an overarching understanding of engineering and engineering habits of mind (Lucas and Hanson 2014). Similarly, the professionals were seen as and identified more with their industry role, rather than their original university discipline. In future research, however, it will be interesting to study how epistemic practices are negotiated and unfold when students with backgrounds in engineering and social science interact in a course build around an interdisciplinary plus co-learner model.

At the same time, it is interesting that methods and efforts used by different group types to co-construct a project focus were varied. This can be linked to differences in how students and professionals positioned the project, either as a regular 'course' project or an 'industry' project. While students appeared to give little weight to the importance of the project topic, the professional groups based their decisions heavily on industry relevance. But when brought together in the mixed groups, this interdisciplinarity stimulated the co-construction of a joint topic through a process of socially shared regulation, integrating diverse perspectives and knowledge bases. In this way, the interdisciplinary plus approach can be seen as providing a contrast to approaches like challenge-based and project-based courses, where external stakeholders provide a project focus to groups.

Only small variations were found in how groups organised and managed the project through meetings and shared resources. Some differences were seen regarding their regulation of learning, as students took a more active and conscious approach to support their learning, for example through more regular monitoring of their progress, both synchronously and asynchronously. We posit that they engaged in stronger regulation in these areas due to their proximity to full time education, whereas the professionals, despite their claimed focus on learning over passing, were focusing more on completing the work rather than engaging in epistemic practices. Thus, professionals in the co-learner model might need extra support regarding regulation and metacognition to be able to employ effective learning strategies (Cervin-Ellqvist et al. 2021).

All groups engaged in collaborative learning to some extent. One initial concern was that professionals might 'run roughshod' over students in mixed groups, yet this was not the case. On the contrary, we saw an example of a professional deliberately holding back due to unfamiliarity with their group. This adds to a previous finding that unfamiliarity can create conflict (O'Connell et al.

2023). In this study, it resulted in a hesitancy to share knowledge or give feedback in order to avoid conflict. Other professionals adapted to the academic course environment and engaged in the project as 'students'. In the mixed groups, students were seen as providing different, yet equally important, skills and knowledge, with a positive impact on the groups' learning. They also took a role as inquisitors of the professionals' knowledge, which can be an important stimulant for knowledge co-construction (Volet et al. 2017). With this in mind, our study supports previous work showing that high performing groups are those in which all members take on a role of knowledge provider, or engage in seeking and/or providing knowledge at some point in their project (Volet et al. 2017). At the same time, it is important to keep in mind that this study relies on interviews with participants and thus how they report that they have experienced the course. We utilised interviews for data collection after the course was completed, which provided rich data. However, it was reliant upon the interviewees' ability to recall events and express themselves (Creswell and Guetterman 2021). While participants' own reflections around epistemic practices provide very important perspectives, it could be interesting in the future to complement the data collection with ethnographic and observational elements to contrast reflections with seeing enactment of practices in action.

With the limitations in mind, we argue that our findings reveal several significant benefits of this co-learner model, where students and professionals are co-learners. First, students benefit from direct access to industry-specific knowledge and practices that are often not covered in academic textbooks by working together with professionals. Furthermore, students gain direct insight into how professionals conceptualise, approach and organise projects. We argue that this can potentially help students in their later transition from university into work life. Second, professionals recognise and appreciate the academic skills and theoretical knowledge that students contribute to the group. This highlights the value of diverse expertise in interdisciplinary plus teams, and the possibilities that lie in this model. The analysis shows how the social dynamics within mixed groups serve as an important catalyst for effective collaboration, and how communication, trust and group cohesion are central factors for students' and professionals' collaborative learning experiences.

