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The CO-SPACE Model: Developing an Analytical Framework for Interdisciplinary Student Collaboration

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Abstract

Grasping the complex field of interdisciplinary collaboration in education has been an ongoing topic of interest in both research and teaching practice. Research highlights several elements such as common goals (boundary objects), interdependency, shared mental models, trust, mutual respect, reflexivity, epistemological transparency, awareness of discipline specific routine behaviors, quality of communication, stability and construction of the team. However, research also agrees that interdisciplinary collaboration is complex and that educational attempts to create these settings often fail in practice. Further, the literature heavily focuses either on the actors' involvement and actions within the interdisciplinary context or on the structural elements of said context, giving less attention to the interplay and interconnectedness between actors and structures in interdisciplinary collaboration. By introducing the concept of relational space, interdisciplinary collaboration is provided with a holistic approach to understanding the complex system students encounter when participating in an interdisciplinary collaborative space. Through a reconceptualization of Löw's sociological model within education, this article expands the literature with an integrated perspective of interdisciplinary collaboration in education including both structural and interpersonal elements. By analytically bringing together actors and institutions, the Interdisciplinary Collaborative Space in Education (CO-SPACE) framework enables an examination of interdisciplinary collaboration as a relational participation space. This approach highlights interdisciplinary collaboration as a multidimensional system, including multiple interacting layers and aspects. Institutional structures, social goods and people all influence the "prefixed" space, affecting how students interpret and place themselves and others within the established participation space, in turn determining access possibilities and how power unfolds. The analysis particularly brings attention to the emergence of sub-spaces, temporal dynamics, and knowledge-related access asymmetries.

Keywords: interdisciplinarity; collaboration; relational space; education; problem- and project-based learning; PBL

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1. Introduction

Interdisciplinarity has been acknowledged as a key factor for achieving better sustainable solutions for the future (Feng et al., 2025; Bertel et al., 2022; Von Wehrden et al., 2019; Braßler & Block, 2017). Future engineering graduates should possess transversal skills such as critical thinking, networking, team leadership and cross-disciplinary teamwork skills to expand their integration of new knowledge, their ability to embrace complexities, and to boost their motivation through interdisciplinary learning (Everett, 2016; Lautamäki &

Saarikoski, 2020; Jensen et al., 2019). In response to this, universities around the world are trying to incorporate more interdisciplinary courses and projects into curricula, establishing and supporting the development of interdisciplinary competences throughout education. However, in practice interdisciplinary collaboration faces several conflicts, often leading to failure (Braßler & Block, 2017; Bertel et al., 2022).

1.1. The Complex Nature of Interdisciplinarity

To foster fruitful student team collaboration, a common goal requiring coordinating activities is needed. According to the literature, the team needs a sense of shared purpose to be able to act in a unified way. There needs to be a result-driven structure, an effective communication system, clear roles, methods for handling performance and giving feedback and a practice for making fact-based judgements (Klein, 2005). Kolmos et al. (2025) frame single-team collaboration as a team of members having ownership, engagement, mutual accountability, open-ended discussions and collective work products. While interdisciplinary teams share similarities with this, they operate in a much more complex environment (Klein, 2005; Kolmos et al., 2025).

The literature has continuously highlighted the importance of a common "boundary object" or "boundary negotiating artifact" as the structuring element of interdisciplinarity (Von Wehrden et al., 2019; Klaassen, 2018; H. W. Routhe et al., 2021; Beddoes, 2020). Establishing fruitful boundary work must bridge both social and cognitive dynamics of knowledge production into a shared research culture. Elements often highlighted as essential are: stability and construction of the team, robust platforms, collaborative readiness, interdependence, quality of communication, mutual learning, reflexivity, evaluation, negotiation and appreciation of differences and limitations, approaches and methods for bridging the involved disciplines, building trust as well as common understanding (Klein, 2014; Lattuca et al., 2012; National Academy of Sciences et al., 2005; Klausen, 2014; Beddoes, 2020; Frickel et al., 2017). Braßler and Block (2017) also stress the importance of spending enough time and gaining professional moderation when wanting to establish meaningful interdisciplinary collaboration.

However, as stated earlier, the complex nature of interdisciplinarity holds several challenges inhibiting the success of intended goals and learning outcomes in education. When students enter an interdisciplinary setting a number of challenges are highlighted in the literature. On the one hand, students are faced with challenges such as communication, disagreements on common goals, underestimation of teamwork, different expectations, disciplinary and methodological differences, preconceptions of one another, variation in task and activities, team size, distribution of roles, time management, insecurity and misunderstandings leading to difficulties in finding common ground and building trust and respect among one another (Feng et al., 2025; Kolmos et al., 2025; Winther et al., 2020; Jensen et al., 2019; Braßler & Block, 2017; Frickel et al., 2017; Klein, 2005; Stock & Burton, 2011). This is further complicated by what are referred to as high-consensus disciplines (Borrego & Newswander, 2008), i.e., sciences with well-defined standards for validated truth, versus low-consensus disciplines, where science contributions are seen as part of a broader conversation rather than claiming one absolute truth.

On the other hand, organizational matters also play a role in the success of interdisciplinary collaboration in education. For instance, rigid, disciplinary, organizational borders may impair valuable and innovative interactions (Norton et al., 2023; Van Den Beemt et al., 2020). Supervisor and teacher support also poses a challenge, as teachers rarely possess the necessary knowledge and competences to support students in interdisciplinary contexts (Van Den Beemt et al., 2020; Jensen et al., 2019). Frickel et al. (2017) also highlight the direct influence that interdisciplinary complexity has on physical establishments such as

the construction of a shared building for interdisciplinary researchers, where tacit, non-transferred physical elements as specific as the placement of tables inhibited researchers' use of such a building as their old disciplinary offices felt more convenient and safe. Thus, interdisciplinarity should be viewed as more than just an intellectual challenge but just as much something affecting and being inhibited by elements such as building architecture, research practice, organizational structures and funding (Frickel et al., 2017).

1.2. Space: A New Way of Grasping Interdisciplinary Collaboration in Education

Different explanations, practices and methods have been highlighted as crucial for future educational settings to establish, plan for and manage meaningful interdisciplinary collaboration (Von Wehrden et al., 2019; Lattuca et al., 2012; Klein, 2005). As of late, researchers within interdisciplinary learning have expanded their scope of research, emphasizing the importance of moving beyond the narrowly focused interactionist perspectives and instead viewing interdisciplinarity as a complex system of both individual components and relationships (Brungs et al., 2021; Frickel et al., 2017). Thus, narrowing the focus to language barriers, differences in research practices or project management skills, etc. reduces the real complexity of interdisciplinary collaboration and neglects the influence and power of, e.g., institutional conditions. Interdisciplinary collaboration does not happen in a "social vacuum" but within institutional structures affecting and forming the possibilities of establishing fruitful collaborative spaces across disciplines (Brungs et al., 2021; Frickel et al., 2017).

Within interdisciplinarity research, the term "space" increasingly emerges, though with slightly different meanings. Frickel et al. (2017) describes elements such as "collaborative space", "social dynamics of the space", "epistemic space", "social space" and "lab space", trying to grasp the complex sphere that interdisciplinarity unfolds within, while Brungs et al. (2021) emphasize the importance of creating "safe" spaces for fruitful collaboration. Klaassen (2018) mentions "a third space" of collaboration, i.e., a space in which co-construction of learning may happen. Beddoes (2020) talks about spaces as important for shared knowledge production, while Kolmos et al. (2025) use the term "problem-solution space" to describe the space present for problem solving among students. Finally, Barry et al. (2008) use terms such as "space of differences", "microsocial space of interdisciplinary practice", "ontological space" and "encultured space". They all add a spatial dimension to the interdisciplinary complexity though without further defining the term.

Fritz and Binder (2018) state, in their work on transdisciplinarity and inclusion of societal actors outside of research, that participation should be seen as more than isolated events. Instead, participation should be viewed as a "relational space" of both situated actions and surrounding institutionalized factors, entangled with wider science–society relations. They state the importance of looking at all factors influencing and forming participation in knowledge production, not delimiting focus to single elements, analyzing and approaching only parts of the whole system (Fritz & Binder, 2018).

In this article we argue that interdisciplinary collaboration in education could benefit from the same holistic approach for analyzing the factors of participation and collaboration, creating a better overview of the elements that interplay and affect one another in interdisciplinary educational settings. In particular, this article tries to conceptualize Martina Löw's sociological concept of relational space (Löw, 2016) into an educational context, answering the following research question:

> *How can Löw's concept of relational space inspire the analysis of interdisciplinary collaboration and does the concept bring new aspects to the field?*

The research question will be exemplified through an empirical case of interdisciplinary student collaboration using a dataset collected in 2021. In previous work, we

reported how narrow interdisciplinary projects like leadENG can contribute to the development of interdisciplinary competences for first-year engineering students (H. Routhe et al., 2022). The paper reported on several aspects from the perspective of students, including the importance of the problem in interdisciplinary projects as well as the importance of facilitation and support from supervisors, of compromises and dependencies, and of interdisciplinary project management and teamwork, as well as the experienced gains of participating in a narrow interdisciplinary project setting. Finally, alignment of learning objectives was highlighted. However, while this paper provides an overview of aspects students count as influential for their interdisciplinary work, it provides little insight into the complex interrelations between these elements and how they determine the interdisciplinary collaborative space and its access possibilities. Therefore, in this paper we further elaborate on these findings and aim to demonstrate how a conceptualization of Löw's theory on relational space contributes an additional, spatial layer to our existing understanding using data to exemplify how this framework can be used to unfold interdisciplinary collaboration in education further.

