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Leadership in Interdisciplinary Engineering Students' Projects: A Faculty Perspective for Supporting the Development of Student Leadership*

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Engineers in the 21st century will be confronted with complex problems that require new competences to engage and collaborate with other disciplines. New engineering competences, such as leadership across interdisciplinary contexts, necessitate important changes in engineering education. To make such changes possible, however, the development of educational leadership is needed, including the creation of organizational structures and the training of staff to support the development of student leadership skills. This leads to the following research question: What kind of leadership can be identified in interdisciplinary student projects from a faculty perspective, and in which way can the development of students' leadership competences be supported? A model is introduced for different leadership concepts at both the faculty and the student levels. The research, comprising three different subcases, is based on data from 12 semi-structured interviews with members of the staff at the Faculty of Engineering and Science and the Technical Faculty for IT and Design at Aalborg University, where student teams work together on solving complex problems. The interview data was transcribed and coded in NVivo using thematic analysis. Findings illustrate the complexity of leadership involved in the student projects, in which teams collaborated with teams, supporting the leadership model introduced in this research, where examples of shared leadership, emergent leadership and rotating leadership were identified at the students' level. Educational leadership – reflected here in curricular structure, learning objectives, and projects as well as facilitation – is important for supporting the development of students' leadership competences.

Keywords: leadership; interdisciplinarity; engineering education; problem-based learning

1. Introduction

Engineers in the 21st century will face complex technological and humanitarian problems that will shape the future of the world [1, p. 63]. In addressing these challenges, all fields will be called for and in this convergence engineering will underpin them all and likely future engineers will become "T-shaped thinkers," as expressed by Cherry Murray, former dean of Harvard School of Engineering and Applied Science [1–3]. In turn, these demands for new engineering competences will eventually require changes in engineering education. The chain from complexity to new engineering competences involves the ability of engineers to apply perspectives and knowledge from fields beyond their own and to work outside the boundaries of their own discipline by drawing from multiple perspectives in interdisciplinary problem-solving [4–6].

Specifically, leadership emerges as an important competence when working in complex interdisciplinary situations and contexts, such as medical crises or sustainability challenges [7–9]. The question is how institutions of engineering education can support students in learning to manage complex problems and work across disciplines. In view of this, facilitating student leadership competences also calls for faculty leadership. In this context, leadership is understood as the competence that includes making changes, creating relationships, influencing and setting directions in different complex situations etc. [10, 11].

For engineering education to adapt, Graham [12, 13] has called for the development of educational leadership and emphasized the need for this to happen. The development of educational leadership includes both training leaders and creating organizational structures that facilitate the impact of leadership [12, 13]. Uljens and Ylimaki add nuance to this by pointing out that while in Europe leadership has been viewed as an administrative and management role, it emerges differently elsewhere; for example, in the US, leadership is paired with a governance perspective. As a result, in European settings, leadership positions have been less developed and prestigious [14].

Although organizational theories form the foundation of leadership research, educational leadership involves a synthesis of organizational and curriculum theories. In this regard, a university's president, deans, heads of departments and schools, and others all have distinct responsibilities and contribute to the direction of education, indicating

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that distributed leadership is at work. A common vision, a shared comprehension of the implementation procedures, and an understanding of how to facilitate these processes are all necessary for bringing about transformation or change across the different levels of leadership.

The literature surrounding engineering education tends to focus on design processes and the factors that must be considered when designing interdisciplinary projects. These factors include vision, educational methodologies, and support structures [4, 15]. However, more clarification is needed to characterize and agree on typologies for interdisciplinary programs and to define learning objectives in order to measure and assess interdisciplinary student competences [16–18].

Most design and curriculum recommendations are oriented toward team and project work to create opportunities for students to learn interdisciplinary collaborative competences, including leadership. Existing literature explores the progression of interdisciplinary projects and what to take into consideration when designing and scaffolding interdisciplinary problems in a way that calls for input from various disciplines [19]. Even among those studies that focus on the design and planning process, however, there is a shortage of studies that include the actor perspective by attending to the roles of (for instance) the leaders, coordinators, and facilitators of the process of transforming an interdisciplinary curriculum, although several Finnish studies investigate the perceptions of interdisciplinarity among engineering faculty, perceptions that vary across disciplines [20–22].

With a focus on a student-centered curriculum, such as a problem- and project-based (PBL) curriculum, the relationships between faculty and students become even more interesting. Students are the owners of the learning process and direct their own learning within a framework created by the faculty and the study regulations. In this learning process, student leadership is both expected and important. For interdisciplinary projects, this becomes even more challenging, as the leadership roles occur on the edge of knowledge for both students and faculty. The balance between faculty and students is an ever-shifting target, both in the planning and design of the framework for student projects and in the facilitation process. Accordingly, leadership, as a concept, shifts between students and faculty, whether it involves supplementing, juxtaposing, or assuming different expressions or forms, depending on the context and depending on the (ever-changing) situation. This leads to the following research question: "How do faculty frame and facilitate leadership in interdisciplinary student projects?"

The research question leads to the next section, which further situates leadership in an educational context.

2. Leadership in an Engineering Educational Context

As stated above, leadership is related to changes, relationships, influence, and setting directions. Numerous studies on leadership behavior and related factors have put forward a variety of results, making comparison a challenge [23]. Rost [24, p. 99] defines 21st-century leadership as "an influence relationship among leaders and their collaborators who intend real changes that reflect their mutual purposes." The key elements in this definition are influence, relationship, real changes, and mutual purposes, indicating a role with far more complexity than one that is merely authoritative and coercive. Indeed, Rost uses the word "collaborator" instead of "follower" in his post-industrial paradigm. The concept of follower is also used in a systematic review by Uhl-Bien, Riggio [25], which highlights the importance of followers or followership as essential in the leadership process.

In addition, Vroom and Jago [26, p. 17] have noted that "leadership depends on the situation." In an educational context, the relevant situations can involve different faculties and departments, with corresponding structural differences at levels ranging from program curriculum to overall education. For example, narrowly defined disciplinary learning objectives or working individually to solve well-defined assignments may not allow for collaboration or leadership. Yet other contexts in which students work together in teams to solve open problems may indeed create opportunities for leadership development. The situational context may also involve different project types, from monodisciplinary projects to broad interdisciplinary projects, or from involving a single student group to involving several student groups [27]. All this variety indicates that leadership differs depending on the problem types and the problem context.

Definitions of interdisciplinarity are numerous [28]; for purposes of this article, the definitions offered by Keestra and Menken [29] concerning multi- and interdisciplinarity are relied on, supplemented by the notion of narrow and broad interdisciplinarity as defined by Klein [30]. Disciplinary and diversity factors create different boundaries [31], and working in interdisciplinary settings involves crossing these boundaries. In such contexts, having the courage to move across boundaries by taking necessary risks is an important competence [31]. Also important when working with boundaries are boundary objects, described by Star and Griemer [32] as objects that are plastic enough to adapt to the local needs and constraints of the different parties employing them, yet robust enough to maintain a common identity across the sites. Thus, boundary objects can be understood as bridging the boundaries between different disciplines.

