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ORIGINAL ARTICLE

Looking beyond your own speciality: student and faculty perceptions of collaboration opportunities

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ABSTRACT

This study examines engineering faculty and students' views of collaboration beyond their own field, based on 12 engineering faculty interviews and a survey with 101 graduate-level mechanical engineering students. Our analysis shows that faculty members' views on collaboration exhibit more diversity in terms of crossing disciplinary, functional, organisational, and geographic boundaries, and they view this collaboration as more integrated into engineering work, professional practices, and problem-solving. Students, in turn, report a narrower scope of collaboration, primarily focusing on multidisciplinary collaboration to utilise engineering output. Our study helps inform engineering educators to integrate diverse collaboration more effectively with course design.

Keywords: Collaboration; engineering education; multidisciplinary collaboration.

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INTRODUCTION

Collaboration across diverse knowledge domains is an important driver of innovation (Borrego & Newswander, 2008; Akkerman & Bakker, 2009). As a result, collaboration, especially multidisciplinary collaboration, is emphasised as a criterion for engineering curricula across the globe (ABET, 2022; Engineering Council, 2020; Engineers Australia, 2010). The inclusion of multidisciplinary teamwork in the engineering education curriculum not only helps students to learn collaboration skills but also problem-solving skills by synthesising multiple perspectives (Lattuca et al., 2017).

To foster a collaborative learning environment and for students to learn different skills, it is important for both educators and students themselves to understand the concept of collaboration, different kinds of collaborations and potential collaborators related to engineering work. However, while many sources agree on the importance of collaboration, exactly how engineering faculty members and students themselves perceive collaboration still remains unclear.

To provide a conceptual basis for understanding collaboration and develop higher education engineering curricula for effective collaboration, in the current study we investigate *how engineering faculty members and students perceive opportunities for collaboration beyond their own speciality.*

THEORETICAL BACKGROUND

In the current study, we examine collaboration from a process perspective (Kolfschoten et al., 2010), focusing on the different collaboration forms that faculty members and students consider important in the context of engineering education.

Broadly, we can distinguish between two types of collaboration that take place in engineering education. Firstly, collaboration occurs across disciplines, both between students of different disciplines and between engineering educators from diverse disciplinary backgrounds (Costa et al., 2019; Dringenberg & Purzer, 2018; Borrego & Newswander, 2008). The range of disciplines participating in engineering education is continuously broadening. For example, Borrego and Newswander (2008) and Sochacka et al. (2016) found that social sciences and art educators increasingly engage in engineering education and joint research efforts. Secondly, collaboration occurs between different organisations, such as schools, universities and engineering firms, to support students' learning and the development of key professional competencies (Gillen et al., 2021). These various forms of collaboration manifest in increasingly diverse and complex engineering practices. Therefore, an important task for engineering educators is to design and facilitate opportunities for students to cultivate a range of collaborative capabilities needed in the field.

Indeed, opportunities to collaborate beyond one's own discipline during studies have been connected to several positive outcomes. For example, studies by McNair et al. (2011), Oehlberg et al. (2012), and Sochacka et al. (2016) on cross-disciplinary student and teacher collaboration have shown that students who collaborate across disciplines develop communication skills and gain the ability to value disciplinary diversity for teamwork, innovation and creativity. Cross-organisational collaborations between universities, industry partners, local communities, or other groups of stakeholders, in turn, have led students to report higher self-efficacy (Dunlap, 2005) and develop various competencies, such as project management, leadership, and time management (Borrego et al., 2013).

While these studies offered interesting insights into the benefits of collaboration for students' learning, many studies do also report students experiencing challenges associated with collaboration. For example, engineering students can struggle to recognize and value the contributions of non-technical fields, which lowers students' performance in collaborative work (Richter & Paretti, 2009). Students can also find connecting to an interdisciplinary topic or problem challenging (Macleod & Van der Veen, 2020). These studies offer valuable insights into the benefits and challenges of collaboration. However, they did not examine collaboration from students' points of view. Since students' views of collaboration are closely related to how they collaborate, more research is needed to understand students' perspectives on collaboration and provide guidance for effective collaboration.