2. Theory

2.1. Relational Space as a Concept

The concept "space" is used interchangeably and with direct meanings. It is inherited with opposite and manifolded meanings and has throughout history undergone huge turns in how to see and approach its meaning (Löw, 2016). Up until the twentieth century, space was widely perceived as something pre-existing and fixed, i.e., as a container, a surface or a territory, with bodies (people and/or artifacts) in it. Space simply existed independently of people's actions, also referred to as an *absolute* space (Harvey, 2006).

As an opposite idea to this static impression of the spatial dimension the idea of a more relativistic "turn of space" arose (Conley, 2012). Here, space, by contrast, is viewed as something *created* by the bodies encountered in the specific space. The understanding of space then becomes an ever-changing object formed, and reformed, by the actions within it, creating a complex setting of interrelations and connectedness (Löw, 2016; Conley, 2012). Harvey calls these spaces either *relative* or *relational*, perceived as either something that is relatively understood in regard to elements, such as time or money, or relationally, as space simply cannot be created without the presence and influence of people (Harvey, 2006).

Massey (2012) supports this idea of space being relational, arguing that: *"If time unfolds as change, then space unfolds as interaction. In that sense space is the social dimension"* (Massey, 2012). She sees space as a multiplicity, as something that is constantly produced and reproduced, as a heterogeneity of practices and processes that, instead of seeing things as an already interconnected whole, sees things as an ongoing product of interconnections between certain elements (Massey, 2012). Harvey acknowledges that when space is viewed as relational, measurements become problematic. Thus, he states that no space is either absolute, relative or relational but can be one or more of them simultaneously or in line depending on the circumstances (Harvey, 2006).

In her book "*The Sociology of Space*" (2016), Martina Löw tries to address this gap by introducing an action-theoretical model for measuring relational space. Through an overall view of space as a relational construction of both people and things, she argues that, by analyzing both structures, bodies and processes, it becomes possible to grasp the vast and complex field of relational space. Only when space is grasped and considered in its full context is it possible to analyze the variations of the relational arrangements and social orders present in a certain space. Things (both artifacts and people) are dependent on their relational placement. The way in which we place certain things, other people, or even ourselves in a space determines not only how these are perceived in a certain position but

also alters the effects they will have in, and on, the space in which they are placed. This not only affects the people involved but also what might be achieved in the specific space (Löw, 2016).

2.2. Relational Space in Education

Using Löw's aspects of relational space as the analytical framework for analyzing a collaborative process such as interdisciplinarity in education forces us to take students, or other participants, viewpoints and experiences, into account. Doing so creates a starting point for looking at which elements actually form and determine the foundation for interactions of participation in interdisciplinary collaborative processes. Using this action-theoretical model provides us with a better understanding of why interdisciplinary collaboration in education sometimes falls short, ending up with differentiated outcomes often far from intended learning outcomes and desired timely development (Fritz & Binder, 2018; Braßler & Block, 2017).

Löw argues that space should be perceived as an interplay between *living beings* and *social goods*. The structuring of these two is relational, creating a foundation for relational arrangements as something that constitutes both action and structures (Löw, 2016). Importantly, this arrangement should be understood as both order and ordering (structures and processes). Fritz and Binder combine Löw's six elements of institutions, people, social goods, synthesis, spacing and access possibilities and list them in a table emphasizing the importance of looking at both structures, bodies, processes and access possibilities (Fritz & Binder, 2018), however, to a lesser degree emphasizing the interconnectedness between them. Figure 1 is an attempt to present the relation between Löw's highlighted elements and how they affect one another.

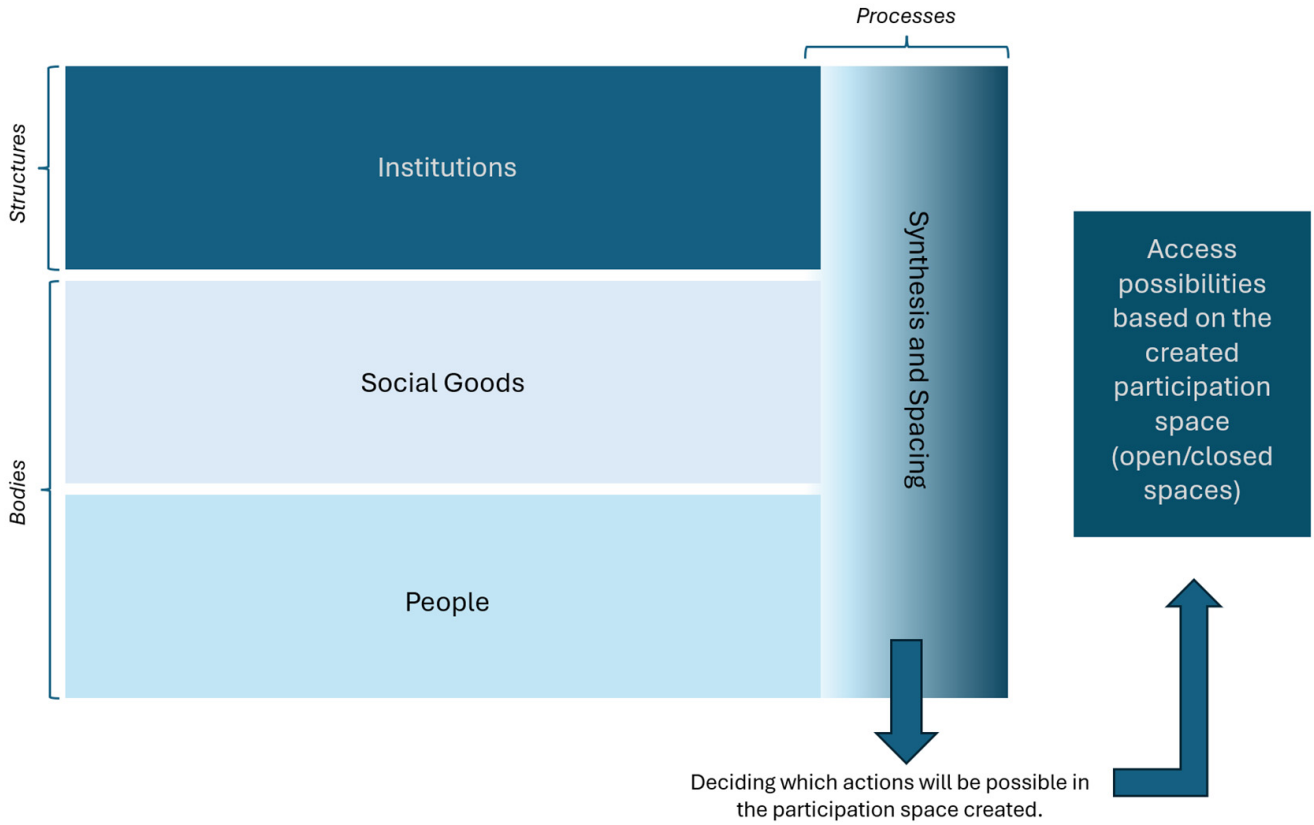

Figure 1. The correlation between the elements of relational space as presented by Löw (2016).

Institutions are presented by Löw as the structuring element, whereas *social goods* and *people* are perceived as the bodies of the system. Placing them in parallel illustrates that these three blocks are the forming elements of an interdisciplinary system (see Figure 1). Through people's (pre)understandings, beliefs and memories (*synthesis*), certain processes and positioning will take place (*spacing*), determining which and to what degree different actions will be performed and managed. Thus, as illustrated in Figure 1, the processes of synthesis and spacing glue together the three blocks into a joint participation space of processes and action, more or less accessible for others to engage in.

The following sections elaborate on the elements visualized above: institutions, social goods, people, synthesis and spacing and access possibilities and how these might be understood within an interdisciplinary educational setting.

2.2.1. Institutions

As mentioned, relational arrangement is a combination of both actions and structures. Structures inherent order and are rules and resources bound to institutions. This is particularly prominent in an educational context, as educational systems build upon several sustaining institutional structures. Löw stresses that structures and action cannot be separated. Structures make actions possible but are at the same time bound to action. Structures may retain their structuring form for a certain time but without (continuous) action they lose their structuring force. Space is therefore not only something that is shaped by humans but also shaping and guiding humans, creating stability and guidelines essential for humans to co-exist in, for instance, educational systems. In practice, we talk about *institutionalized* spaces, i.e., spaces fixed with rules and resources of importance that we continuously agree upon.

Consider a classroom: the room upholds different rules and norms such as the teacher being the one with the authority and power to determine the agenda. This is enforced through the way classrooms are furnished, with tables and chairs facing the teacher. Institutional rules are the sanctioning of action and seen as the constitution of sense. In the classroom this may be the rule of raising your hand when wanting to contribute or staying silent when the teacher is speaking. Institutional resources are, on the other hand, a medium through which power is upheld or exercised, as in the case with the placement of furniture. Here, there is a distinction between allocative resources (material resources) and authoritative resources (people). In this context, rules cannot be conceptualized without attachment or reference to one or more resources to uphold the rule. Further, structures should be seen as more than just economic, political and legal. According to Löw, spatial and temporal structures should also be considered in a relational arrangement (Löw, 2016; Fritz & Binder, 2018). Scott (1999) presents three pillars of institutions: *regulative* (formal, explicit policies, rules and regulations such as learning objectives, rules for use of certain equipment or overall regulations and policies for entering a university), *normative* (social structures such as social obligations, shared values and expectations such as specific expectations of workload or appearance) and *cognitive* (beliefs, symbolic systems and shared understandings like cultural models, language and use of symbols such as ontological and epistemological beliefs, specific terms in language and symbols used differently in different disciplines), showing the variety of ways in which institutions may affect and regulate practice over time.