Researching leadership in engineering educational contexts involves the vertical structure of the organization, namely the faculty and facilitators, or what was described in the introduction as educational leadership, as well as the horizontal structure, or the students and student groups. In this regard, alignment or coordination throughout the whole organization is fundamental, as underscored by Henry Mintzberg: "The structure of an organization can be defined simply as the sum total of the ways in which labor is divided into distinct tasks and then its coordination is achieved among these tasks" [33, p. 2].The shift from working with a single monodisciplinary team to working on projects with more than one team while crossing disciplines adds further dimensions to team-based project work as well as to the organization and to the leadership itself.

The different concepts of leadership used in this article, together with their connections, are illustrated in Fig. 1. In this research, distributed leadership is interpreted as leadership at the faculty level, referred to above as educational leadership, and team leadership is related to student teams. Concepts such as "shared leadership" and "emergent leadership," referring to Morgeson et al. [34], along with the principle of "rotating leadership," are used at the student level. Fig. 1 is explained in further detail.

Leadership in engineering education involves a combination of different leadership concepts at different levels. This research distinguishes between leadership at the faculty level and leadership at the student level.

2.1 Leadership at the Faculty Level

The concept of distributed leadership is used at the faculty level. According to a conceptual review by Bolden [35], the concepts of distributed leadership and shared leadership are similar in origin. In what has been referred to by Harris et al. [36, p. 439] as seminal work, Spillane et al. [37] reignited interest in leadership as practice, a construct that was then reconceptualized by distributed leadership theory. This new conception modeled the interaction between leaders, followers, and their situation as a triangle. Notably, in this model the interactions among individuals are critical; followers constitute one of the three fundamental elements, and there may be multiple leaders, both formal and informal [38]. Distributed leadership is often enacted in school systems or in the field of educational leadership, with a focus on the staff [36, 37, 39–41]. According to Bolden [35], there are different frameworks of distributed leadership, including Gronn's [42] framework, which outlines three main patterns: spontaneous collaboration, intuitive working relations, and institutionalized practice. The latter features "a variety of structural relations and institutionalised arrangements which constitute attempts to regularise distributed action" [42, p. 429]. Here, an interesting connection is identified between the distribution of leadership and program structure. Hence, from a faculty point of view, leadership can be expressed by means of the learn-

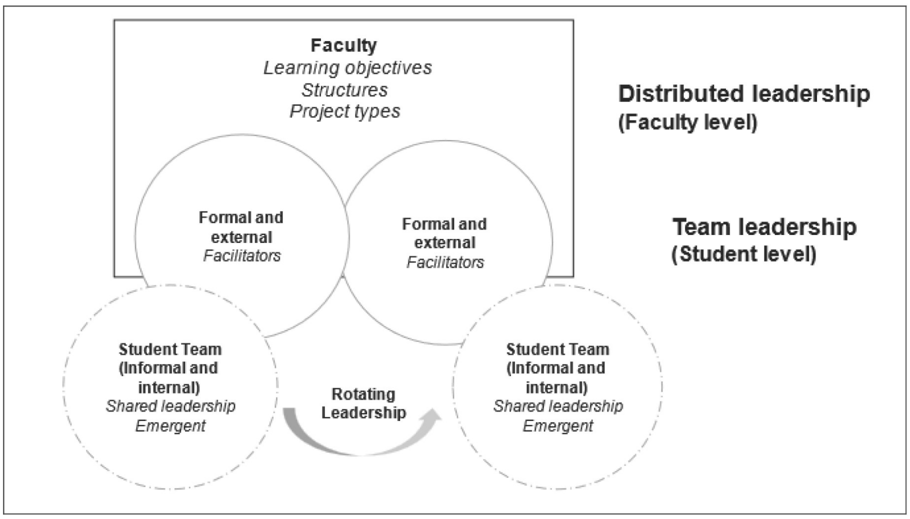

Fig. 1. Different leadership concepts in interdisciplinary engineering student projects, indicating two levels of leadership: the faculty level and the student level, and the importance of facilitators connecting faculty and students.

ing objectives, the structure of the educational program, and the different project types established. The role of the facilitators, representing the faculty, is to guarantee that the students will live up to expectations. The facilitators can have different levels of involvement, and there are different types of facilitation [43]. Within the context of leadership theory, facilitators act as formal elements of leadership, mainly taking on an external role comparable to that of a coach (in the terminology of Morgeson et al. [34]) or a liaison [33].

2.2 Leadership at the Student Level

When the focus shifts to student leadership in contexts where students work in teams, the ''leadership in teams'' aspect is important [44–46]. Zaccaro et al. [47, p. 83] have highlighted the importance of team efficiency as related to leadership:

> ''Team leadership is essential for team effectiveness. The contribution of leadership to effective team performance rests on the extent to which team leaders help members to achieve a synergistic threshold, where collective effort accomplishes more than the sum of individual abilities or efforts.''

In turn, Hanna et al. [48, p. 83] have defined team leadership as ''the study of overall leadership occurring in a team,'' which involves both a lateral dimension (members) and a vertical dimension (formal leadership). In an educational context where students do not act as formal leaders, understanding the sources of leadership in teams becomes crucial. Similarly, Morgeson et al. [34] describe the sources of leadership in teams as having two dimensions: the locus of leadership and the formality of leadership. The locus can be internal or external, and the level of formality can be formal or informal. Leadership that is internal and informal is categorized as shared or emergent leadership [34, pp. 8–9]; these two concepts are elaborated in more detail below. Leadership that is internal and formal can be represented by a team leader or project manager. Leadership that is external and formal is represented by a sponsor, coach, or team advisor, whereas leadership that is external and informal can be represented by a mentor, champion, or executive coordinator [34, p. 9].

As mentioned above, the study of shared leadership originates in earlier work such as Gibb [49]. The traditional view of leadership was more focused on a stable hierarchy and the relationship between leaders and their followers, while in shared leadership the role of the leader shifts from one group member to another depending on the context and the environment. Additionally, with shared leadership there is more focus on the process as a whole and the relations between participants [50]. Definitions vary, with Pearce and Conger [51, p. 1] defining it as ''a dynamic, interactive influence process among individuals in groups for which the objective is to lead one another to the achievement of group or organizational goals or both.'' In turn, Carson et al. [52, p. 1218] define shared leadership as ''an emergent team property that results from the distribution of leadership influence across multiple team members.'' Avolio et al. [53] use the terms ''shared leadership,'' ''distributed leadership,'' and ''collective leadership'' interchangeably; however, in the current research these terms are used with different meanings. Shared leadership can occur in a team with or without a formal leader, and vertical leadership does not preclude lateral shared leadership. Instead, vertical, and lateral leadership are two important sources of team leadership that should operate in tandem [52, 54, 55].

Similar to shared leadership, emergent leadership lacks a precise definition. This has been indicated by Schneier and Goktepe [56], with support from Hanna et al. [48]. To adopt a common conceptualization of emergent leadership, Hanna et al. [48, p. 82] define it ''as the degree to which an individual with no formal status or authority is perceived by one or more team members as exhibiting leaderlike influence.'' Thus, in contrast to shared leadership, emergent leadership can be ascribed to an individual person. Supplementing both these concepts is the concept of rotating leadership, which may be used in connection with both shared and emergent leadership. Rotating leadership can be defined as a process in which the control over decision-making alternates between different partner organizations, using the complementary competences of each to make better-informed decisions [57].

