Journal of
Problem Based Learning
in Higher Education

VOL 14 • 1

Vol 14, No. 1, Page 189-210
doi.org/10.54337/ojs.jpblhe.v14i1.11019

"What is in it for me?"

Student Perspectives on Interdisciplinary Learning Activities

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Abstract

This paper reports on a study of interdisciplinary student collaboration conducted at a PBL university. It reports on a range of university-wide study activities, initiated for the purpose of strengthening interdisciplinary collaboration across study programs. The majority of projects investigated were organized as problem-based project work. In some projects, students formed groups with fellow students from their own program but collaborated with student groups from other programs. In other projects, individual students from different programs and institutions formed groups. The study has a specific focus on students' experiences of these activities, particularly how they experience cognitive, social, and epistemic gains from participating in interdisciplinary collaboration. The study finds that students acquire

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Received 11 November 2025 | Accepted 22 September 2026 | Published 26 November 2026
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knowledge from 'foreign disciplines' to complete the interdisciplinary project but also that they appreciate disciplinary boundaries and differences as well as the contribution that other disciplines can make towards realizing the goals of the group. The participants also realize how interdisciplinary collaboration constitutes valuable preparation for future job contexts. Concluding that the interviewed students experienced interdisciplinary collaboration as both highly rewarding and more challenging than project work within the framework of their own program or discipline, the paper suggests that the concept of 'hard fun' (Barrett, 2012) may be a relevant point of departure for future research.

Keywords: Interdisciplinarity; Student collaboration; Problem-Based Learning

Introduction

Most universities encourage interdisciplinary collaboration but refrain from in-depth restructuring of departments and programs along interdisciplinary lines (Lindvig, 2022). Instead, universities host several interdisciplinary research centers, groups, and projects and offer interdisciplinary programs, often with the experience that realizing interdisciplinarity in education is associated with practical obstacles, ranging from incompatible timetables (Lyall et al., 2015) to assessment criteria that differ across disciplines. Often institutions and individual teachers go to great lengths to offer students interdisciplinary learning opportunities. Such opportunities require an extra effort on the part of academic and administrative staff (Holgaard et al., 2025) and may also require new curricular frameworks. Given these efforts, investigating students' experience of and perspectives on interdisciplinary activities is important. The purpose of this paper is to focus on the value of interdisciplinary study activities seen from a student perspective. Thus, based on an interview study involving student participants in interdisciplinary study activities, the research question that we intend to answer is:

Which cognitive, social, and epistemic gains do students experience when participating in interdisciplinary study activities?

The ambition is to listen to student voices across different interdisciplinary activities to understand what students find attractive about these projects, which value they ascribe to them, and how they relate their experience to the ways in which the activities were organized. The intention is to generate knowledge that is useful to researchers interested in interdisciplinary learning, to organizers of interdisciplinary study activities, and to students who consider including such activities in their academic careers.

The setting

This study reports on three different interdisciplinary study activities organized within a university-wide initiative to promote interdisciplinary collaboration among students. Interviews were conducted with members of six student groups participating in these activities. The study was conducted at a Danish PBL university. Consequently, two of the investigated activities (involving four student groups) were arranged as problem-based project work. Project work takes the form of group-organized, semester-long projects, researching a student-defined problem. With some variation across semesters and programs, the semester projects take up a half or a third of the students' workload. One of the investigated activities was arranged as an extracurricular activity. In all cases, the students actively selected the interdisciplinary activity. Where the interdisciplinary activity, in the form of an interdisciplinary project, constituted a credit-bearing, integral part of their program, the students had the option of choosing an ordinary project or an internship, in other words a project that did not require them to engage knowledge beyond their own discipline.