2.2.2. Social Goods

In the example with the classroom, one might immediately think of chalk boards, monitors/projectors, computers, paper, pencils, tables and chairs placed in a certain characteristic way. This specific imagination of space emerges from both present and past material

and symbolic action. Viewing relational space from this point of view is looking at the space's social goods. Social goods can be both material and symbolic. In education, material goods could be chairs, tables, boards, use of laboratories or certain equipment. Symbolic goods are representation of the values and regulations in the room, e.g., school uniforms or slogans, or specific methods tied to subjects and disciplines such as the characteristic use of maps presented by land surveyors. Both material and symbolic goods are co-existing, often present simultaneously, though one may come more directly to the fore than the other. In Fiske (1990) on communication studies, the concept of *symbols* is used to describe objects that in one way or another are able to represent something else. He uses the example of a Rolls-Royce being the symbol of wealth and/or power, describing how objects may form metaphors or metonymy, stating or communicating something. In an educational context one example could be how students dress, symbolizing their attachment to a specific discipline like, for instance, those in biology wearing outdoor clothing or those in law study wearing suits. Importantly, Löw rejects the thought of social goods as something merely placed by people. Rather, social goods influence people as well, making social goods equally important in the constitution of space (Löw, 2016; Fritz & Binder, 2018).

2.2.3. People

While space is often perceived as material elements being placed and moved among people, Löw argues that people just as well place themselves and others in the space. In the classroom, the teacher is both creating and forming the space but also restrained by certain ways of doing, norms and regulations determined by the space itself. Through this, people are not only creating spaces but also integrated into the elements of the space itself. They both obtain and vacate spaces over time. The teacher influences the space with, for instance, their body language, gestures and language, and even though he or she is more actively engaged in the space they are still being more or less affected by the surroundings of learning outcomes, formal and informal norms and values at the school, power relations present in the space, etc.

2.2.4. Synthesis and Spacing

As mentioned, the creation of spaces cannot be analyzed without looking at action. Löw claims that relational spaces always are a result of processes, or what she refers to as "ordering". By dividing processes into spacing and synthesis, she claims that space will first be constituted when social goods and people are directed by the positioning of markings (e.g., street signs) or placed spatially in a certain way. This process is what she refers to as spacing. It is the process of deploying, establishing or positioning oneself or others in a space. This placing of social goods and/or people is actively produced and reproduced through the process of synthesis. Synthesis is required for action to take place within spaces. It is the process of integrating people and social goods into places through imagination, memory and perception. In the constitution of space, one cannot exist without the other, and operation of both synthesis and spacing will always be present as action is processual. Synthesis and spacing are what create action in a space and by that also how, for instance, students interact and counteract in regard to the more or less pre-established educational setting they engage in (Löw, 2016; Fritz & Binder, 2018).

2.2.5. Access Possibilities

When a space is established, we talk about a participation space and, as with any other matter of participation, there will always be certain possibilities of access. Access possibility is about having access to the social goods present in a certain space. Two students in a laboratory may seem equally justified to use the equipment present, but only one has the license required from the institution to use it, and thus the other will have less opportunity

to contribute. Similarly, when some team members know each other from the past, it might leave less space to move forward, placing newcomers in a more difficult position into the collaborative space. Power is imminent in all interactions and based on the amount of power one possesses, inhibiting or strengthening possibilities for action within the space (Löw, 2016; Fritz & Binder, 2018).

2.3. Conceptualizing Relational Space as a Way of Looking at Interdisciplinary Collaboration in Education

As space is the process of both order and ordering, space becomes an analysis of both structures and interrelations. Thus, a scientific analysis of relational space in interdisciplinary collaboration in education must include both an analysis of its institutions, social goods and people on the one hand and how these are perceived and positioned through synthesis and spacing on the other. This way, we can gain insight into which elements are influencing whether a particular collaborative space opens up or closes in regard to participants.

Elaborating on Figure 1, Figure 2 models the elements in a way that visualizes the complexity of how interdisciplinary educational spaces unfold. Figure 2 shows, with the participants' gaze into the space, how space is relative, differing depending on how and by whom it is perceived. This is further complicated by the fact that students with different disciplinary backgrounds might have additional differentiated understandings and beliefs based on their different established ontological and epistemological approaches to science and scientific practice. An analysis of interdisciplinary collaborative spaces should therefore be a process of both determining the spatial possibilities served by institutions, people and social goods and the possibilities, boundaries and formations negotiated and perceived differently by the participants.

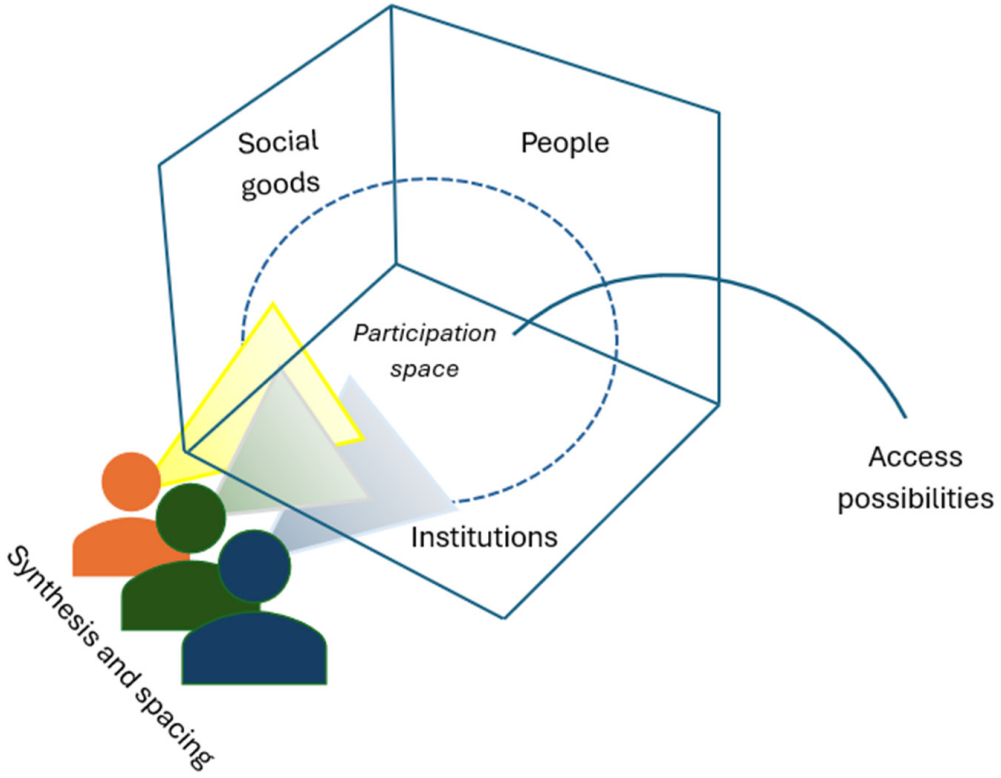

Figure 2. Visualization of the interplay between the 6 elements presented by Löw (2016) and adapted to an interdisciplinary educational context. The dashed lines visualize the participation space, and the colored figures represent participants or viewers of the specific space in focus.

3. Methods

To test the feasibility of this conceptualization of Löw's action-theoretical model in interdisciplinary collaboration in education, an empirical case study from an interdisciplinary course, leadENG, at Aalborg University is included.

3.1. Context

Aalborg University has, since its beginning in 1974, been introducing students to a problem- and project-based approach (PBL) as the main learning pedagogy. Every semester, students are required to hand in a project report counting for approximately 15–20 European Credit Transfer System (ECTS) points, accounting for about half of their time each semester. Students normally form teams of 4–6 people collaborating on a shared task of formulating, investigating, and analyzing a specific problem of interest. In most cases, the problem is a real-world problem, often specified, validated, and/or developed in collaboration with external stakeholders. First-year students are introduced to the PBL approach, giving students tools and methods for how collaborating and managing their projects during their time at the university (De Graaff & Kolmos, 2007; Askehave et al., 2015).

For years, all ten semesters have focused on discipline-specific team collaboration. Problems are formulated and tailored to fit into specific programs, giving students a direct focus regarding learning objectives for each semester. Increasingly, AAU, along with other universities, are exploring ways to provide students with the possibility to engage in interdisciplinary learning and collaboration, through extra-curricular activities and events as well as interdisciplinary projects, such as megaprojects (Winther et al., 2020). However, research into such initiatives concludes that students' PBL competences become tacit with time and that their articulation of, reflection on and ability to transfer these PBL competences from a discipline-specific context to other interdisciplinary contexts is limited (H. Routhe et al., 2022; Kolmos et al., 2024). To mitigate this problem, AAU have launched different initiatives, including variation and progression in the sort of project formations students experience during their time at the university. Different interdisciplinary projects have been initiated in the last few years, including leadENG.

3.2. Case

LeadENG is an interdisciplinary project course at AAU, that launched in the spring of 2021. With the aim of supporting engineering students' success in the introduction to cross-disciplinary collaboration, the leadENG initiative minimizes the complexity of real-world megaprojects by narrowing the collaborative complexity to participants in and across the Faculty of Engineering and Science, inviting only high-consensus disciplines to participate. LeadENG was initiated as a 2nd-semester student project with different interdisciplinary project proposals, including the manufacturing of a car ("*A Small Electrical Vehicle*"). Each participating discipline-specific semester group works on a separate part of the car, forming a project to fit the semester's learning objectives. The interdisciplinary collaboration occurs in the building of the car. Here, several groups from different engineering or technical backgrounds can work together on constructing and aligning the individual parts of the car into a moving unit. In this study, we include data from one such interdisciplinary collaboration (one space) elaborating on how institutions, social goods, and people are experienced, unfolding students' synthesis and spacing, and mapping out how the participation space creates possibilities for participation in an interdisciplinary collaboration among high-consensus disciplines that, on paper, might have better possibilities for achieving fruitful collaboration. In this case, it is important to note that the students had to engage in fully online collaboration throughout part of their project period due to COVID-19.