In this study, the leadership concepts described above are illustrated in Fig. 1. Different levels of leadership (shared, emergent, and rotating) are applied in relation to students and are interpreted as leadership among peers, or horizontal leadership typologies. In contrast, distributed leadership is related to the faculty level, or vertical leadership, which has also been referred to as educational leadership.

With this interpretation of the different types of leadership involved, the next section describes the current case study, including the collection and processing of data.

3. Methodology

This research is based on a qualitative approach. Faculty members at the university were interviewed to explore their experiences of the identified types of leadership in relation to different positions and projects where more than one student group was engaged.

3.1 The Aalborg University Case

At Aalborg University (AAU), a special PBL model has been used as a pedagogical approach since 1974 [58]. Students at AAU spend half of their curricular time on projects that last a full semester. Students working in a PBL environment are not limited to developing only their disciplinary competences; rather, participating in project work results in the development of additional competences (PBL competences), including problem-oriented, interpersonal, structural, and meta-cognitive competences [59]. It is common for students to work in stable groups where decision-making and collaboration remain within the monodisciplinary group without the need to coordinate across more diffuse contexts [60]. However, variation theory can be used to enhance student learning as students' experiencing variation in the object of learning offers one way to encourage reflection and transform tacit knowledge into explicit knowledge [61]. To challenge students to work beyond disciplinary student groups, variation in relation to project work initiatives is implemented to introduce students to different project types [27, 31]. Some of these initiatives are the focus in this research paper.

An example of students working in a multidisciplinary situation is a project where the students are divided into groups by discipline and the tasks are assigned; accordingly, that is (say), the mechanics team works with the mechanical component, the electronics team works with the hardware, and the software team writes the code. Examples of teams working with narrow interdisciplinarity include teams of engineers working together on a system project, e.g., building an electronic car together [27, 62, 63]. The distinction between multidisciplinarity and narrow interdisciplinarity can be challenging to draw as the differences can be placed on a continuum. Finally, broad interdisciplinarity occurs when engineers collaborate with disciplines from the humanities or the social sciences, which operate within distinct paradigms of their own [64, 65].

In this research, three different subcases from AAU are examined: two inter-team projects, where multiple teams from the same discipline work together, and a system project, where multiple teams work together in a narrow interdisciplinary setting [27]. Selecting these three different subcases incorporates institutionalized projects with a broad representation of different levels of disciplinarity and faculty involvement in order to address the research question.

Subcase 1 – AAUSAT: An organization of students that develops, builds, and launches satellites, AAUSAT has launched five different satellites since 2001 and is currently working on a sixth [66, 67]. This is an extracurricular student organization operating with support from staff in the Department of Electronic Systems at AAU. As most participants in the organization are students in the Department of Electronic Systems, this case is considered an example of an inter-team project [68, 69].

Subcase 2 – Giraf Project: In 2011, the Giraf project (Graphical Interface Resources for Autistic Folk) was established at the Department of Computer Science. The purpose of the project is to develop an application for autistic children experiencing language challenges. This curricular project involves third-year Software Engineering undergraduates at AAU [70]. This case is also considered an example of an inter-team project.

Subcase 3 – leadENG: In 2021, the Faculty of Engineering and Science at AAU launched a concept called leadENG, in which students from that department work together in a narrow interdisciplinary setting [71]. Research supporting leadENG indicates that students working in these narrow interdisciplinary projects have been able to collaborate and coordinate, especially in systems where a physical boundary object was present [62, 63]. The leadENG projects are all categorized as either inter-team projects or system projects, and the activities are considered curricular; however, the development of a working sample or product is not within the scope of the curriculum. Examples of leadENG projects from 2023 include:

- *Project 1:* In this windmill project, two groups from second-semester Materials and Production and two groups from second-semester Energy collaborated, with all groups located in Aalborg. This was the second generation of the windmill project. In the first year (2022), a total of nine groups participated from across four disciplines: Building and Construction, Materials and Production, Energy, and Engineering Sciences. All of these were second-semester groups.
- *Project 2:* This project to build a prototype of a catamaran and docking station involved the collaboration of two groups from second-semester Energy and one group from fourth-semester Machine Technique. All groups were based in Esbjerg. The project was based on a catamaran from the previous semester.
- *Project 3:* This project involved testing bioactive extracts with the aim of finding potential new bio-based medicines. One student, from eighth-semester Energy, was based in Esbjerg, and one group, from fourth-semester Chemistry, was based in Aalborg. The project has been active for two years, with different student groups participating.

- *Project 4:* In this third-generation electric vehicle project, three groups from Energy – one second-semester group and two fourth-semester groups – worked on what is now a platform. There was also participation by the previous year's groups from Materials and Production, mainly the second-semester groups but also one sixth-semester group.
- *Project 5:* This project involved developing off-grid masts with their own electricity supply for lighting, cameras, and similar purposes. Four groups of second-semester Energy students were involved.

3.2 Data Collection

The qualitative data in this study consists of 12 semi-structured interviews with 10 members of the Faculty of Engineering and Science and three members of the Technical Faculty of IT and Design, for a total of 13 participants. Three of the participants from the Faculty of Engineering and Science were members of administration and management, and the other 10 were facilitators, though some of them also held other positions. The semi-structured interview method was selected to balance researcher control with giving the participants the opportunity to respond freely and add more to the interview, if necessary, thereby assuring that all central topics were addressed. Indeed, semi-structured interviews are "open ended enough to allow interviewees to express their perspectives on a topic or issue and also allow for comparable data that can be compared across respondents" [72, p. 359]. The semi-structured interview was also determined to be the most effective way to fulfill the intention of conducting one interview with each participant in 2023, considering the diversity of leadership in terms of the roles and affiliations of the participants.

One interview, conducted online in June 2022, involved two participants who worked as facilitators in leadENG 2022. The other 11 interviews, involving one participant each, were conducted in May and June 2023. Three of these interviews were conducted online due to the participants' location at AAU Esbjerg. One of the participants from leadENG 2023 in Aalborg had also been interviewed as a representative of leadENG 2022. The duration of the interviews was between 30 and 45 minutes, and all interviews were conducted in Danish. An overview of the interviews is presented in Table 1. The respective interview guides used in 2022 and 2023 can be found in Appendix 1 and Appendix 2, accordingly.

3.3 Data Processing

The interviews were recorded and initially transcribed using an automatic speech recognition system, Whisperer AI. The thematic analysis (TA) method was used for data processing, consisting of six phases as outlined by Braun and Clarke [73]. The first phase, that of familiarization with the data, occurred during the process of finalizing the transcription after using Whisperer AI. After the initial transcription, all files (TSV files = Tab-Separated Values) were transferred to Excel and listened through; minor errors or ambiguities were corrected during this process. Next, the files were converted to PDF format and imported into NVivo.