However, given that research has demonstrated systematic differences between novices and experts in a range of fields (Ericsson et al., 2006), student perceptions and outcomes of collaboration can also be assumed to differ from those of professional engineers. Indeed, research has shown that while more experienced engineers and designers take an integrated approach to problem-solving, novice and graduate students tend to struggle with problem definition and additional iterations (Ahmed et al., 2003; Cross, 2004; Eteläpelto, 2000; Björklund, 2013). Although studies comparing novice and expert engineers are relatively rare, research on engineering education does suggest collaboration to be valued as both a teaching practice and a key competency by academic experts (Borrego et al., 2010). In particular, engineering educators use interdisciplinary capstone projects and service-learning projects, where students work in teams, facilitated by scaffolding structures, such as milestones on the team's work plan, ideation, and prototype, to support students' team progress (Borrego et al. 2010; Van den Beemt et al., 2020). Further, Alves et al. (2016) found that the reasoning for engineering teachers' use of collaborative project-based learning is to foster students' teamwork and communication skills, in addition to problem-solving skills.

Other extant studies have illuminated collaborative processes through case studies, examining for example teacher collaboration and student collaboration in project-based learning (Sochacka et al., 2016; Dringenberg & Purzer, 2018), as well as collaboration between universities and industry partners (Gillen et al., 2021; Rojas, 2001). While these studies show the importance of collaboration that teachers put on engineering education and provide detailed descriptions of specific kinds of collaborative efforts, less is known about faculty perspective on different collaboration opportunities and respective reasonings.

As motivation to pursue collaboration - or any activity - hinges on the perceived value and expectancy of such efforts bearing fruit (Eccles & Wigfield 2002), a better understanding of both faculty and student perceptions of collaboration can help to predict what types of collaboration they are likely to pursue. This, in turn, can inform what kind of educational support might be needed to develop such practice further. As such, in this paper, we examine both faculty members' and students' perspectives on collaboration opportunities beyond their own speciality.

METHODS AND DATA

The study was conducted in a mechanical engineering degree programme at a Nordic university. Data was collected through semi-structured interviews (Merriam & Tisdell, 2015) with faculty members and an online questionnaire for students (Creswell, 2002), both initiatives originating from teaching development efforts. The data collection was designed and conducted by the second author together with the teaching team of the degree program.

Faculty data collection

First, 12 engineering faculty members from the degree program were interviewed. Interview requests were sent to the faculty representatives of the seven different advanced study topics included within the degree programme, seeking two interviewees from each advanced study topic. Seven professors, three postdoctoral researchers and two doctoral researchers volunteered, representing all seven advanced study topics, such as product development and marine technology. The interviewees' work experience in engineering ranged from a few years to more than 20 years.

Semi-structured interviews were then conducted with the 12 faculty members on the required capabilities in the field of the interviewee. The interviewees were prompted to reflect freely on the core skills, knowledge, and attitudes important from the perspective of the advanced study topic they represented, the role of collaboration and sustainability for engineers within their field. Moreover, they were asked about the collaborators that engineers need in their field. As the intention was to create teaching videos, the interviews were video recorded by a colleague and transcribed verbatim.

Student data collection

The student data from the study comes from a teaching effort aiming to increase student awareness of collaboration opportunities that utilised one of the teaching videos created based on the 12 faculty interviews. Data was collected from a course that was compulsory for all master's level (graduate) degree students of the mechanical engineering program. Most students were in their first year of the two-year degree program. First, all students were shown a 17-minute video on collaboration, consisting of interview snippets (separately approved by the interviewees for sharing) from the 12 faculty interviews that had been sorted into short sections on the usefulness of collaboration spanning functional, disciplinary, geographic, and organisational boundaries. It is important to note that the video may have influenced student responses in the direction of aligning them with the faculty interviewees - a limitation of the current study.

After students watched the video, they were given a short online survey, designed by the teaching team for the course. The current study uses the last question in the survey, an open-ended reflection question "Who do you think would be useful to collaborate with outside of the mechanical engineering program? Explain why." 101 students filled out this question in the survey, with responses typically being a few sentences of text.

Data analysis

We then analysed the faculty interview data and student survey data. First, we inductively analysed the transcripts of faculty members with open coding (Charmaz, 2006) to remain open to all possible insights. Then the codes were categorised thematically (Braun & Clarke, 2006) based on the types of collaborations and their reasoning for different collaborations. Similarly, student data was coded through thematic analysis, first creating separate categories for this data. Then, the categories and the data within the categories in the faculty and student responses were compared with one another in terms of their content and frequency, examining differences and similarities in the type of collaborations reported and the reasoning shared for these.

RESULTS

This section presents different types of collaboration mentioned in the data set: (1) cross-disciplinary and functional collaboration, (2) cross-organisational, and (3) cross-geographical collaboration. Further, we provide insights into the reasoning for each type of collaboration, to understand the different potential impacts these types of collaboration may have on students' learning. Table 1 presents a summary of the most salient categories and themes.