3.3. Data

Data consists of semi-structured focus group interviews. A total of 15 students participated in 3 focus group interviews, see Table 1.

Table 1. Overview of data collected at the first round of the leadENG initiative.

Year	Semester	Study Program	Project	Sub Project	Data Collection	Number of Students
leadENG						
21	2. Semester	Materials and Production	Small Electrical vehicle I	Rare wheel suspension system and drive shaft	Semi structured focus group interviews Observations for background information Access to collaborative Teams channel	5 students
21	2. Semester	Materials and Production		Brake system		5 students
21	2. Semester	Energy		Propulsion design		5 students

All participating students have worked on a discipline-specific project at the university prior to their participation in the leadENG project, giving an opportunity to further reflect on their experiences in comparison.

Interviews were collected at the end of the semester and lasted approximately 30–60 min each (see interview guide in Appendix A). In addition, observations were made and used as background information, partly for understanding the structure of the initiative, but also for gaining a deeper understanding of some of the answers given by the respondents regarding structures and specific events throughout their participation. During the process of gathering data, access was also granted to the shared Teams channels providing the opportunity to follow progress and online, written interaction and sharing among the participating groups.

3.4. Data Analysis

Data was transcribed and coded in NVivo and Word using Löw's 6 elements of space (institutions, social goods, people, spacing, synthesis and access possibilities). This served as a starting point for analyzing the data, with room for other elements occurring in the datasets as well, using an abductive approach. To further analyze the complexity and relational aspects of the different elements in the analysis, mapping was used to support the spatial understanding and formation of the collaborative space unfolding. This mapping visualizes not only each element but also the complexity of interrelations between them, providing a deeper understanding of the complex space students encounter when engaging in and managing an interdisciplinary collaborative space such as leadENG. Adding the mapping, the influence of the aspects such as timing and knowledge became clear. While the analysis provides insights into each of the elements themselves as well as the interconnections between them, the map itself is a static picture of the subjects and elements students remember from their time in the leadENG project. In reality, the system has developed over time, having bits and pieces present at different times, with lesser or greater influence on different phases in the process.

All three datasets were coded separately before moving on to the analysis, to not draw premature conclusions or seek similarities, potentially missing out on other relevant aspects. Data was analyzed iteratively, moving back and forth between creating the maps and analyzing the 6 elements. Each of the 6 elements was given a color on a sticky note. As the data was analyzed and placed into each of the categories, a specific-colored sticky note connected to one of the categories was prepared to use in the mapping. After the

first round of analysis the mapping was sketched out on a large piece of paper, making it possible to move the sticky notes around, forming and reforming the mapping as the analysis unfolded. Doing so provided an opportunity to view the space from different angles. Aspects and connections became clearer when outlining the map, restructuring or adding to the existing notes of the categories that had helped form the map in the first place, see Figure 3.

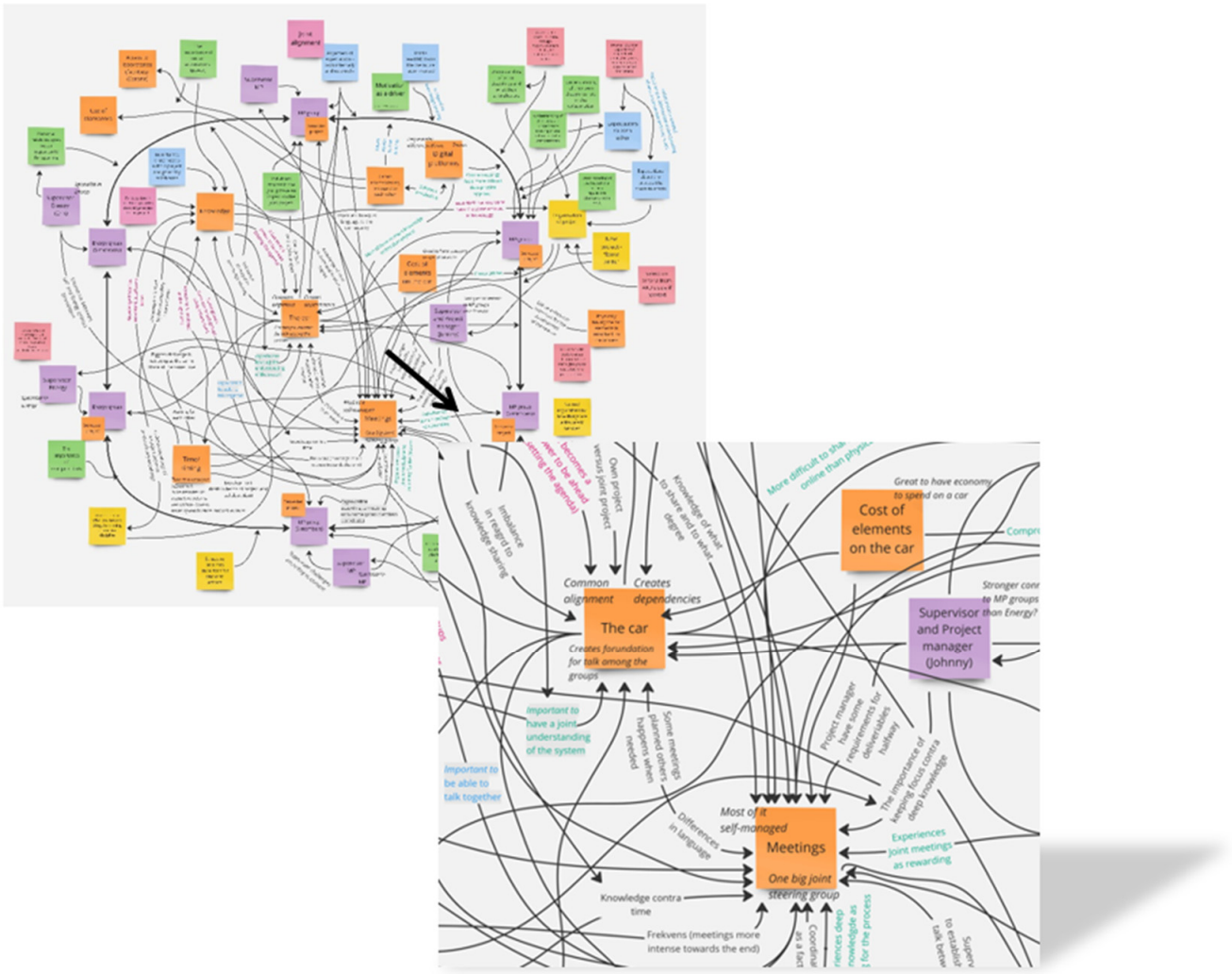

Figure 3. Mapping of leadENG project.

The analysis concluded with both an overview of elements connected to each of the categories and an overall map highlighting elements of importance from the data both visually and in more depth.

4. Results

The following analysis aims to exemplify the usability of the concept of relational space in understanding interdisciplinary collaboration in education. The section is structured around three blocks: (i) institutional structures, (ii) people, (iii) social goods, using Löw's concepts and considerations as the guiding lens. Under each of the sections, synthesis, spacing and access possibilities are included, combining institutional, physical elements with understandings and interpretations from the students. Further elaboration on access possibilities in connection with the established participation space will be elaborated in Section 5.

4.1. Analyzing leadENG Through the Lens of Relational Space

4.1.1. Institutional Structures

As the aim of the interdisciplinary initiative leadENG is to create a collaborative space for engineering students, the institutional structures draw the first lines of the participation space in the aim itself. Only engineering students from 2nd semester were initially allowed to join the project in 2021. Further, students highlight in the interviews that both their learning objectives and semester coordinators created further boundaries for whom and to what degree students could participate in the leadENG project. One student articulates:

> "*But we didn't know if we were allowed to participate in the beginning. It was something our semester coordinator chose, so if there were a lot of applicants, some would be cut out*".

Also, later in the process, a student articulates the following about their possibilities for action:

> "*It was also important that they got their objectives and projects fulfilled. Therefore, we said that they could just write that this is what they would like, but this was unfortunately not something they could be allowed to fulfill*".

As Löw stresses in her work, structures are essential for actions to happen as they guide students in regard to expectations and formalities in the project work. These quotes demonstrate that the institutional structures form and guide students at different stages in the project period, creating boundaries, and maybe even barriers, for students in regard to how and when different actions are possible.

Another aspect students highlight as central for aligning the participating groups is the importance of everyone knowing about general team collaboration, project management and project writing. Lack of awareness of the general institutional frames for producing a project (in this case at AAU) is articulated as an increasing risk for misunderstandings. This includes not only the written rules but the tacit discipline-specific rules about knowledge sharing, presentation of knowledge, ontological and epistemological approaches to knowledge, etc. as well. One student expressed:

> "*. . . First of all, you need to learn how to make a project, and how it functions to work in disciplinary groups. This, before getting the possibility to work in a bigger collaborative context as this*".

Another student highlights:

> "*So, before beginning the actual project, there needs to be clarity about all regulations and so, so everyone knows about the same things*".

Students articulate these structures as fruitful for the collaboration. Having recognizable structures (in this case the AAU PBL approach) as the common ground for collaboration gives students a familiar starting point in regard to collaboration and project management.