The second phase of the TA involved generating initial codes. In this first iteration in NVivo, 34 different codes were identified. Examples of codes include Structure, Organization, Coordination,

Table 1. Overview of the semi-structured interviews from 2022 and 2023

Project	Participants	Discipline	Interview Format	Position and Acronym
AAUSAT	1	Electronic Systems	In person	Facilitator, AAUSAT
Giraf Project	1	Computer Science	In person	Facilitator, Giraf
Giraf Project	1	Computer Science	In person	Facilitator, Giraf
leadENG	1	Adm & Management	In person	Adm & Mng, leadENG
leadENG	1	Adm & Management	In person	Adm & Mng, leadENG
leadENG	1	Adm & Management	In person	Adm & Mng, leadENG
leadENG Projects 2022	2	Materials & Production and Energy	Online	Facilitator, leadENG 2022
leadENG Project 1 2023	1	Energy	In person	Facilitator, leadENG 2023
	1	Materials & Production	In person	Facilitator, leadENG 2023
leadENG Project 2 2023	1	Energy	Online (Esbjerg)	Facilitator, leadENG 2023
leadENG Project 3 2023	1	Chemistry	In person	Facilitator, leadENG 2023
	1	Energy	Online (Esbjerg)	Facilitator, leadENG 2023
	1	Energy	Online (Esbjerg)	Facilitator, leadENG 2023
leadENG Project 4 2023	1	Energy	In person	Facilitator, leadENG 2023
leadENG Project 5 2023	1	Energy	In person	Facilitator, leadENG 2023

Facilitators (Collaboration, Leadership, Challenges, etc.) and Students (Coordinating, Leadership, Challenges, etc.). The third phase, which involved searching for themes, took its point of departure from the 34 initial NVivo codes. The first search resulted in three themes: (1) the project's purpose; (2) framing and structuring the project work; and (3) the actors (facilitators, students). The fourth and fifth phases involved reviewing potential themes and defining and naming themes. Here, it is important to note that the coding process is not linear but rather shifts back and forth between the steps as needed.

In the course of finalizing the themes, challenges were identified in studying student leadership without considering the context. The context here is interdisciplinarity and complexity, and because these were student projects, they were influenced by faculty, shaped by the faculty's vision for interdisciplinarity and the faculty's framing of the projects themselves. The different projects in this research took place in different contexts, each of them more or less interdisciplinary and from different disciplines with different traditions and paradigms. These contexts linked software (SW) projects to entities as diverse as customers; engineering systems such as vertical windmills, electric cars, etc.; satellite systems mainly involving electronics engineers; and (finally) biochemical research projects without a system approach but with a goal of finding and extracting new polyphenols or antioxidants to be used in medicine or in relation to sustainability perspectives.

Accordingly, the first theme was identified as the leadership context, incorporating three subthemes: (1) drivers for interdisciplinary projects, (2) organizing principles for interdisciplinary projects, and (3) project boundaries and boundary objects. The second theme was identified as the enactment of leadership, with two subthemes: (1) facilitators' enactment of leadership and (2) students' enactment of leadership.

The last step toward completing the TA involved producing a report, starting with the findings outlined in the following section.

4. Findings

Based on the TA described above, two main themes were identified. These themes are described below in separate subsections. The first theme relates to the leadership context, including the motivation or drivers for interdisciplinary work – that is, the needs to be fulfilled. In turn, this connects to findings regarding how interdisciplinary projects are organized, along with a description of project boundaries and boundary objects. The second theme, leadership enactment, is divided between the enactment of facilitator leadership and the enactment of student leadership.

4.1 Theme 1: The Leadership Context

As noted above, the contexts and drivers for interdisciplinarity were different in each of the selected cases. Although the cases came from different faculties and institutes, with corresponding variation in the way that the learning objectives and projects were organized, the value of engaging students in interdisciplinary projects that involve collaboration with other student groups was agreed upon.

4.1.1 Drivers for Interdisciplinary Projects

In this research, different motivations or drivers have been identified for different interdisciplinary projects. Interdisciplinary projects like AAUSAT, the Giraf Project, and the leadENG projects were established with ongoing societal changes in mind that necessitate the development of new engineering competences. An important mission of these projects is to offer students some experience in interfacing with other disciplines along with the understanding of what it means to collaborate. In turn, this encourages students to look beyond technology and engineering. For example:

> ". . . and keep an eye out for the fact that there are other elements in the solutions than just the technical within the engineering subject you are studying, what you are specializing in." (Adm & Mng, leadENG)

Some programs were motivated by the recognition of a more system-oriented approach as a future need, as in the case of an energy system, which cannot be created within a single discipline because of its complexity:

> "I would say that our field is becoming more and more interdisciplinary. It is very general. Also, from the research side, I think there is a growing realization that you do not create an optimal energy system just based on monodisciplinarity." (Adm & Mng, leadENG)

The need for a wider understanding and a system-oriented approach is recognized as being important for engineering students, and a way to fulfill this need is through interdisciplinary projects. In some disciplines, new expertise and competences from other disciplines will be necessary in the future. For example, big data is already an issue in many programs, moving research and work from the lab to the computer and into data processing.

> "We have just done a lecture in our study plan called data science. Because it's coming. . . it's coming. Lots of big data is coming. . . So, people, today you can say, for one day in the lab, that's probably three days for data processing." (Facilitator, leadENG 2023)

Another driver of interdisciplinarity is employability, as the future will require engineers to be trained with the needs of society in mind as well as the potential for lifelong learning. It will be necessary for engineers to develop T-shaped profiles, combining the attributes of generalists and specialists, so that they can embrace other disciplines while manifesting the specialized competences required by society.

> "And then, of course, we have to make sure that the person we train is someone needed out in society. . . And then that balance between being specialists and generalists. And students prepared for lifelong learning." (Adm & Mng, leadENG)

Aligning students' desired future competences with employability, the findings reveal some of these competences. Simply switching from a laboratory in one location to another laboratory elsewhere can increase learning and experience in a way that aligns with the variations discussed above for improving students' learning. More specifically, desirable competences for students include responding critically and challenging results or solutions, thereby drawing attention to new directions that may offer new solutions.

> "But while the train really rumbles out there, right? Then some students who are critical and daring go in and say, 'hey, that can't be right, or it doesn't work well, right?' We really need those. We don't need those who just say 'well, that's just how it is.' That's what my model says . . . thinking precisely with that slightly larger system perspective. I may well have to build a valve that can solve this. But is it really the valve that can solve it?" (Adm & Mng, leadENG)

Moreover, student leadership and initiative are also considered important competences that must be facilitated:

> "The students must run it themselves. That is, facilitators must buy into it, but the students must also be able to envision it themselves." (Adm & Mng, leadENG)

To sum up, the need for interdisciplinarity is recognized for different reasons, including system thinking, growing complexity, and emerging technologies like big data that create new demands on engineering employability and future engineering competences. Future engineers will require a foundation in these competences in order to think critically, make necessary changes, and take the lead in technical terms.

4.1.2 Organizing Principles for Interdisciplinary Projects

The engagement of different faculties and institutes is reflected in the different organizing principles for the different project initiatives. Some projects are more limited in terms of learning objectives and semester themes, while other projects, like AAUSAT, are extracurricular activities and require less vertical control.