Cross-disciplinary and cross-functional collaboration

Crossing disciplinary boundaries in collaboration was the most common form of collaboration brought up by faculty and students alike, but they emphasised different collaboration purposes. Eight out of 12 faculty members brought up collaboration with others from different disciplines. They focused on how multidisciplinary collaboration facilitates students' learning of problem-solving through an integrated process. For example, a product development professor described the value of art and design disciplines to engineering students for identifying and defining problems which complement and facilitate effective and creative problem-solving:

> *Universities are very good at teaching engineers to become problem-solvers. But what I have learnt from art and design education is that design students learn much more about identifying the problems that are not visible often. So, combining these two approaches is really good and fruitful for successful development.*

Besides integrating disciplinary knowledge and insights for problem-solving, faculty members also discussed how crossing disciplinary boundaries can discover new ways of doing and developing breakthroughs, rather than reinventing the wheel. In particular, two faculty members talked about the need to collaborate between engineering, computer science, arts, business, and material science to develop new technologies and ways of doing and impact the field and society.

Faculty members also discussed how multidisciplinary collaboration improves engineering practices. They mentioned a wide range of disciplines that engineers can work with, including those both within and outside the engineering realm. For example, mechanical engineers can work with collaborators from electrical engineering, computer science, medical science, material, business, art, and design. This type of multidisciplinary collaboration highlights the combined efforts of each disciplinary contribution to engineering practices. As one mechatronics post-doctoral researcher stated:

> *Collaboration is at the heart of mechatronics. [Although] we're taught at the mechanical engineering department with mechanical engineering skills, we need to collaborate as much as possible with autonomous systems and control engineers, electrical engineers, computer scientists, and product development because it's at the heart of making anything tangible.*

Overall, faculty members' perspectives emphasise the impact of multidisciplinary collaboration on problem-solving, developing breakthroughs, as well as improvising existing practices.

Closely tied to multidisciplinary collaboration, half of the faculty members (6 out of 12) emphasised collaboration towards crossing functional boundaries in engineering practice, working with people from other functional units, such as manufacturing, assembling, shipping, supply, sales, accounting, and marketing. For example, another product development professor shared that:

> *When you develop products for people, you need to work with those people, [including] users and people who assemble and manufacture. Also, if you work within an organisation, you also need to work with the sales or marketing team, and those from other departments, depending on your product and your company.*

Similar to faculty responses, students (95 in 101) also emphasised multidisciplinary collaboration and cross-functional collaboration for engineers, although students' perceptions of collaboration opportunities were narrower. Business, management, and economics (42 in 101), electrical engineering (39 in 101), art and design (34 in 101), and computer science (29 in 101) were the four most frequently referenced groups of disciplines for multidisciplinary collaboration, but a range of disciplines, functions and professions were brought up. An additional nine students mentioned opportunities to have collaborators from all disciplines, with limited specifications on how these could then contribute.

Overall, students did not tend to differentiate cross-disciplinary from cross-functional collaboration. They focused more on the need to collaborate with other disciplines from a cross-functional perspective to improve the market performance of produced solutions. Students often talked about disciplines along with functions. For example, one student noted:

> *Mechanical engineers cannot solve any problems by themselves […] For example, in my workplace, we work daily with designers, electrical engineers, software developers, physicists, usability designers, and sales persons... The list is endless.*

Students' responses showed clear interest in collaboration, particularly with various business and design functions or fields. The reasoning for such collaboration typically referred to needing disciplinary expertise from different disciplines. Their responses focus on collaboration as working in parallel with different functions, rather than viewing collaboration as an integrated process to co-construct novel solutions together. For example, students' examples separated commercialising products by marketing as an additional element separate from the technical engineering solutions, such as:

> *The most important one we need to collaborate with is someone who can connect the products and markets so that a company [has] the ability to sell what we design and make our production meaningful. By that standard, one can be someone who studies in the realm of industrial management and investment management.*

However, the level and depth of student reasoning did vary, with some students representing collaboration as an integrated activity for producing better solutions:

> *City bikes contain a lot of mechanical features but there is also a need for software elements and sensors [...]. The effectiveness of city bikes can be monitored by the data of bike-riding and the number of users who are using it, which is more related to data science […] If the bikes are battery-powered, creating charging technology and [including] batteries in a user-friendly way is part of user-centric design. So, we can see that a simple bike involves a lot of fields and disciplines nowadays.*