Theoretical framework: Cognitive, social, and epistemic gains

This study assumes that understanding interdisciplinary student collaboration requires an interdisciplinary theoretical approach. Firstly, we draw on contributions from cognitive psychology and social learning theory (Vygotsky, 1978; Wertsch and Tulviste, 1992) to understand what individual participants learned from the collaboration. Secondly, we draw on theories on leadership and coordination in groups and organizations to identify how participants develop their collaboration skills in these socially demanding activities. Thirdly, we include epistemological theory to identify how various forms of disciplinary knowledge and differing epistemic practices influence collaboration and the creation of a shared product. The inclusion of an epistemic perspective considers gains beyond individual learning and enables an appreciation of the knowledge developed in the projects, including innovative ideas resulting from interdisciplinary collaboration.

As will be illustrated in the following brief review of existing literature, empirical studies of interdisciplinary student collaboration often draw on similar theoretical approaches. It is, however, rare that these theoretical approaches are combined to serve as a framework for subsequent analysis as is the case in this study.

Amelink et al. (2024) focus on development of 'complex thinking skills' and agree with Routhe et al. (2023) that students through interdisciplinary project work reach an advanced understanding of how different disciplines can complement each other. Thomassen & Stentoft (2020) emphasize the promotion of 'metacognitive competences' (p. 5). Braβler and Dettmers (2017) as well as Klaassen (2018) conceive of interdisciplinary groups as social learning environments where the 'meeting of different perspectives' enables 'co-construction of learning' (Klaassen 2018, p. 843). Some studies investigate how students manage the complex social task of coordinating interdisciplinary projects and find that participants learn to overcome stereotypical thinking about "others" and to appreciate contributions across disciplinary boundaries (Ellingsen et al. 2021; Routhe et al. 2023). Studies with an epistemic focus pay attention to how disciplines differ in their epistemic practices and knowledge structures, creating challenges in interdisciplinary collaboration, illustrated by Arthar et al.'s (2024) study on an interdisciplinary group's laborious process of arriving at a shared understanding of the very problem they intended to solve. Often, however, the solution of complex problems requires the integration of widely different knowledge areas as illustrated in Kirsop-Taylor et al.'s study on PBL in a political ecology program (2021).

In this paper, we understand the cognitive dimensions of learning in interdisciplinary contexts based on sociocultural theories of learning (e.g. Vygotsky, 1978; Wertsch & Tulviste, 1992; Lattuca, 2002; McMurtry, 2024). Thus, while learning is viewed as involving individual cognitive processes, it originates in social relations and interactions with the socio-material context (Wertsch & Tulviste, 1992). The latter point is reflected in the Vygotskyan concept of mediation, which Lattuca (2002) connects to the context of interdisciplinary learning. Lattuca defines mediational means as 'the products of sociocultural evolution' appropriated by individuals so that they 'may participate in the particular social practices of [their] culture' (715). She further categorizes disciplines as mediational means that 'frame the thinking and the intellectual activity of individuals who use them' (715).

Consequently, interdisciplinary learning contexts require adaption to the mediational means represented by the participating disciplines. Sociocultural learning theory helps us understand that this endeavor not only involves familiarizing oneself with different types of knowledge and epistemic practices, but also the ways in which individuals have adapted cognitively to these practices. Following sociocultural approaches, learning in disciplinary communities requires the internalization of ways of talking, writing, and thinking typical of the discipline. As participants in interdisciplinary activities have adapted to different *disciplinary* social and material contexts, instances of cognitive development are likely to emerge as accounts of experiences of

cognitive dissonance (disruption of existing understandings) and cognitive adaptation to new environments (characterized by gaining familiarity with unfamiliar theories, methods, technologies etc.).

Furthermore, interdisciplinary learning environments foster complex social dynamics. Sociological accounts of disciplines conceptualize them as relatively stable social orders in which the status of the individual member is defined by academic accomplishments in the field. Academic titles and degrees, grades, and consensus around quality standards indicate a well-ordered social system into which individuals are socialized. Disciplinary social orders are, for example, reified in curricula, syllabi, and exam requirements but, at the same time, dynamic and subject to ongoing negotiation in the university's everyday practices, not least at universities that adopt student-centered and project-organized learning forms. Such learning forms are generally seen as conducive to students' development of collaboration and project management skills (Routhe et al., 2023).