> "And you can also say that this is very fluffy, it is subject to very little control. So, it's like standing and balancing on a knife edge all the time, right? . . . And it's also a bit different from semester projects or normal projects, [where] there is a deadline – we must finish, hand in [the work], and we must take the exam. So, it's completely different." (Facilitator, AAUSAT)

Certainly, working with extracurricular activities creates different possibilities for deadlines, content, and control compared to curricular activities. An extracurricular activity tends to be structured more loosely, and participation in the project depends on student initiative. In contrast to the AAUSAT project, the Giraf project is a curricular project. In some disciplines a standard or framework is defined from the outside; for example, with SW and the Giraf project there are opportunities to work with standards or within a framework like scrum, where some of the roles, concepts, and processes are already defined, such as those of scrum master, product owner, sprint planning meeting, and backlog. Such opportunities exist for all disciplines, of course, but they are more traditionally connected with SW development, a fact that illustrates the different approaches characteristic of different disciplines. Along these lines, using the scrum framework supports and inspires the students to lead the projects:

> "But what we have mostly done in the last few years is that there is a group that goes in and acts as the scrum master, and another group that acts as the product owner. And then it's the people from [those groups] who then run the rest of the process and share the responsibility internally [in the group]. But it differs from year to year, because sometimes the students have tried to make it so that they just have a scrum committee, where a member from each group acted as a scrum master. . ." (Facilitator, Giraf)

Another organizing concept from SW used in the Giraf project is full-stack teams, which involves SW teams covering the development of an application from the front end (i.e., the graphical user interface) to the back end (i.e., the server level). The use of this approach indicates that different competences, or even disciplines in a narrow sense, are valuable in a SW project like Giraf.

For the leadENG projects, a more central form of control is necessary. The projects coexist with the different curricula from the institutes and programs that are involved, necessitating a central person who manages the projects and ensures that all requirements are effectively met. With this incorporation of different departments and curricula, a framework defined at the management level is necessary to better support the process. Throughout the project, from the system level to the individual group level, there can be conflicts in relation to dependencies, etc. Thus, finding the right balance between the benefits and the risks of depending on others is important.

> "The three coordinators who have been involved . . . have pretty much agreed that these leadENG projects are cool. This means that they can reach further, reach deeper with larger communities, lifting together. We also agree that every project must be able to be completed successfully, independently of the others. . . . So, it has been a balancing act." (Facilitator, leadENG 2023)

The importance of developing a project within the framework of the curricula, including the right participants and making it possible for students to take leadership, is also highlighted in the leadENG context:

> "The goal has been somewhat described from the start of this project description. How it makes sense that these groups work together. . . They can navigate [the process] themselves, and they can also change the [goal or] target themselves without the others suffering." (Facilitator, leadENG 2023)

In this regard, finding a balance at the level of dependencies is crucial. At certain points, the different groups must be independent of each other, while at other points, mutual dependence is the key to interdisciplinary collaboration.

> "There must be some deliverables between groups; they must be dependent on each other in some way. Because otherwise they have nothing to collaborate with. But of course, it is also a challenge that the deliverables or dependence must not be so strong that they cannot be filled project-wise by something that goes wrong." (Facilitator, leadENG 2023)

The balance between the dependencies in the projects is important to consider as there can be a drive from students to decouple the elements in the projects. To maintain collaboration between student groups the facilitator must maintain the relationships and dependencies.

> "[Among students,] there is a big drive to get it decoupled in different projects so that they are not dependent on each other. Because in the end it is their own exam that they are worried about, and not the others'. So, they are very quick to set a dividing line. . . and then [they] try to make interfaces as small as possible." (Facilitator, leadENG 2023)

Finding a balance is key, as the learning objectives from the disciplines weigh the most heavily. Indeed, the challenge is to coordinate projects that are suitable across different disciplines.

In the design of interdisciplinary projects, distinctive considerations must be applied to the organizing principles. These include whether the activity is curricular or extracurricular, how closely the learning objectives are defined, and the level of dependency between the teams involved. Traditionally, SW development uses the scrum framework to support the engineering students, but considering different frameworks may support other students in interdisciplinary projects. Finally, finding the right projects or the right boundary objects and defining the right boundaries between the participating engineering students are crucial for successful interdisciplinary project work.

4.1.3 Boundaries and Boundary Objects

Different boundaries and boundary objects can be identified in the cases outlined above, from disciplinary boundaries to interdisciplinary boundaries and boundaries involving time, such as boundaries between semesters. In turn, boundary objects range over a spectrum of sizes and life cycles, from physical boundary objects like a platform to be built, to starting from scratch every semester, to SW implementations or more processual relations.

For the AAUSAT project, the boundary object is always something sent into space that takes more than a semester to finalize. Since this is an extracurricular activity with a longer timeframe to completion, boundaries here include the semesters and different student volunteers. As the timeframe spans multiple semesters and participation is voluntary, students who participate at the start of the project may not necessarily be part of finalizing the project; thus, some students may inherit the work of previous students.

Similarly, the Giraf project spans multiple semesters. In this case, the idea of using "old" code to enhance the learning process is highlighted as bringing a realistic element into student learning as there are advantages to not starting from scratch every time. This introduces relay projects, projects that span multiple semesters. In the Giraf project, the boundary object is the application developed for real end-users:

> ". . . We get a few more realistic elements in, if it is old code that you have to take over. . . I kind of have an idea that one of the aspects we could take from there and get better at around organization is this thing about doing relay projects. In other words, one often does not start from scratch." (Facilitator, Giraf)

The leadENG projects are more diverse than either the AAUSAT or the Giraf projects, as several projects are active at the same time. For leadENG, the boundary objects are an electric car, a windmill, a catamaran with docking station, grid masts, and the process of testing bioactive extracts. A common product can be the target to work toward, creating ownership, motivation, and commitment because it makes sense to the students.

> "Very much in effect here. . . [is the fact] that it is motivating to have a common product that you work toward. It is motivating and engaging, and it is also binding. You know that there are other groups that are also driven in this way. And then you have some schedules, some deadlines, which you have a commitment to live up to." (Facilitator, leadENG 2022)

Some projects have been active for more than one semester, allowing for the development of a platform for future use or the creation of an experience for improvement; examples include the electric car and the process of testing bioactive extracts. This creates a boundary in relation to the timeframe of the semesters. Thus, an electric car platform has been developed for leadENG, providing an opportunity for new points of departure in the future.

> "In other words, I would say that the projects have matured. And we also had a small hypothesis about that from the start. . . [thinking] that we should try to get some platforms that you could work from, so that you don't have to constantly formulate new projects. And the car project is, after all, a good example of where it succeeds. You have started with something very, very simple. Then there are other student groups who have built on these concepts and the knowledge gained from the previous leadENG projects. Now I want to develop autonomous controls." (Adm & Mng, leadENG)

Working with a platform as a starting point may create other challenges in relation to interdisciplinarity, especially when a longer time horizon is involved. With a platform, it may be easier to initiate a transition into regular student projects, where facilitators and students can choose optimizing different parts or components. When a platform is developed, the need for collaboration may decrease, if focus is shifting to optimizing the platform or modules instead of working on a new development. This is an example of a declining boundary object, and it indicates the importance of considering the life cycle of the project from the start or considering the involvement of new disciplines at different phases of the project.

> "And I think that you have to think about it from the start. What could phase 1, 2, 3, 4, 5 be? How many phases can there be? Something that can give a suitable level of disciplinarity in the institutes and then also give meaning to the project." (Facilitator, leadENG 2023)

The outcome of a leadENG project is not always a product. For example, with the research concerning testing bioactive extracts, a method of analysis binds one team together in one place while another team researches the characteristics and possible uses of a bioactive extract in medicine or pharmaceuticals.