Cross-organisational collaboration

In addition to crossing disciplinary and functional boundaries, collaboration across organisations was brought up. Five of the faculty members emphasised collaboration with the industry. The importance for students to work with real-world problems and challenges by the industry partners were highlighted to help students learn to define problems, develop possible solutions, and prototype and test for innovation. Besides collaborating with the industry, faculty members also mentioned collaboration with academia, governmental organisations and professional societies to contribute to policy-making and societal and industrial impact, such as academic researchers working with ship classification bodies in the shipping industry. As an arctic technology doctoral researcher said:

> *Universities, companies, and classification societies all have their own agenda, but I think it [...] helps to use this kind of [collaboration] as an asset to [make a bigger impact].*

In contrast, only six out of 101 students referenced opportunities to collaborate with industry partners to help develop professional competencies and build relationships for future employment as well as align with governmental interests. For example, one student said:

> *It is important, career-wise, to collaborate with the industry and see what skills are needed and make connections.*

Besides collaborating with partners, a few other students also mentioned working with governmental bodies for civic responsibility, with different stakeholders to understand different needs for product development, and with other universities and schools to explore more learning opportunities.

Cross-geographical collaboration

Finally, while four faculty members discussed the importance of collaboration crossing geographic boundaries, the only reference made to international collaboration by students was one instance of exchange studies:

> *[...] mechanical engineering should be combined more with [computer science in mechatronics]. For example, more exchange opportunities can be created for [the university's] students to go to other countries such as TUM (Technical University of München).*

Four faculty members, in turn, emphasised the importance of working in an international environment, particularly for specific subfields. For example, a marine technology professor shared that:

> *International collaboration can be very important in the maritime field and has different facets [of international collaboration]. For example, if somebody works for a shipping company, international collaboration is on a daily basis. [They] have to discuss with the international crew.*

The faculty also highlighted the benefits of international student collaboration and research collaboration as ways to exchange knowledge and ideas to tackle problems and develop novel solutions for example, with different perspectives and approaches to sustainability and engineering materials.

Table 1. Types and purposes of collaboration brought up by engineering faculty and students

Type of collaboration	**Faculty interviews**		**Student survey**	
	Salience	**Purpose (when mentioned)**	**Salience**	**Purpose (when mentioned)**
Cross-disciplinary	8/12 mentioned this form of collaboration, (between different engineering disciplines and art, design, computer science, business, material science, medical science, etc.)	Engage in problem-solving in an integrated process with other disciplines; develop new ways of doing and breakthroughs; improve the engineering practices	95/101 (Electrical engineering, business, economics, design, computer science, data science, medical sciences, chemistry, architecture, environmental engineering, etc.)	Improve the market performance of produced solutions with add-on elements from other disciplines/functions
Cross-functional	6/12 mentioned this form of collaboration, (with other functional units, such as manufacturing, assembling, shipping, supply, sales, accounting, marketing, etc.)	Improve engineering practices and their outcomes		
Cross-organisational	5/12 mentioned this form of collaboration, (between academia and industry partners, governmental organisations, professional societies, etc.)	Tackle real-world problems or challenges; create a bigger impact across organisations	6/101 mentioned this form of collaboration (with industry, and governmental bodies)	Develop professional competencies for employment; align with governmental interests.
Cross-geographical	4/12 mentioned this form of collaboration, (with different countries in general)	Exchange knowledge and skills; facilitate international work for certain fields	1/101 mentioned this form of collaboration (through exchange studies).	Have other learning opportunities

DISCUSSION AND CONCLUSIONS

Our study examined the collaboration perceptions of engineering faculty members and graduate students, discovering clear gaps between faculty and student perceptions concerning the diversity and nature of collaboration. Faculty perceptions covered a wider range of collaboration partners and purposes integrated into engineering practice, with most students focused mainly on cross-disciplinary and cross-functional collaboration to commercialise engineering solutions. It is noteworthy that these differences were observed despite students having been exposed to a video sharing the faculty's perceptions immediately prior to sharing their own views on collaboration. As studies have shown that compared to novices, experts tend to possess a more elaborate understanding, knowledge, and experiences of their fields (Cross, 2004; Ericsson et al., 2006; Eteläpelto, 2000), the differences in scope of collaboration views can also be expected. In particular, more experienced engineering and education scholars have been shown to appreciate the interactions and connections between different disciplines and adopt a reciprocal approach to collaboration (Borrego & Newswander, 2008). The current study adds to this by demonstrating how such views can differ between students and experts, with implications for educators on how to scaffold building more expert-like understanding to students.