As seen earlier, Löw underpins the importance of seeing relational arrangements as more than just regulations and guidelines. Institutional structures are temporal spatial aspects as well. Following this understanding, time becomes an institutional element influencing to what degree students collaborate and create cross-lines between them. The projects are limited to a certain amount of hours, giving students a prefixed timely space to maneuver in, where students need to balance (appropriate) knowledge acquisition, project management and establishment of collaboration. Time was stated by students as needed for determining how and to what degree communication was needed but also how to use the different physical and digital platforms present. Another element of time shared by a student was how each of the groups needed time to understand how to look ahead in time to figure out when things were needed from the others to give them the best possible foundation for establishing an ongoing collaboration.

Data also indicates that the shared, established participation space of leadENG may create pressure, where some groups feel behind or have not had the time to do all the things needed from them. This, both in terms of institutional structures and requests from other groups. One student articulates:

> "*People [from the other groups] have been waiting on us, and we just haven't had the time to do it*".

Another student explains about the time pressure:

> "*. . . So, they were also really much under time pressure in regard to some simulations, and they didn't have that much knowledge about how to have that build. So, I said that if they could give me the wanted gearing then I could make a proposal for them. And then we made some changes to that along the way because I started making it too big. . . but I also said that they had to accept that this was a quick fix because we also were under time pressure in our group. . .*"

Time becomes an institutional structure pushing the students in several ways. This is not unusual for the students as time is a factor in disciplinary projects as well. However, in the interdisciplinary context, the analysis shows that time, in interplay with the cross-collaborative space, shapes situations in which students place themselves and others in roles that allow them to either exert pressure or experience being pushed, particularly in relation to perceptions of falling behind other groups.

Another relevant aspect of time, revealed when following the groups' work on the car, concerns the continued work on the car after project hand-in, making the project report only one mandatory deliverable, while the overall project became the fabrication of the car. In this way, time becomes relative to the students not just during the project towards the semester exam but fulfilling a greater motivation as well. With that, time becomes an ongoing resource influencing the production and reproduction of the space.

As mentioned above, exams play a role in the participation space established, both as an institutional structure but also as an object placing the groups in regard to one another in the system. One student underpins:

> "*It is not just one exam this depends on. It is like 6 exams that are dependent on our work*".

This articulation shows not only that the exams become an ongoing present actor throughout the project influencing the space in one way or another but it also stresses the interesting notion of the exams becoming an establishing dependency among the students, moving focus from dependencies only established through a shared boundary object, as in this case, the production of a car.

Another, more indirect, institutional structure committed to spacing is the importance of having an understanding of both one's own but also others' ontological and epistemological beliefs. One student articulates the disciplinary boundaries and possibilities of interdisciplinary collaboration as follows:

> "*So, we could achieve more, because we were more groups collaborating on it. We had some different skills that made a car seem realistic and buildable. We wouldn't be able to build a car ourselves as an [name of the discipline] group. We wouldn't have the knowledge and competence to do so*".

Seen from the literature, it is important to be aware of your competences and limitations in an interdisciplinary context, and knowing when and to what degree you should ask for help or support with one or more tasks related to the problem or project in focus (Lattuca et al., 2012). This is of course to produce the best possible outcome, but also in regard to the placement of one another in the participation space. Having misaligned understandings or beliefs about each other's disciplinary qualities and competences may ultimately end in some groups becoming disappointed about other groups' work, developing a misbelief

in one another that in the end pushes the groups further away from each other, or in a worst-case scenario, entirely out of the collaborative space.

One student emphasizes the importance of aligned expectations such as:

> "*And they maybe had some expectations to us, that we couldn't fulfill, and we had some to them that they couldn't fulfill either. And then, there could of course also be the other case where we could surprise them with some things that they didn't expect us to be able to do*".

This again points back to the direct institutional structures of learning objectives:

> "*. . . we are completely different places. We would have liked to build something smart and fancy, not something that looked like a racecar. You could have done something that fulfilled your learning objectives to a higher degree, where the others were a bit more interested in what the sustainability concept is. We should probably recycle the entire car instead of building our own. There, we were in different places in terms of which part of the curriculum could be accomplished*".

A final aspect of institutional structures highlighted in the interviews is the importance of having disciplinary courses connected to the interdisciplinary project. Students emphasized that they need to have sufficient knowledge to form the baseline for participating in the project and to fulfill the tasks they encounter. If they do not, or feel that they lack the opportunities to gain the knowledge needed, groups may be pushed further away or entirely left out of the participation space, resulting in exclusion or power shifts as some know more than others.

Gathering the elements from above, the analysis exemplifies that institutional structures form the foundation, negotiation and reshaping of the participation space established among the students, see Table 2.

4.1.2. People

The leadENG initiative is led by a number of project managers each having the responsibility to plan, coordinate and execute the project. In this case, the project manager is also supervising one of the groups, making it easier for students to reach out to the project manager, clarifying uncertainties and doubts. However, while this project manager allocates a lot of hours to the project framing, advocating and securing the progress of the project, interviews with students both from the same discipline as the project manager and students from outside this discipline reveal that there might be a misalignment in regard to knowledge on the project. One student articulates:

> "*Yeah, it was also rather chaotic because it seemed as if [name of project manager], now he seems as the head of the leadENG project, and it seemed like [the other discipline] knew more than we did. They had more information. . . There were different specifications and so on, on the car, and some expectations that [the other discipline] were informed about. . . And some time went by before we had the first Wednesday meeting, so in that time we were less informed in regard to what we needed to prepare for. You can say, it would have helped if we had the same information from the beginning*".

Following Löw's notion about people having just as much influence on the spatial establishment as material elements, this quote exemplifies how the project manager forms the placing of groups in the participation space with some groups knowing more than others. This is likely not intentional but simply because of the closer disciplinary distance to some of the groups, underpinning the importance of educators being actively aware of their influence and role in the created participation space.

Table 2. Key elements on institutional structures based on data.

Element from Löws Theory	Key Elements from Data	(Re)figuration of the Participation Space Based on Spacing and Synthesis	Access Possibilities
Institutions (Structures)	**Institutional norms/rules/ Regulations** - Disciplinary differences - PBL principles - Exams	• Groups may be included/excluded by the institution • The influence of exams • Different regulations for how to handle and share knowledge place students either further or closer to each other. If students fail to align language misunderstandings and misalignment may occur • It is important that everyone knows about general collaboration, project management and project writing (at AAU). Understanding different institutional frames helps students limit the possibility of misunderstandings • It is important to understand both one's own and other participating groups discipline in the placement of each other in the system • Norms/rules as a starting point for students when entering a new project (recognizable structures). PBL principles may be of help. • Articulation of expectations to one another	- Criteria from AAU - Alignment (or mutual understanding) of languages, approaches and understandings - Agreed recognizable structures - Agreement about the balance between deep knowledge, project management and collaboration in the time given - A good understanding of one's own disciplinary competences and starting point - The degree of helping out/letting students experience and finding the way in the space themselves by supervisors and coordinators
	Organization of the project - Supervisors' role - Self-management - Time	• Balance between deep knowledge, project management and collaboration in the time given. • Time-management • The balance for supervisors between helping students proceed and letting them figure out how to approach and be in the space themselves • The shared space creates pressure where some may feel behind or feel like they don't have the time to do it all • Not being at the same phase in the project at the same time (creates pressure/misalignment)	
	Connection to other disciplinary courses	• Experiences the space (leadENG) as a place where they can use the things they learn from their disciplinary courses (the importance of relevant courses to help with the needed baseline for working on the project)	

Supervisors are appointed to each project group originating from the semester group's discipline. Students see the supervisors as specialists helping to deepen the students' knowledge but also clarifying doubts and elements that are hard to grasp. One student articulates when asked about what the supervisor helped with:

> "*. . . there are some disciplinary things that, at least in the context of connection to the car have been completely or very difficult to understand. But certainly, also processes of calculating backwards. And doing this and that to understand how we should calculate [disciplinary] consumption, etc. It has been very confusing for me. . .*"

Also, supervisors help students to know where to be in the process at a certain time. Midway through the semester, each group had a status seminar, and this seminar was used as a milestone for achieving certain elements on the car set by the supervisor. This also aligns with the notion of supervisors being the "brokers" (Wenger, 1998) for establishing common ground and understanding among the groups. By helping the groups to move forward and securely progress at a certain pace, the supervisors help groups to keep up more or less the same momentum without having some falling way behind the others. One student says:

> "*. . . but then our supervisor said that maybe we should start by talking to the other groups about how much they actually were able to drag out of [element on the car] and how fast it would be able to go. . .*"

The elements also relate to students' presumptions and understandings of one another. If students fail to see the need for, and dependencies among, one another, they end up just assuming and estimating things about the boundary object (in this case the car), limiting the amount of coordination and collaboration needed to secure truthful and accurate progression. One student reflects on the extent to which they have experienced collaboration:

> "*It depends on which group we talk about. That's for sure. For some groups, we have had a lot of contact, but there are also groups we barely have talked to*".

Also, more directly one group talks about the interdisciplinary collaboration where one student articulates:

> "*We had a lot of collaboration with the group from [discipline], because we needed to talk about how fast this [element on the car] should go, and how we had it all fit together between the two groups. I almost think that we are the only ones that have had a fair amount of collaboration with [discipline]. It has been exciting and difficult*".

These statements exemplify the influence and importance of ongoing alignment and compromises keeping a fruitful and accurate collaborative participation space. Students need to see the need for interdisciplinary collaboration, not just having a boundary object stating this on a piece of paper.