The different learning objectives for leadENG projects, as discussed above, relate to the different disciplines and semesters involved and constitute important boundaries. The interview participants agreed that disciplinarity must be significant and the projects must fit with the learning objectives associated with the semesters involved in the project timelines. This is the first priority, and then the goal is to determine the most suitable projects.

As indicated in this research, there are many considerations regarding boundaries and boundary objects. These include defining the projects in relation to their life cycle as well as being able to continue interdisciplinary work and not just optimize part of a product from a disciplinary standpoint. Moreover, the learning objectives and the different disciplines involved need to match factors like semester structures and the span of the projects across semesters.

4.2 Theme 2: Leadership Enactment

As indicated above, leadership is situational. These findings indicate that establishing the ground for students' leadership development has multiple aspects. The need for interdisciplinary student leadership must be recognized, and supporting organizational principles must align with the right projects in order to create space for leadership to emerge. For leadership to thrive, there must be space for change and initiative. Beyond these contextual conditions, various actors play a role in interdisciplinary engineering student projects. For example, facilitators play an important role in the disciplinary student projects, and this role becomes more complex when the projects involve different groups and disciplines. The engagement of several disciplines influences the role of the facilitators, who must engage with disciplines outside their own. Moreover, the enactment of leadership involves the students themselves as they collaborate across different disciplinary boundaries on completing a project.

4.2.1 Facilitators' Enactment of Leadership

Working with projects like the cases in this study includes the role of the facilitators in relation to leadership. In projects that involve different disciplines, groups, and departments, alignment and coordination between these different institutions become important.

> "A leadENG facilitator should ideally be able to work together with a facilitator from another institute. And that requires other competences. . . because you can't just see it from your own perspective and expertise. In fact, you must also master the [skill] of seeing it in an interdisciplinary way, so that you can scaffold and support your group. So, it [involves] a different set of competences." (Adm & Mng, leadENG)

Working with interdisciplinary projects involves coordination across disciplines, unlike working with traditional monodisciplinary projects. For the latter, facilitators act within their own disciplines, which simplifies the process of making decisions and giving advice. In contrast, facilitators of interdisciplinary projects must sometimes consult other disciplinary facilitators concerning the subject matter, whether to supplement their limited knowledge or as support for decision-making.

For monodisciplinary projects, the participating student groups are easily identified, but for interdisciplinary projects, decisions concerning who should participate are important to the ability to succeed. It is important for the student projects both to be realizable in technical terms and to fit within the scope of the students' competences and learning objectives for the current semester. As a result, the facilitators of interdisciplinary projects have an important role in balancing the learning objectives related to the specific semester and outlining the framework for the interdisciplinarity, ensuring that the semester's learning objectives can be fulfilled and are within the scope of the project(s). The formal responsibility for this is placed on the facilitators:

> "It is still largely the facilitators who say: this is the goal, these are the means, we will get there. So, a lot of management comes formally from the facilitators, of course. We define the project. It must be that way." (Facilitator, leadENG 2023)

From the start of the project, an important task to be fulfilled by the facilitators is establishing a connection between the groups involved and ensuring that communication among the participants is in place. When a project, whether disciplinary or interdisciplinary, involves several groups, an important part of initiating communication is assisting the students in setting common goals and creating common ground:

> ". . . they must be able to communicate, they must be able to understand each other [and] reach for something concrete that is not just talk. They should be able to set some common goals and say, 'this is what we are trying to do.'" (Facilitator, leadENG 2023)

Facilitators also have the important task of encouraging motivation for and commitment to student projects, establishing the right balance of ownership and competition to enable the projects' successful completion:

> "The most important thing is [to encourage] commitment among the students, [to ensure] that they are really passionate about [the project.]. And there will also be a bit of, I wouldn't say competition, but at least there will be perhaps some love of honor when it has to run. . ." (Facilitator, leadENG 2023)

During the interviews, examples emerged of students' using their summer vacations to finish the project as the curricular project turned into an extracurricular event. There are different approaches to encouraging ownership and prompting students to take on leadership and responsibility for their work, and the initial phase of the project appears to be important for that.

> "As facilitators, we have encouraged [the students] to have these meetings [about specifications]. And plan. . . at this meeting. . . 'you are the one in charge, and you are the one who decides what the agenda is. We would like to help create the framework, but it is up to you to run it. . . . It is much better that you manage it yourself.'" (Facilitator, leadENG 2023)

Handing over the responsibility and ownership for the project can be enacted in a very clear way, without the risk of misunderstandings, as illustrated in this situation from the Giraf project:

> "I say, 'now this is not my project anymore. Now it's your project.' And then I tell them that we will take a 10-minute break because I have talked for half an hour or something and presented a topic. And I tell [the students] that after [the break], it's [their] project. Just as we normally in the project group [one group project] will own the project. Then it's no longer mine. I am a consultant." (Facilitator, Giraf)

Occasionally, if the expectations are not entirely clear, this can lead to misunderstandings regarding who takes the lead on the project as students may expect the facilitators to make the leadership decisions. However, among the interviewees there was general agreement that the facilitator is not situated within the group but rather on the sidelines. Being on the sidelines from the start help the facilitators to ensure that the students get a good start, and the facilitators can be ready to support the students, if help is needed. By monitoring the student groups, facilitators can situate their scaffolding based on the students' actions.

> "It also depends on the group [of students that you get]. Sometimes I have had a group that always knew what to do. They had a plan. . . you get a feeling after a few meetings." (Facilitator leadENG 2023)

As facilitators monitor student groups, it is important for them to consider the differences between the different groups and find the right balance in offering the appropriate amount of leadership to each group. Ultimately, the boundary between the facilitator's leadership role and that of the students depends on the students' attitude; it can be versatile and situation dependent.

> ". . . [if a] group is well-functioning and can aim for these goals, and they take a direction that makes sense, then they have a very free framework. . . . Then you [as the facilitator] can sit back a little more. [You can] give them some good input, some inspiration, motivate them in what they are doing. [You can] try to address some of the questions that you can consider, [rather] than demanding results." (Facilitator, leadENG 2023)

In summary, the facilitators' enactment of leadership in relation to students working in different interdisciplinary groups includes working across boundaries to frame the projects and helping students to balance the disciplinary learning objectives. Since different goals may coexist in an interdisciplinary setting or a setting involving more groups, creating common ground is vital. Another important role for the facilitators is to foster motivation, responsibility, and ownership among the students by allowing them to take leadership to the extent possible within the framework, while carefully monitoring the students' learning processes in relation to the goals of each semester.