First, most students seemed to conceptualise cross-disciplinary collaboration as an additional element to add on top of engineering solutions, rather than as an integrated process for problem-solving and developing novel solutions in engineering work. Such a narrow view of collaboration may limit students' ability to recognize and value the contributions of other fields (Richter & Paretti, 2009). Moreover, adopting a segmented way of working, with engineering students being responsible for technical solutions and business and design students being responsible for commercialising and aestheticizing a product, is suboptimal, as non-technical students may not feel valued for their contributions to problem-solving (Macleod & Van der Veen, 2020). The observed lack of integration may stem from a limited understanding of the benefits of interdisciplinary collaboration - for example, Dringenberg and Purzer (2018) found that not all students were aware of the contributions of different viewpoints in the context of first-year engineering students solving ill-structured problems with peers from different engineering fields. These students were unable to tolerate a higher level of ambiguity or appreciate multiple perspectives from their team members. If educators wish to support students in conceptualising collaboration as an integral and integrated part of engineering, the current study suggests that additional efforts are needed to showcase how and why such collaborators might contribute to engineering problem-solving. Indeed, Lattuca et al. (2017) found that when engineering faculty emphasised applying knowledge from non-engineering fields and understanding how cultural, environmental, and economic contexts contribute to integrated engineering problem-solving, students reported higher levels of interdisciplinary competence.

Second, the current study suggests that cross-disciplinary and functional collaboration are more salient opportunities for students than cross-organisational or cross-geographical collaboration, despite all three being featured in the video shown prior to the survey. When cross-organisational collaboration was brought up by students, it was typically from the perspective of developing professional competencies in the context of university-industry collaboration. Indeed, engineering programs and higher education in general increasingly involve industrial partners in capstone projects (Marvri et al., 2021). Such collaboration with industrial partners encourages an increase in students' professional confidence (Dunlap, 2005). In comparison with university-industry collaboration, other organisational collaborators, such as governmental organisations and professional societies, were less mentioned by students than by faculty members. Yet, studies have shown that these can yield similar benefits to industrial collaboration in professional skills and preparation for work (Huff et al., 2016; May & Chubin, 2003). With the added benefits of increasing students' skills for social change (Huff et al., 2016; Litchfield et al., 2016; Cilio et al., 2011), educators could seek more diverse organisational collaborators in project-based learning and utilise service learning (Jacoby, 2003). Similarly, more opportunities for cross-geographical collaboration within one's studies, for example through international project sponsors or student collaborators in project-based courses (e.g., Mikkonen et al., 2018) could be called for, particularly as integrated collaboration in a transnational context remains challenging even for professionals (Subramaniam, 2006; Okhuysen & Eisenhardt, 2002).

Given the current results on student perceptions, we suggest that in order to pave the way for understanding and seeking more integrated and varied purposes for collaboration, engineering teachers need to 1) explicate the benefits of looking beyond one's own speciality to cross disciplinary, geographic, functional, and organisational boundaries, and 2) provide engineering students opportunities to engage in such diverse collaboration activities to build first-hand experiences in how such collaboration can be integrated within engineering work itself. Similar to separate ethics training risking presenting ethics as a discrete or peripheral issue rather than an integrated and central consideration in engineering work (Lönngren, 2021), the current study highlights the need to broaden student perceptions of the connection between engineering and diverse collaborators. Illuminating new collaboration avenues and more integrated opportunities can pave the way for developing more effective boundary-spanning collaboration capabilities to tackle complex problems through systemic innovation.

As we studied a limited number of engineering faculty members and students from a single institution, the results may not be generalizable. Additionally, we employed different formats of prompts and data collection for faculty members and students. Our questions focused on "who" and "collaborators", which may have directed student and faculty attention to persons rather than organisations or fields. Moreover, the faculty interview video and related survey questions may have prompted students to align their responses with the views voiced by the faculty members. As such, more research is needed to validate the salience of the types and purposes of collaboration identified in the current study, and how they interact. Further studies could also link the reasoning of these categories to learning and behavioural outcomes, such as the likelihood of selecting courses from different disciplines, as well as potential antecedents, such as type and amount of experience in the field. With the differences in scope and integration in collaboration perceptions observed in the current study, engineering educators can design collaborative learning activities to explicate the benefits of diverse collaboration and offer opportunities to gain first-hand experience of integrated collaboration with different disciplines, organisations and cultures.

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