Among the potential *social gains* from interdisciplinary collaboration, we focus on leadership and coordination skills. Alvesson & Spicer (2012) view leadership as social practices contributing to the steering of organizational processes towards a goal. These processes are distributed among several individuals located in various positions in the organization. Similarly, Gronn (2002) and Harris & Spillane (2006) apply the term 'distributed leadership'. In principle, leadership may be enacted without designated leader figures (Sutherland et al., 2013). 'Leaderless leadership' involves understanding leadership as a 'relational, socially constructed phenomenon' concerned with the 'management of meaning' (Sutherland et al., 2013, 760), resembling Gioia & Chittipeddi's view of leadership as sense-giving and sense-making processes (1991). Such conceptualizations of leadership processes will help understanding leadership and coordination processes in student groups. Particularly, we take an interest in how students, when leading and coordinating interdisciplinary projects, manage responsibility and decision-making in the diverse and complex settings that these projects constitute.

The students in this study participate in activities that require extensive planning on the part of the teaching staff to create well-functioning frameworks for student learning (Holgaard et al., 2025). Despite these efforts, students may still find themselves in an academic grey zone because (some of) the scaffolding disciplinary structures are disabled or at least relativized to accommodate the interdisciplinary activity. To understand what students gain from navigating in such an environment, we draw on Akkerman and Bakker's concept of *coordination* that includes 'establishing communicative connections', 'translation between different worlds', 'enhancing boundary permeability', and

'routinization' (Akkerman & Bakker, 2011). These concepts involve identifying patterns of communication between the participating students and exploring the extent to which the participants develop mutual understanding across disciplinary boundaries.

Finally, the study seeks to identify *epistemic gains* achieved in interdisciplinary study activities. Arthars et al. (2024) define interdisciplinarity as 'knowledge work that includes different kinds of engagement with knowledge beyond a single discipline' (p. 409). Thus, interdisciplinarity is understood as an epistemic accomplishment, involving 'integration of disciplinary ideas and tools, such as concepts, theories, and methods' (p. 408). Goodyear and Zenios (2007) distinguish between *learning* as a personal matter and *knowledge building* as a public one. Bereiter (2002) explains the distinction in the following way 'In producing [...] theory I have created knowledge, whereas in the other cases I may be said to have acquired knowledge (possibly through some internal constructive process) and created ways of instilling similar knowledge in others. Thus, creating a knowledge object is one thing and helping others to know is another. The first I call knowledge building; the second learning' (Bereiter, 2002, p. 68). Knowledge building implies using and producing epistemic products, 'conceptual artifacts' (Bereiter, 2002), which are 'discussable ideas, ranging from theories, designs, and plans down to concepts' (p. 68). Within disciplines and sub-disciplines, knowledge building takes place through different forms of 'progressive discourses', through which knowledge is advanced in a particular knowledge community.

In interdisciplinary collaboration projects, participants draw on different conceptual artifacts and master different knowledge-progressing discourses (Arthars et al., 2024). In interdisciplinary collaboration, the point is not necessarily to reach agreement but to advance the state of knowledge through discussions of disagreements, which requires common understanding (Bereiter, 2002). Existing research in the epistemic dimension of interdisciplinary collaboration demonstrates the challenging nature of such collaboration: we are familiar with the conceptual artifacts and progressive discourses of our own epistemic culture, but not their counterparts in other cultures. At the same time, participants in the present study are expected to produce *interdisciplinary conceptual artifacts* such as solving a health challenge, developing sustainable building material etc.

Contributions to understanding the epistemic dimensions of interdisciplinary collaboration consider if students can strengthen their ability to develop valuable knowledge in such collaborations. Goodyear and Zenios (2007) view university education as 'apprenticeship in knowledge work' (p. 352). Following this trail of thought, one type of epistemic gain could be developing the

students' *epistemic fluency*, defined by Goodyear and Zenios as the ability to 'recognize, appreciate and understand the subtlety and complexity of a belief system that one has not encountered before, whether that belief system is associated with a religious or ethnic community, or a scientific or professional community' (Goodyear & Zenios, 2007, p. 358). We expect epistemic fluency to appear in the data as reports of better understanding of the logics of others' disciplines and an appreciation of the contributions of these disciplines to the project/activity. Furthermore, increased epistemic fluency may emerge as reports on the experience that one can 'think with' the epistemic tools/conceptual artefacts (concepts, theories etc.) provided by another discipline.