While our study presents a number of benefits of the co-learner model, we also identified several challenges that need to be addressed. First, professionals tend to have demanding work schedules and family responsibilities. From the analysis, it becomes clear that professionals' constraints are defining how groups work together and thus potentially sidestep student needs and desires. If it is not ensured that professionals are provided with the time necessary to take the course, this can result in an unhealthy and unsustainably stressful learning environment for both them and regular students as they are forced to adapt. Further, the pure reliance on online meetings, while convenient, can limit the depth of interaction, interpersonal relation and collaboration, ultimately negating the expected effects on learning though group projects (Wong 2023). With respect to different educational backgrounds, a core challenge of interdisciplinary iPBL is related to the differences in disciplines and backgrounds, where vastly different vocabulary, procedural and content knowledge complicate collaborative learning particularly in the beginning (O'Connell et al. 2023; Piccardo et al. 2022). Therefore, it is key for teachers to provide a common foundation through classroom lectures (Leblanc 2009). Finally, aligning and integrating an interdisciplinarity plus approach within the boundaries of the curriculum and administrative routines can be challenging.

Taking a step back, we look at differences and similarities between the co-learner model described here with two other models described in the literature to involve industrial stakeholders: (1) as clients and (2) as mentors. Regarding the first model, there is a multitude of case studies that show how industry stakeholders can provide projects, challenges or problems that students work on within their course (e.g. Leblanc 2009; Piccardo et al. 2022). The way students and professional interact vary in these approaches, but in general, professionals are positioned as customer or client and students as contractors. Also, projects can be either loosely defined and very open, or more targeted, leaving little room for students. This is a clear difference from the co-learner model described here, where students and professionals work together on more equal terms over a prolonged period of time and develop projects together. While a client's model mimics how different companies or units within a larger company might interact with each other, the co-learner model resembles more how interdisciplinary teams might work together in industry. Considering the administrative framing and logistics, a client model will often be easier to realise, as it does not require professionals actively participating in the project. At the same time, competence development for professionals is limited in the client model.

The second model that can be seen in literature is a mentor model, where industry professionals act as mentors for students (e.g. Sagheb, Walkup, and Smith 2022). In this way, students get to interact with professionals and might be introduced to epistemic practices and knowledge central to industry. However, students and professionals normally do not have a shared project that they work on together, beyond the development of the student. We argue that having professionals within groups that can pass or fail the course shifts their roles so that they become peers with the students, rather than external experts. Their industry expertise then becomes one facet of the group's range of skills and knowledge. This can be seen in the mixed groups where there is an acknowledgement of the different skills and knowledge the professionals and students bring. Furthermore, the collaboration between students and professionals around a shared project directly influences the way they co-regulate their respective learning. When comparing the two models, we can see that the mentor model puts a clear responsibility on the professional and has the students' development in focus, whereas in the co-learner model the personal and professional development of both students and professionals is a consequence of working together.

Overall, we argue that all three models have advantages and disadvantages and fulfil different needs. For educators, it is important to consider what fits in their particular context and what they would like to achieve. From a research perspective, we argue, there is a clear need for both empirical research that studies all three models in more detail, as well as theoretical and conceptual research. From a conceptual point of view, we propose that the theory of transactional distance (Moore 1991) between professionals and students in the three models would be an interesting starting point. Based on our initial work presented here, it appears that the transactional distance decreases from the client over the mentor and to the co-learner model. However, more work is clearly needed to understand the different factors at play in the three models.

5.1. Statements on ethics

All procedures in this study were conducted in accordance with applicable laws and institutional guidelines for research ethics ensuring strict adherence to ethical principles throughout this study. No sensitive data were collected, quotes were used ensuring participant anonymity. Detailed information about the study was provided to participants before beginning the interviews, reassuring them of their right to voluntary participation and withdrawal. All participants provided their informed consent.

Acknowledgements

We would like to express our gratitude to the Chalmers Tracks Initiative for their funding, which made this research possible. We also thank the students and professionals who participated in the interviews. Their willingness to share their experiences and insights significantly contributed to the richness and depth of our findings. Finally, we would like to thank the anonymous reviewers for their constructive feedback and insightful suggestions.

Disclosure statement

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

Funding

This work was supported by Chalmers Tracks Initiative.

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