4.2.2 Faculty Planning of Students' Enactment of Leadership

Creating space for student leadership is necessary to encourage student enactment of leadership as an emerging engineering competence. There must be space for students to make decisions, set directions, and initiate changes. As discussed in the previous section, facilitators play an important role in scaffolding the space for student leadership. Specifically, curricular projects involve balancing this space with the learning objectives, and in extracurricular projects facilitators must guide the students in the right direction. At the same time, working with different disciplines and with different groups creates new situations for the process of learning leadership. In this way, leadership development is supported by interdisciplinarity as students must explain the issue at hand to students from other disciplines, acting as experts in their own discipline:

> "I think it's just that when you meet the other . . . partner, then you're in a slightly superior situation because you have to tell them about your subject; you're the expert. And vice versa in the other situation. [Both partners] must show each other around, both must educate, and also facilitate, help, and take care [of the others], which is also a large part of a leader's role." (Facilitator, leadENG 2023)

As students take charge of their projects in an interdisciplinary setting that involves collaborating with other groups, this creates new challenges and enhances their learning process. Ultimately, it is the students' role to formulate a problem in a context, develop a coherent project, and do so in collaboration with other disciplines, and this can be challenging. Yet having an influence on the overall project creates space for student decision-making and leadership:

> "They saw my four bids for some projects, and then they said: 'We don't want them. We have another idea that we would like to try to sell you now.' " (Facilitator, Giraf)

It is important to adjust expectations regarding who takes the lead in different situations, and it is still the facilitator's responsibility to continuously monitor the process, as mentioned above, while at a certain point they must let the students take the lead themselves:

> "I spent some of last year as a kind of an experiment on what happens if I don't really go in and do something active, letting [the students] coordinate themselves. And there I can say that they built a new generation." (Facilitator, leadENG 2023)

In this regard, expectations can reach beyond facilitation, e.g., when students from different semesters are working across the semester boundary. This can create an opportunity and a challenge concerning leadership as students from more advanced semesters may naturally act as leaders due to their greater knowledge and experience. The situation may come as a surprise for these students but may constitute an opportunity for them to enact leadership. With students from different semesters working in collaboration, expectations must be addressed before entering the relationship, but such a collaboration can be a good idea as it can be another way to create space for leadership with considerable potential. It should be noted that the informal leadership role of the more advanced students is distinct from the formal leadership role, which still belongs to the facilitators.

These findings outline the situational factors that can encourage students to take charge of and responsibility for their projects, thus developing leadership competence. In the interview extracts above, the facilitators mention several examples of students' taking the lead in the projects. For instance, the AAUSAT project is student-led. However, there is an important difference between this project and the other projects in this research as AAUSAT is an extracurricular project without learning objectives to consider. With AAUSAT, the students are volunteers and are free to leave the project if they want to, and when they do so, leadership is redistributed among the remaining students:

> "This means that the [students] we have left are the ones who take leadership on themselves and those who can collaborate and make things work down in the Centre, so I don't take on too much." (Facilitator, AAUSAT)

In the Giraf case, where the facilitator clearly switches from a leadership to a consultant role, leadership has always been transferred to the students, and someone has always taken the lead:

> "It hasn't happened yet, in all the 11–12 years we have

run [the project], that no one has stepped up and taken [the leadership role]. So, some natural leaders are nurtured. Sometimes [the leaders] are two or three people from the same group. And sometimes [it is] a single leader. . ." (Facilitator, Giraf)

In leadENG, with many groups collaborating, the student-organized coordination meetings offered an opportunity to observe and monitor students as they took responsibility for the project:

"I have participated in a few leadENG meetings, that is, coordination meetings . . . where you just sit and listen. The [students] themselves find out how to set an agenda, to discuss things, to create a schedule and things like that. I think that is instructive, and they have figured it out themselves." (Facilitator, leadENG 2022)

Furthermore, leadership can be connected either to a single student or, sometimes, to a group of students, and sometimes the leadership role shifts. Different leadership constellations can be observed in the cases outlined in this study. There are examples of individuals who step into the leadership role in what could be characterized as emergent leadership, as one person takes on the leadership role for the entire project. In other cases, leadership is formed by small groups, with a more shared leadership approach. This shared approach is sometimes initiated by an individual student who suggests that their group take the lead on behalf of the whole group.

"It is usually a group, but you can sometimes see that there is a person who gets his group to agree that they take that [leadership] role. After all, it requires someone to stand up and say: 'What should we do? I think this or that.' And [so they] control the process." (Facilitator, Giraf)

Sometimes the lead shifts between groups, depending on the need for decisions. For example, a Machine group took over control after an Energy group because their part of the project required decisions on dimensioning:

"In the first two meetings, the Energy group [second semester] took on the initiative, management, and coordination, including with respect to procurement in this budget task here. But then in the last meeting, where we had to lock some of these things down, it was the Machine group [fourth semester] that took over control of the dimensioning." (Facilitator, leadENG 2023)

This case of rotating leadership in connection with the different disciplinarities involved is an example of what happens in the boundary work between different disciplines with different learning objectives. Shared leadership can emerge not only within a single group but also between different disciplinary groups, and rotating leadership shifts between the groups doing boundary work according to the need for clarification and decisions. Different distributions of leadership roles can be identified by observing the different groups; sometimes a single person leads within the technical component in addition to managing the project tasks, while in another group the leading and managing tasks are divided or shared.

In a discussion of leadership, the role of followership is equally important. In this regard, it is important to note that not all students want or need to be involved directly in leadership:

"There are also some who sit. . . who are students, after all, and want to say, 'I am not that interested in the project we are doing. I just want to do something cool and be happy with these people.' This is fine, as there are probably slightly different types." (Facilitator, Giraf)

Without followership, there is no leadership, and an awareness of followership is just as important as an awareness of leadership. The interviewees in this study agreed that it can be challenging to generalize across students and student groups as they differ and pursue their studies in different contexts. Leadership conditions vary from individual to individual, from group to group, and from year to year, in addition to depending on the disciplines involved.

Ultimately, working across different boundaries like disciplines, groups, and semesters offers new opportunities for leadership development among students. In creating space for student leadership, facilitators hand over responsibility while continuing to monitor the process and balance the disciplinary learning objectives. Emergent leadership, shared leadership, rotating leadership, and even sharing or rotating leadership between groups have been identified in the cases presented in this study. Finally, the concept of followership must be recognized as an important dimension of the leadership process.

5. Discussion

This study reveals the complexity of students' inter-team and system projects, highlighting the interdependence of the different actors involved in developing leadership as an emerging competence among engineering students. This process includes the faculty's role in organizing and structuring, the facilitators' role in supporting student development within the framework, and finally the roles of the students themselves as they work toward project completion. In these complex organizations, there is no "one size fits all" model. With reference to Fig. 1, all the different leadership concepts are in action; the process is dynamic and depends on the specific situation.

The findings show that interdisciplinarity is important for multiple reasons, including the rise of system thinking, growing complexity, and emerging technologies like big data. New demands for future engineering competences such as critical thinking, initiating change, and taking the lead in technical terms influence the current curricula. In the design of interdisciplinary projects, different curricular perspectives must be applied to the organizing principles, and the level of dependency between the different teams involved is important to define. Frameworks such as scrum, known from SW development, may be used to support students involved in interdisciplinary projects. For successful interdisciplinary project work, it is crucial to find the right projects or boundary objects and define the right boundaries between the participating engineering teams.

In addition, the projects need to match the different disciplines or semesters involved and their respective learning objectives. The duration of the projects must be considered as some may be completed after one semester, but others may continue for several semesters, as in relay projects. For the latter, it is necessary to define the project's life cycle or different project phases and to determine whether the focus will be on new development based on a project platform, on optimization, or both. All these considerations are important in what was initially defined as educational leadership. If one of the goals is to develop student competences like critical thinking, the ability to initiate change, and the capacity to take on leadership roles, the institutional logics in the various departments involved must support this. With narrow disciplinary learning objectives, it is difficult to develop such competences; space must be made for leadership. At the same time, the disciplinary foundation is important and needs to be secured.