Methods

This interview study investigates projects involving interdisciplinary student collaboration. As the projects were part of a university-wide initiative to promote interdisciplinary collaboration among students, data stems from a heterogenous sample of projects involving different programs and departments. Despite the heterogeneity of the projects, all interviews focus on the experience of collaborating with fellow students from different programs and disciplines and what can be gained from this experience. As the study focuses solely on the student perspective, a qualitative interview study was deemed the most suitable approach to gain a concrete and detailed insight into the practical experience of collaborating across disciplinary boundaries. While an interview study holds the potential of obtaining rich and detailed accounts of interdisciplinary collaboration processes, it also involves practical challenges. In this study, the primary challenge was to recruit interviewees, as the number of potential participants was limited, and only a few (see Table 1) accepted the invitation to participate in an interview. The authors had to accommodate the conditions of each interview to students' busy schedules, which meant that the number of participants varied from interview to interview (as illustrated in Table 1). Students who volunteered to be interviewed may have had a more positive experience than the participants who did not accept an interview invitation. All interviewed students expressed a sense of pride in their final products, which may contribute to their interest in sharing their experience. That said, students also brought critical points to the fore, which may also explain their interest in being interviewed.

As researchers, the authors were involved in a university initiative to support more interdisciplinary collaboration between students and were familiar with the institutional rationale behind promotion of interdisciplinarity. The responsibility for the arrangement of study activities was placed at program

level, implying that the activities were initiated, planned, and carried out by members of the teaching staff of the involved programs. The authors conducting the follow-up research have no affiliation with the programs arranging the interdisciplinary activities. As the authors were not responsible for or involved in arranging or running the interdisciplinary study activities, there were no overlapping interests between the student participants and the researchers. Before the interview, participants received written information on the purpose of the study and the context to which it would contribute. To ensure that every participant fully understood the scope and purpose of the research, every interview session included an introduction repeating the conditions involved in the research. Finally, students signed a letter of consent stating the purpose of the interview. This document detailed the topics of the interview (thematic focus on disciplinary knowledge and learning in interdisciplinary contexts, no questions about personal or sensitive issues). Full anonymity was guaranteed.

The study included students at bachelor and master's level. In the following, the study activity will be referred to as ENG, GAME, and HEALTH reflecting the focus of the activity. The participating student groups will be referred to as ENG1, ENG2, ENG3, GAME1, HEALTH1 and HEALTH2. The GAME group was interviewed twice during the project work, GAME 1a and GAME1b refer to the same group but to different group interviews. The GAME activity involved master's degree students from a range of computer science and media science programs offered by different institutions. During a semester-long collaboration process, students were expected to develop a computer game, drawing on the various competences present in the group. Additionally, the students completed the required program-specific exams. In the HEALTH project (a three-day workshop), the students were asked to identify a health challenge and suggest an innovative solution. Students from different programs (medicine, nursing etc.) worked together in groups. The participants in each HEALTH group were quite diverse in terms of educational background. Two students were enrolled in academic medical programs at the university, while others were completing their final years of the professional bachelor's in nursing. Finally, some participants were from a short-cycle program in social work and healthcare (in Danish: SOSU).

The ENG projects took their point of departure in a technological product requiring the collaboration between different engineering programs. In this program, students joined the project as a group focusing on one specific part of the product. These students faced a double task: developing their part of the product and writing an academic report on the theoretical and disciplinary aspects of product development.