One student explains:

> "*So, we had made this gearing. . . where we could get it down to approximately 35 km/h, but then we just had to talk to [another group], that showed to have completely different numbers than what we have calculated with, because they were able to drag more out of it. So, we figured out that we needed to put on a chain and also that our gearing was completely off. So yeah, but then we became a little better together, and got to talk about what we actually were going to do and from there what each group should be in charge of. . . It was also a bit challenging to talk to them getting the right numbers out. . . In the end we succeeded with this, so you need to have compromises with one another*".

Here, it is also indicated that adjustment of language becomes of importance in the participation space and that communication in general may be a challenge. A thing highlighted as smoothing for entering the collaborative space in regard to alignment and knowledge sharing was relations outside collaborative work, e.g., familial ties:

> "*. . . So, it also makes it a bit easier, that my brother is a group member in one of the other groups*".

Löw also underpins this positive influence of being more familiar to one another, leaving less space between the participating parties (or in this case the groups) when wanting to create a fruitful participation space (Löw, 2016). Further, as stated several times in the literature as well (National Academy of Sciences et al., 2005; Klausen, 2014), good communication is a key factor for achieving good collaboration and progression in the participation space:

> "*I also think it is much about communication. . . there is something with the fact that we don't know the people from the other groups that well. So, we had to figure out how to communicate with the others in the best way. And when we finally cracked that, then I actually think it became quite good*".

In the end, it comes down to whether students perceive other students as helpful and giving or inhibiting for the progression. If they do not see the benefit of the collaboration, they lack the ability to place the other groups positively in the participation space, making the interdisciplinary collaboration harder or even unnecessary. One student frames the synergy between the groups in the following way:

> "*. . . maybe saying that the others are specialists is a bit too much. But they have worked with something that we haven't, and we have achieved things that they haven't been part of. And when we join this, we can gather the pieces into one*".

Another way of placing the groups in the space is through a sense of shared responsibility, as one student articulates:

> "*Well, if we don't do anything, then it is not just ourselves it will affect. It is also all the others*".

How students perceive and interpret both their own but also other groups (or even people and social goods in general) and their position in the participation space is a recurrent topic throughout this analysis. Depending on how students synthesize and understand the experiences they have in the space, their following actions and positioning will be influenced by this. One student explains how they position themselves in regard to the other groups:

> "*I almost only listened at the [specification on the car] group [presenting at the meetings] as they are the ones we collaborate with. . . [the other group] were not that important, also because they had said that they wouldn't use it on the back, so that I knew I could disregard. So, when I heard from the two groups, I spent the remaining time just sitting there wishing for it [the meeting] to be done. I had gotten the knowledge I needed and used enough time on that*".

Table 3 summarizes key findings related to Löw's concept of people.

4.1.3. Social Goods

Students on several occasions mention the importance of physical spaces for collaboration. Having a group room for jointly working on their project is beneficial, having shared physical spaces to meet, share ideas and coordinate face-to-face. One student emphasizes:

> "*. . .If we have had the physical space, it would have been much better I think*".

To this comment, another group member supplements:

> "*I also think so. But on the contrary, so is Teams [digital platform] a good place for sharing documents so everyone got them. For instance, budget have always been shared in a shared folder, drawings of the car have always been there as well*".

This student highlights the importance of having online platforms to share ideas and knowledge related to the overarching leadENG project across the groups as well. Several students articulate in the interviews that online platforms are good for quick updates and informal meetings among a few of the participating groups. A place to get a fast answer to a question or a message, though for more in-depth communication and knowledge sharing online platforms were challenging. The students viewed a combination of the physical group rooms and online platforms as fruitful for the collaboration.

Table 3. Key elements on people based on data.

Element from Löws Theory	Key Elements from Data	(Re)figuration of the Participation Space Based on Spacing and Synthesis	Access Possibilities
People (Bodies)	**Project Manager**	• Keeping an overview of the project (being the person the groups turn to when in doubt of something related to the overall project) • Make some initial framing for the cross-collaboration • It is important to be aware of students across disciplines getting the same amount of knowledge to minimize some feeling misled or behind	- Others' perception of your belonging in the room (experience of dependencies) - Supervisors as brokers between the groups - Clear separation between project functions (supervisors, project managers etc.) or better alignment. - Equal knowledge information from project managers and supervisors across the groups
	Groups	• Some groups find common ground while others don't (the ability to see the value of the other groups/dependences among them) • Expectations, alignment and compromises to one another • Personal relations strengthen the collaboration across the semester groups • The importance of good communication	
	Supervisors	• Specialist • Help resolve challenges according to content and time-management • Helps establish collaboration among groups (broker) (common ground and understanding of differences in competences)	

The physical placement of the group rooms is emphasized by more students as valuable. Students articulate the importance of feeling located close to one another to create easier access and clarity on when groups can reach one another. One of the students, from a group not placed in the same area as the others, articulates:

"*But all [disciplinary] groups connected to the production of the car were located at the same place, whereas we were located in a completely different building. It would have been better to be near the others*".

Another student also points out:

"*. . . being back at campus, then we could just walk around joining the other group rooms. It was smart that we could see each other, asking questions like "how did you think of doing this here?" it was definitely better*".

Students feel they get better possibilities for collaboration among the groups when being placed close to one another. Students articulate that having opportunities to see when other groups were available (possibly because of windows in the group room doors) and talking to one another gave better, easier access to communicate and collaborate, missing in the online space where contact was much harder. One student explains about the online space:

"*. . . even though we agreed upon the terms that we could just join each other's group rooms, it wasn't that easy in reality. You couldn't just choose a group room and join it, if they were in an important meeting or something, so each time we had to write on their channel first. This was much easier in the physical group rooms where we could look into the room and see if they were available. . .*"

The online platform risks becoming a restricted space for collaboration where the separated online group rooms create more isolated/non-transparent barriers between the groups.

Another social good emphasized by the students as influencing the participation space is the use and appearance of meetings. Through the mapping, it became clear that meetings become a node for collaboration where students interact, share and develop knowledge and focus points jointly. Biweekly steering group meetings (decided by the project manager) were held for all participating students. Some students see these recurring meetings as fruitful while others see them as inhibiting the progress at the end of the project. However, students generally agree that the meetings have a timely development where the frequency of meetings becomes more intense towards the end. Some meetings happen spontaneously when needed while others are prescheduled. One student explains:

"*. . . we had more of that kind of meetings where we talked about how we collected the shared ensembles, where we had some preparation, we all met and discussed at the meetings. But apart from that, most meetings were some where we just went into the other group rooms either online or physical*".

Another student underlines the importance of meetings for product integration:

"*So, it was just like if we had a working task where you thought something was missing. For instance, this with the gearing. We need to calculate how big a sprocket we need for our chain drive. We do not know that much about [specific element on the car], so then we had a meeting with the [specification on the car] group. They gave us some data, some empirical evidence about the [the specific element on the car] we have chosen. And then we can do our part*".

A student from another group also emphasized the degree of integration among the groups:

"*There were a lot of things that needed to be integrated, there were our drawings, and they had to figure out how much space we would have [on the car] and there was also something about weight. There were suddenly a lot of things that needed to align*".

Combining the different meetings with the earlier mentioned aspect of physical and online spaces, the participation space starts forming various smaller "sub-spaces", all with different aims, norms and structures. Bringing in the analysis of social goods seems to unfold a more nuanced picture of the space established among the students. The overall participation space we try to manage and guide seems to be a system of several sub-spaces where groups and/or individuals move in and out of both the overall established participation space and the continually emerging sub-spaces, creating a situation where the space(s) may be renegotiated several times throughout a project, all affecting the possibilities for collaboration, negotiation and access in the overall participation space.

Making the mapping for this analysis, different formations were outlined in the beginning, but quite early it became clear that the most suitable way of visualizing the space was having the collaborative space centered with the car, placing the groups around it, forming a ring. Having the car as the integrating point of departure provides students with a foundation for collaboration and shared visions in the space. From this starting point it became possible to place the other aspects of both people, institutions, social goods, synthesis, spacing and access possibilities, letting the participation space change in size and appearance as the process of visualizing the collaboration developed. As one student phrases:

"*So, our task is to get the car running, the car that [other discipline] is building. . .*"

Another student also emphasizes the dependencies created among the groups in the system through the influence of the shared boundary object:

"*. . . we also have some responsibility not just for ourselves but also for the other groups doing this. The other groups are kind of dependent on what we are doing*".

This, though, also includes an understanding of compromises needed. For instance, one student talks about a situation where they wanted to have a specific gearing of the car, figuring out that this would give a diameter of the sprocket at one and a half meters, simply too big for the other groups to integrate in their work, thus compromising on this.

Another element of interest is accessibility to facilities. This both consists of access to laboratories needed and materials for sharing knowledge. For the latter, one student articulated the importance of blackboards:

"*We were also lucky when we had to do statics and strength lab on our work. For this, we were able to get into our group rooms, because for these two things we especially needed a blackboard, so it was easier for us to agree on things in person instead of sitting with a computer mouse. It never becomes just as pretty as it does on a blackboard*".

Similarly, one student articulates the importance of having the spare parts of the car physically present in front of them, to be able to see dimensions and links between the elements of the car:

"*We needed the spare parts [of the car] in hand, before being able to draw them, and get some calculations, we could use on our own product*".

Also access to laboratories was articulated by some students as essential for their work on the project:

"*Because we haven't been present at any laboratory making experiments, we ended up just getting data, for this work, motor data. But also in regard to the work on [specific part of the car]. Here, we had to ask [our supervisor] for help on how to analyze the data that we got from both [specific parts of the car] as we didn't do any of the experiments ourselves*".