This points to a key role in the interdisciplinary journey: that of the facilitators. Facilitators have a versatile leadership function in a PBL context, acting as the link between faculty and student teams in a disciplinary context. Working on interdisciplinary projects with teams of teams adds to the complexity of the facilitator role, as facilitators' enactment of leadership may involve several groups while working across boundaries (disciplinary, interdisciplinary, semester, etc.) to frame the projects. Moreover, it is the facilitators' responsibility to help students balance disciplinary learning objectives with other goals that coexist in an interdisciplinary setting or a setting with more groups involved, creating common ground and mutual adjustment. This is comparable to a liaison role [33]. Facilitators also foster motivation, responsibility, and ownership among the students and encourage them to take on leadership roles within the framework of the project while carefully monitoring their learning process in relation to the semester goals. Together, facilitators and faculty comprise the formal, educational leadership that supports the development of leadership competences among students.

As the informal leadership participants, students are offered new opportunities when they participate in projects that cross disciplinary, group, or semester boundaries, which create room for their leadership development. The above cases illustrate how further space for student leadership is created by facilitators' handing over responsibility to their students while monitoring the process and balancing the disciplinary learning objectives. As a result, examples of student leadership can be identified throughout this study. Emergent leadership, shared leadership, rotating leadership, and even sharing or rotating leadership between groups can be identified. At the same time, the important role of followership in the leadership process can be recognized. The dynamic is clear: as leadership shifts between formal and informal and across horizontal lines, former leaders may become followers and vice versa. Indeed, "formal and informal structures are intertwined and often indistinguishable" [33, p. 9]. Indeed, other research indicates the fluid nature of leadership in what is characterized as multidisciplinary teams [74].

Supporting students' development of the different leadership concepts identified in this research, the active learning environment of PBL involving different project types in close collaboration with the facilitators is a very useable approach. This is also supported by Aquere et al. [75] referring to PBL and the importance of coordination, in this case relating to project management processes. PBL as a mean of developing students' leadership competences is also agreed by Sonnenberg-Klein and Coyle [76, p. 9] adding very importantly that the cultivating of students leadership not solely can rely on extracurricular activities. Creating space and making leadership explicit to students in an active-learning environment, supported by courses might be the way to develop the necessary students' leadership competences. Maybe support in terms of a leadership model is needed [77].

To relate this study to a future context and further research, a concept that resonates with the cases described in this research is that of Multiteam Systems (MTS). MTS was defined by Mathieu et al. [78, p. 290] as:

> "two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals. MTS boundaries are defined by virtue of the fact that all teams within the system, while pursuing different proximal goals, share at least one common distal goal."

An important part of the effectiveness of MTS is related to coordination and leadership, both within teams and between teams as framed by the defined project boundaries [78]. According to Mathieu et al. [78, p. 322], MTS leadership is most necessary for problems where multiple solutions exist or for solutions implemented in complex circumstances.

MTS and the inter-team and system projects in this study share many similarities, and future research in this area would benefit from using the theoretical understanding behind MTS to improve engineering education as this understanding promises to add depth to the organization of complex interdisciplinary student projects. In turn, this may influence educational leadership and the creation of new opportunities for engineering students to succeed, further developing student leadership and other emerging competences needed by the engineers of the future.

The potential limitations on this study may be related to the size of the study and the specific context where the research has been conducted, as it may not be possible to transfer the knowledge to other contexts and as pointed out in Handley et al. [79] there is no convergence of consensus concerning engineering leadership and there may be disciplinary differences to take into account.

6. Conclusion

As explored in this study, leadership development among engineering students is context- and situation-dependent. Sometimes the students lead themselves, while in other situations more facilitator scaffolding is required, illustrating how formal and informal leadership must be balanced depending on current needs. Clear expectations concerning the distribution of leadership between facilitators and students help to promote student leadership, and a clear relation between leadership and followership is crucial as both roles are needed. Thus, the space for student leadership must be co-created and nurtured to integrate the development of leadership competences into engineering education with leadership as an explicit competence to be developed.

Given these findings, this study highlights the complexity associated with leadership in large interdisciplinary student projects and student projects that involve teams of teams. Inherent in such contexts are systemic complexities that include different groups, semesters, institutions, and disciplines in addition to various learning objectives, project types, and product life cycles. Accordingly, all the leadership concepts introduced in the theoretical section can be identified in this study, with distributed, shared, emergent, and rotating leadership in evidence alongside the concept of followership. Thus, understanding and describing leadership in relation to larger student projects requires the full spectrum of leadership concepts.

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Appendix 1. Guide for the semi-structured interviews in 2023

Introductory Questions
What is your background? What is your position? What different kinds of problem/project types have you been working with in relation to the students? *(Simple → Complex)* What was the purpose of these projects?
Project Types
What study projects have you worked on where several study groups were involved? What disciplines have the students come from? What has determined the composition of the groups? Did they choose it themselves or was it done by others? Is there a difference between the leadENG project you are a supervisor for this year and projects you supervised in previous years? (Expand if necessary.) How did the coordination take place in the overall project and between the groups? What has been your role in these multi-study group projects?
Leadership (Formal ↔ Informal – External ↔ Internal)
Can you name some important leadership qualities? (Facilitators – students – others) How would you characterize leadership in relation to the study projects with several groups you have participated in? Who has exercised leadership in those study projects? How has it been distributed? How would you characterize your own role in the study projects where there have been several study groups? Are there any leadership tasks in projects with multiple study groups that are different from the tasks in projects with only one study group? Is there a difference in the leadership role if different disciplines are involved? Is there a difference in the leadership role if external partners are involved? What leadership challenges have you experienced in these study projects?
Different Goals
Who has defined the goals of the overall project? How are leadership and uniting goals related to common goals? Have you experienced conflicts between the individual team goals and the overall system goals? (Solution) Have you experienced conflicts between learning goals and participating in a larger system? (Solution)
Final Remarks
What has been your most important role in these multi-group student projects? Any final remarks?

Appendix 2. Guide for the semi-structured interview in 2022

Introductory Question
What is your background?
Experiences
How have you experienced the leadENG projects this year? Are there any differences between leadENG this year and last year? What has worked well, and what has worked less well? What experience do you have of the students participating in leadENG this year? (How have you experienced the students talking about and experiencing the process?) How have you experienced being a supervisor for a group that has participated in leadENG? Have you experienced a difference in being a semester supervisor and being a supervisor for a group that also works with leadENG projects? What are your experiences with student outcomes after their participation in leadENG? Is there a difference compared to students who have not participated? Have you experienced differences between the various leadENG projects?
Leadership
How much have you been involved in the work the students have done in relation to the leadENG projects? What proportions of the leadENG projects have been taken up respectively with supervisor meetings and exams? How has responsibility been distributed in the project? Have the students taken responsibility for their own projects and the overall project? How have you experienced the management of the leadENG projects? Who has led the overall projects?
Different Goals
Has there been a connection between the group's issues and goals and leadENG's issues and goals?
Final Remarks
What has been your most important role in the multi-group study projects? Any final remarks?

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