Although all the projects involved students collaborating across program boundaries, the project organization differed. Firstly, in some of the projects students were enrolled as individuals and formed interdisciplinary teams ('intra-group interdisciplinarity'), but the sample also includes projects where students formed groups with students from the same program but collaborated with student groups from other programs ('inter-group interdisciplinarity'). Secondly, the projects also differed in relation to the organizational set-up of the collaboration. In the inter-group projects, students organized frameworks for the inter-group collaboration themselves. Within the individual group, relations were informal without predefined group roles. This organizing principle also applied to the groups involved in the three-day HEALTH workshop, but the organizers provided facilitation of the group process. In the GAME project, students were recruited into predefined roles and had quasi-formal titles/positions from the outset. The table below illustrates these aspects of group organization.

	Intragroup /intergroup interdisciplinarity	**Students are assigned predefined organizational roles**	**Number of participants in the included groups (number of students interviewed)**
HEALTH 1	Intragroup	No	4 (1)
HEALTH 2	Intragroup	No	5 (1)
GAME 1a	Intragroup	Yes	11 (5)
GAME 1b	Intragroup	Yes	11 (2)
ENG 1	Intergroup	No	3(1)
ENG 2	Intergroup	No	7 (3)
ENG 3	Intergroup	No	2 (2)

Table 1. Overview of interviews.

The interviews lasted between 20 and 70 minutes. The interviewer presented herself to the students as a member of a research group studying interdisciplinary collaboration. In nearly all projects, the interviewed students belonged to a larger team. Thus, the statements represent the experiences of the students interviewed and not necessarily the entire group. This point is relevant as interdisciplinary collaboration can be 'thorny', precisely because of the different disciplinary perspectives represented in such projects. As one of the interviewees put it: 'it was not all smooth sailing'. Based on online presentations of the interdisciplinary study, interview guides were developed that on the one hand ensured coverage of the focal themes of the study (the social and organizational set-up of the activity, students' motivation for participating, experiences of disciplinary boundaries, engagement of 'foreign' knowledge, the

resulting products, and the students' experience of outcomes) and, on the other hand, were sensitive to the particular context of the activity. The interview guide sought to encourage participants to provide concrete and detailed descriptions of the collaboration process, the learning experience, and the resulting products. Ironically, the interviewer's unfamiliarity with the disciplinary content of the involved programs (e.g., engineering) prompted rich and detailed accounts of the working processes, the resulting products, and the knowledge involved in creating them. Furthermore, the addressed themes prompted participants to reflect on the entire process from the first acquaintance with the interdisciplinary activity to the final outcomes, including implications for the students' imagined academic and professional futures.

All interviews were transcribed verbatim. Subsequently, data were coded using the data analysis software Nvivo. Data analysis was guided by the principles of thematic analysis (Braun and Clarke, 2021). Student statements on the collaboration processes and their experience of them were primarily coded in terms cognitive, social, or epistemic aspects. Statements that addressed learning beyond one's own discipline (from fellow students, literature, and supervisors) were coded as cognitive gains, and statements that addressed learning from organizational and social issues were coded as social gains. Finally, statements that addressed the involved knowledges, knowledge practices, and knowledge products were coded as epistemic gains.

Findings

The following section presents the study's findings in relation to cognitive gains (*Interdisciplinary collaboration and social learning*) with a focus on the learning outcomes from interdisciplinary collaboration; social gains (*leadership and coordination*) focusing on organizational processes, and finally epistemic gains (*interdisciplinary conceptual artefacts*) focusing on the knowledge produced in the projects.

Interdisciplinary collaboration and social learning

Interdisciplinary groups as social learning communities seem to feature three characteristics:

1. Disciplinary perspectives (and boundaries) become manifest as concrete experiences of different foci and priorities.
2. Participants can learn from disciplinary 'foreigners' by acquiring select mediational means from foreign disciplines.

3. Eclectically familiarizing oneself with certain mediational means from other disciplines (to accomplish specific tasks) is not the same as learning *within* the discipline.