Again, the physical aspect of having things or equipment closely located and accessible to students demonstrates a potentially important subject to consider in the planning and facilitation of interdisciplinary collaboration. This, at least for engineering students. Extending the analysis to consist of both human and non-human factors provides us with an understanding

of spatial influence being more than facilitating collaboration across the participating groups. This analysis illustrates that attention must also be placed on physical decor and accessibility.

Another aspect, revealed when creating the mapping, was that the elements of time and knowledge not only present themselves as institutional structures but become social goods in the space as well. Time given for the project is one thing, but students also emphasize timing as influencing the collaborative space in a different way. This is neither a material nor symbolic element and therefore also addressed as an *immaterial* element.

A group highlights the aspect of timing, waiting for one another, and that this has been one of the most challenging things in the collaboration with the other groups. This aspect of timing and having time to do all the elements expected by the other groups is also one of the things emphasized in the articulations about the frequency of meetings. Students highlight that timing becomes of essence when trying to establish an interplay with the other groups. Timing becomes both a developing necessity for establishing a fruitful participation space but also for the groups to align and work together. One student emphasizes that being ahead provides the group with an opportunity to set the scene, determining what to put on the agenda at the meetings:

> "*It has also had a bit of an advantage. We were the ones that could decide the agenda. We have chosen this and this, and then the rest of you just have to adjust to this*".

Following the line of understanding structures and actions as intertwined elements, time not only exemplifies how institutional structures influence students' actions but also that these actions feed into the existing institutional structures.

Knowledge is also revealed as a social good in the analysis. Especially, lack of knowledge (linking to the aspect of timing above) is a recurring theme in the interviews. Not being aligned and having some falling behind in retrieving or producing data useful for the other groups seem to push the groups further away from one another, creating frustration. Also, technical articulations of knowledge may exclude some. One student explains:

> "*. . . It has been hard to communicate things, being sure that he [a student from another group] understands the things we are explaining and vice versa*".

Also, elements of having general knowledge about project writing, management and collaboration are, as mentioned earlier, stated as significant. Students underpin the importance of having the same amount of knowledge from the beginning, securing the overall direction of the project. Knowledge then seems to become a power in the space. It seems like an influential player, either getting enough knowledge or the right knowledge.

The last relevant aspect in the analysis of social goods is that the influence and use of knowledge change over time. As the space changes character, the degree of knowledge and contributions from the other groups also change. One student articulates:

> "*But we also got some knowledge out of it. Where we could see, if we made a [specific element on the car], then we would get another ground clearance than we expected. So, this was something we got out of it in the beginning in regard to what they were doing. But then, the longer we got into the project, we just wanted to see their 3D drawing. . . to see if that aligned with ours. . .*"

This quote indicates that time and knowledge are central aspects to consider. They seem to change in both character and power throughout the project period, with deep knowledge being particularly important in the beginning, whereas time and timing are of essence at the end of the project period.

Table 4 summarizes key aspects to consider related to the concept of social goods.

Table 4. Key elements on social goods based on data.

Element from Löws Theory	Sub Element	Key Elements from Data	(Re)figuration of the Participation Space Based on Spacing and Synthesis	Access Possibilities
Social Goods (Bodies)	*Material*	**The influence of a boundary crossing object**	• A joint product (may) provide(s) dependencies • Compromises are needed in the development of a joint product • The importance of having the car parts physically present in front of you. It is easier to make the dimensions and to see the links between each group	- The importance and influence of the product - Dependencies are created by the product/experience of dependencies based on the product - Product determines the degree of interdisciplinarity in the system - The importance of physical parts to work on - The importance of physical spaces for collaboration - Project development and how student groups follow each other regarding development (some may get in front of others) - Participation in meetings - Knowledge/Lack of knowledge between participants places the groups in a certain way (pushes one another further away or get closer to one another) - Knowledge is power (set the scene by knowing more/acting like you know more) - Becomes a power to be in front of the others - Common language creates common ground
		Accessibility to facilities	• Access to laboratories when needed (timing) • Use of blackboards/other materials for sharing findings etc.	
		Physical vs. online platforms for collaboration - Digital platforms like MS Teams, Messenger etc. - Group rooms Meetings	• Each of the platforms creates a certain space for collaboration (they can do different things) • The combination of online- and physical "meet ups" is good – gives students a place for sharing written knowledge and asking quick questions (online) and a space for collaboration and direct, more advanced communication (physical) • The physical placement of the groups becomes important for the space (the feeling of being close to each other means they more easily can reach each other and gives a feeling of better possibilities for collaboration.) • Meetings become crucial for the collaboration. Creates a deeper and better understanding of the other elements/involved in the system • Some meetings are determined beforehand; others happen spontaneously when needed • Meetings become important for (product) integration	
	Immaterial	**The influence of timing**	• Timing becomes an actor in the system regarding coordination, deliverables etc. (being ahead becomes a power for setting the scene) • Feeling of efficiency in the system	
		Knowledge	• Lack of knowledge between participants pushes the groups further away from one another (pushes students to just assume things instead of making the calculations together) • Technical articulations/knowledge exclude some • Having the right knowledge at the right time	

5. Discussion

Using the conceptualization of the elements institutions, social goods, people, synthesis and spacing in an interdisciplinary educational context, the analysis demonstrates that the forming of participation spaces is a complex interconnected system of processes and formations. Recognizing that students' preunderstandings and interpretation together with the pre-established institutionalized surroundings shape the foundation of the participation space may provide practice with a more holistic perspective of the learning spaces formed in education. This perspective suggests that interdisciplinary educational spaces need to remain dynamic enough to be restructured and shaped as the product and process evolves.

5.1. New Aspects to Interdisciplinary Collaboration in Education

Considering both elements, aspects and interrelations in the space, the "social vacuum" (Frickel et al., 2017) of previous interdisciplinary work is connected to the scaffolding elements of institutional conditions, personal attributes and influence of non-living social goods, all affecting to what degree a fruitful collaborative space may be established. Thus, we argue interdisciplinary collaboration should not be limited to an understanding of just students' preunderstandings, approaches and prejudices in connection to a shared boundary object. Rather, both the spatial formation, space for action, interaction and in the end access possibilities become a complex interplay between both institutional structures, influence of different social goods and more or less support from different key persons in the system. This, not only on a horizontal shaping dimension but just as much vertically, presenting the depth and rigidness of each element, see Figure 4.

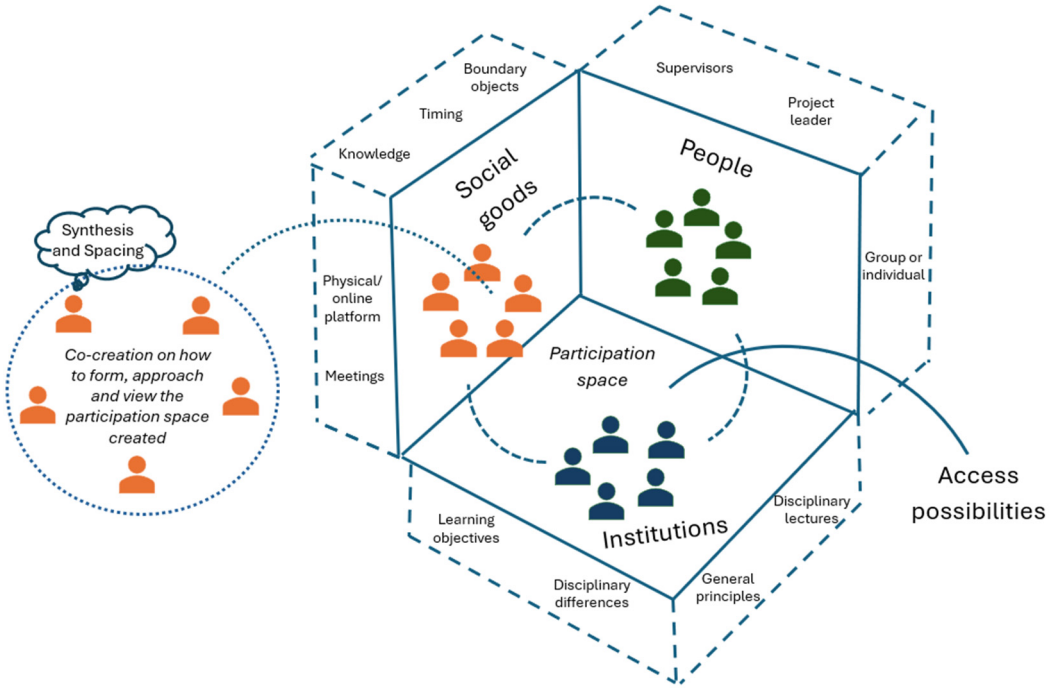

Figure 4. Updated visualization based on findings from analysis. The depth (dashed lines) to each category visualizes the possibilities for forming and reshaping the (more or less) institutionalized boundaries present for students in an educational setting, visualizing not only the shaping factors of each category but the rigidness as well. The dashed line in a circle visualizes the co-creation happening within each of the disciplinary teams.

5.2. How to Grasp Relational Space in an Educational Context

The analysis indicates that synthesis and spacing become central processes to consider in the establishment of the collaborative space. Institutional structures may create more

or less rigid structures but to what degree students choose to follow or disregard these is up to them. Supervisors may guide, push or even demand students to follow a certain direction in their projects but it is still entirely up to the students to what extent they choose to follow these directions. In the same way, social goods such as the product in focus, access to facilities, timing and knowledge all become more or less important, determined by how the students interpret them.

The analysis points to the complexity with which synthesis and spacing are negotiated and implemented in the collaborative space. Synthesis and spacing have in this analysis been conducted and analyzed as a shared unit in each disciplinary group. Figure 4 introduces the notion of viewing an interdisciplinary educational space as more than just cross-disciplinary students establishing shared agreements for how to collaborate. Instead, space is a complex setting of individuals, entering a disciplinary group, sharing and aligning viewpoints and positionings, alongside the establishment of the interdisciplinary collaborative space established with several other groups. This not only creates a complex aligning and negotiation where students need to manage their own preunderstandings, standpoints and ideas but also a continuous co-creation of aligning and (re)aligning understandings with the rest of the groups, securing not only a shared direction in the interdisciplinary project but in the disciplinary group as well. Students' discussion of the different questions in the interviews revealed that they enter a complex space of aligning and determining their own presumptions and understandings not only with the other groups but internally in the disciplinary group as well. Students are thus at the same time both observers and actors within the established participation space (see Figure 4), creating a complex interplay between the institutional structures, social goods and people in combination with students' synthesis and spacing. This is further complicated by the fact that students form groups in which negotiations about the space will, and must, take place as well.

Following the understanding of space visualized in Figure 4 two dimensions of attention points are drawn here: the physical aspects of institutions, people and social goods, and the cognitive aspects, being synthesis and spacing. This also aligns with the division of structures, bodies and processes presented in Fritz and Binder's work (Fritz & Binder, 2018). Here, structures become the foundation for reproduction and bodies as the actors and processes determining the actions present in the space. In an educational context, the establishment of a collaborative space as a complex co-existing sphere of institutions, people and social goods becomes both the pre-establishing, structuring and embodying elements in a complex interplay. Laboratories not only become a social good but also an institutional structure of prior established norms and rules determining who, for instance, are allowed to enter. Established learning objectives or ways of doing may become institutionalized within supervisors over time because "this is how things always have been done here". This, similarly, affects and forms students over time. This influences to what degree new structures and initiatives, such as interdisciplinary projects, may thrive, and even more so if these projects should follow the understanding of projects not just being either inter-, multi- or simply disciplinary but something more dynamic and in flux, where students, and other stakeholders or actors, can jump in and out of the collaborative space determined by the needs and wants of the people in the space or by the product or problem in focus.

5.3. The Complexity of Creating Dependencies

As specified in the Introduction, dependencies are often highlighted as crucial for establishing fruitful interdisciplinary collaboration. Finding a boundary object that binds the participants together is often stated as the key to establish common ground. Notably, in this analysis, the product correlates to how students choose to place themselves and the other groups in regard to other aspects of the collaboration. Elements such as availability, timing

and presumptions also influence to what degree dependencies in the participation space are created. Concretely, they articulate that they have to produce the car and that they need each other to fulfill this complex task, but several times during the interviews students talk about this dependency on a different level. Not just the fact that they need information to complete their own work but that they contribute to something bigger and that they need to take this seriously. They talk about their dependencies through the upcoming exams and their individual work on semester projects, moving focus from just producing the shared car to dependencies in the individual products. Using the elements of Löw's framework inspires the analysis to view data with a more nuanced lens, moving focus from just stating the importance of creating dependencies to investigating how students articulate their positioning, understandings and rationale behind their actions, unfolding a more complex and dynamic understanding of how students create dependencies within interdisciplinary projects.

Viewing the elements above indicates a strong connection both with the product and between the groups. As stated above, focus should be moved from just focusing on establishing a coherent cross-disciplinary product or problem to also establishing the groups' understanding of how they see the influence of the other groups in regard to the production of this product. This analysis demonstrates that it depends just as much on students' experience of dependencies as of the actual dependencies present in the product or problem. If students fail to place the others in a crucial position in the space in regard to solving their own problem, this analysis indicates that groups tend to push each other further away using estimates or general calculations instead.

5.4. Interrelations as an Important Indicator

Taking interrelations into account doing the mapping provided the opportunity to grasp each of the element's links and influence on one another. The mapping shows that meetings, the car, and the ring of collaboration between groups are characterized by a high degree of connectivity, suggesting that these elements play a key role in structuring the system. Relevant to note is that, even though these elements all are of importance, their influence becomes of real interest when connected to other elements such as time and knowledge. Time becomes equal to development in the space. This, not in the sense of just letting time pass and then evolvement will naturally happen, but rather timing things, so groups have the right spare part, knowledge and access at the right time become crucial. Also, time is articulated as one of the biggest challenges for collaboration. All groups indicate that not being at the same phase at the same time inhibits each group's work but also the overall product, which again connects to the element of knowledge, i.e., what to share and to what degree. Focusing on one of the elements connected with several links in the system is meetings, relevant for establishing common ground and moving forward. Moving forward is, however, determined by a balance between deep knowledge and keeping momentum at meetings. All three interviewed groups touch upon the importance of having a balance between deep knowledge and timing. Deep knowledge is appreciated at the beginning of the project whereas the right knowledge is crucial at the end. Feeling a need to share deep (for some, irrelevant) knowledge all the way through the project inhibits the progress and momentum of the collaboration and process. Another interrelation attached to the element of knowledge is the imbalance of not every group in the space having the same amount of knowledge. This, both in terms of administrative knowledge about the project, but also technical knowledge shared among some groups outside of the general meetings. It is articulated that it is more difficult to share knowledge online than physically connecting physical placement/online platforms, knowledge, timing and meetings to the degree necessary for establishment of fruitful

interdisciplinary collaboration. This indicates that the interrelations unfold other, more complex, aspects and connections to consider.

5.5. Maneuvering in an Educational Institutionalized Space

Trying to grasp the complex environment of interdisciplinary collaboration shown through this analysis, Figure 4 visually conceptualizes Löw's framework in regard to interdisciplinarity in education. Especially, the depth of each spatial category, often existing even before being established as a joint participation space, is a relevant outcome of the analysis. This depth has been visualized by drawing dashed lines shaping a thicker or thinner box of each surface in the space. Doing this, the intention is to underline the importance of paying attention to not only the influencing elements in each category but the rigidness and shaping character of each of them as well. Space, then, is not only considering the shaping boundaries around the participation space but also the depth of each of these, depending on the influence and inflexibility of each element in the categories. Paying attention to this also draws attention to the fact that interdisciplinary collaboration should be dynamic, able to shape and reshape depending on different dimensions such as the problem in focus. This not only influences the established participation space but the degree of interdisciplinarity as well. A student emphasizes in the analysis that the degree of interaction and knowledge needed changes during the process, indicating that, instead of having a static picture of the collaboration established in complex project settings, such as inter-, multi- and transdisciplinary, maybe all of them can be present at different times depending on the knowledge and to what degree it is needed at a given time.

5.6. Limitations to This Study

While this analysis provides insights into how relational space can be used to deepen the understanding of the educational interdisciplinary spaces students may engage in, it is important to point out its limitations.

As mentioned earlier, interviews have been conducted retrospectively, giving room for students to reflect upon the entire process they have been engaged in, however, making it more likely that the answers become general, missing out on specific, temporal aspects appearing along the way. In reality, theory supports the idea that relational spaces are in flux and that this project has developed throughout the project period, having elements of greater or lesser influence at different phases in the process. In future work, it would be interesting to conduct data collection throughout the process, following the groups' development in both assumptions and collaboration as it unfolds.

Another relevant aspect is the limited number of students. The sample size of this study has been fairly small, focusing on demonstrating the usefulness of Löw's theory in reality. Future studies should include a larger number of students, preferably from different projects but also from a wider range of disciplines, including both high-consensus disciplines, as in this study, but also low-consensus disciplines, to investigate what happens when a broader range of disciplines are invited into the same space of collaboration.

6. Conclusions and Future Work

Viewing interdisciplinary collaboration in education through the lens of relational space has provided this research with an opportunity to view the interdisciplinary process from a system point of view grasping the complexity present. Connecting collaborative elements with the interrelations they establish provides us with a deeper understanding of the interconnectedness of the elements influential in an educational context. Interdisciplinary collaboration is more than just focusing on the intellectual level and can be understood as an interconnected system of both institutional structures, people, social

goods and students' positioning and understandings. Further, this analysis indicates the importance of recognizing that interdisciplinary processes cannot be seen as static, with the ability to plan and predict in detail from the beginning. They are dynamic and in flux with the possibility for participants to negotiate, plan and reshape, or even leave, enter or re-enter, as needed for solving the problem. As the character of the space changes over time, the degree of knowledge from the other groups also changes, influencing how we view and articulate whether the system can be seen as interdisciplinary, multidisciplinary or even transdisciplinary. Moreover, timing, knowledge and the emergence of multiple sub-spaces appear as important aspects shaping students' participation. Students face a complex setting of several sub-spaces, all with different possibilities, barriers and norms, underpinning the importance of creating future interdisciplinary educational spaces that are flexible for change, repositioning and reproduction as the project unfolds.

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Appendix A. Interview Guide

Preliminary Questions
Try and tell us about your participation in the X project? What did you work with?
Why did you choose to participate in the X project?
What did you expect of the process before you started?
Experiences participating in a narrow interdisciplinary project
How were your experiences participating in the X project? (What functioned well/what did not?)
How was the project structured? (What functioned well/what did not?)
How did you experience the interdisciplinary collaboration among the groups? (Degree of collaboration)
How did you manage the collaboration among the groups? (How many meetings/timing)
What type of knowledge have you shared among the groups? (Difficulties in understanding each other)
Can you try and tell us how (and if) the process has been different from your ordinary semester projects?

Retrospective reflections
Have you gained a better understanding of your own disciplinary contributions?
What have you learned being part of X?
What do you think should be done to improve X further?

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