Disciplinary perspectives and boundaries are articulated as experiences of unfamiliarity with knowledge fields and as experiences of discipline-specific approaches and orientations, for example in relation to the understanding and prioritization of tasks. In some cases, these experiences cause frustration, and in others (as the following quote illustrates) they enrich the working process because perspectives are considered that would otherwise be ignored:

> 'Her [medical student] way of thinking was perhaps at a higher level than ours as SOSU or nurses. There were details that she considered that we did not think of, and there were situations where she thought: we cannot present this because this idea is not properly developed. Because if we say we will use AI, she needed to know how we would use AI. While as SOSU and nurses we thought: this will come later in the process.' (HEALTH 2)

In all cases, including cases where different disciplinary perspectives caused certain frictions, the interviewees were able to couple others' behavior to disciplinary backgrounds, understanding that different disciplinary traditions and forms of training result in a particular mix of strengths and weaknesses.
Disciplinary boundaries also become visible to participants as they – due to the interdisciplinary character of their project - are confronted with completely unfamiliar knowledge:

> 'I think that the ENG project has made us improve more than if we had chosen some other project that maybe had included basic energy calculations where I feel that the level of our project was quite high compared to other projects and also in relation to the product that we had to make. We also included a lot of theory that was not included in the curriculum. In the exam, we were asked about much of that theory, including more advanced theory, particularly thermodynamics.' (ENG2).

> 'We knew that we could say something about the absorption of sound, and that this issue was relevant in relation to bricks, as they are supposed to be in a house – but that was more or less the understanding we had of that. We did not really know the advantages and disadvantages of the method, and why precisely we used that method, and what the underlying theory was. We had no clue about all this. So, already here we were far beyond our boundaries.' (ENG1)

Here, the student recalls the sense of perplexity that she and her fellow group members felt when including this unfamiliar knowledge in their project to reach the intended results. Understanding her own field and its boundaries, she also realizes that this was far beyond the scope of her program. Across the projects, participants report on occasions where they had to familiarize themselves with unfamiliar knowledge under time pressure. Here the particular social quality of learning in interdisciplinary groups becomes evident. The material contains multiple reports on how the participants succeeded with their projects because they reached out across disciplinary boundaries to relevant resource persons (more advanced students and experts in other departments/programs) and/or were able to draw productively on other group members' knowledge and skills. For example, design students were forced to acquire basic programming skills to support the GAME project team's overburdened programmers. Similarly, a design student taught his skills in a particular design software to the team's art director. The diversity of knowledge and competences in interdisciplinary contexts allows the individual participants to access their peers' specialized knowledge.

At the same time, acquiring a specific 'portion' of another discipline differs from having gone through semesters of introduction into a discipline's theoretical and methodological universe. Students do not develop a sense of the 'foreign' discipline as a mental map allowing them to navigate knowledgeably between the discipline's different areas and approaches:

> 'I was interested in this because it was totally new, and we did not know anything about it. Also, it was like – I knew I had to familiarize myself with it because it would be part of the exam [because it was included in the project]. But the exact analytic method that we used, I know a lot about that now. But generally – about sound, I think – and now I use some PBL concepts – but this funnel, I have focused a lot [on something specific] at the bottom of the funnel that is 'sound'. But if I had to zoom out – I would not be able to do that – it is a very specific knowledge I have got. (ENG1)

Leadership and coordination

From the outset, the social setup of the interdisciplinary projects differed along two dimensions: the extent to which the involved students had collaborated previously and the organizational arrangement within the group (predefined/formal roles or loose/negotiated collaborative relations). In the ENG groups, the students knew each other from previous semester projects. In the rest of the groups, the students came from different programs and institutions. In one of the latter projects, the GAME project, students were recruited into different roles reflecting project team roles in the game industry.

Recruitment for these roles was based on the students' educational backgrounds. The social setup was predetermined by the responsible programs and institutions. The different organizational approaches to the interdisciplinary groups resulted in different social and organizational processes among the students and in different collaboration experiences.

In the projects without predetermined roles, students did *not* problematize the social and organizational relations among them. Rather, collaborative relations seem to already exist or develop in response to the challenges they met (e.g. having to contact and organize meetings with staff from other programs or having to present results to a large group of people). In hindsight, these challenges are described as opportunities for developing personal confidence and collaboration skills:

> 'I remember when I started my education, just asking a supervisor for help was challenging. Now I am used to that and now I think that it has become a little more […] acceptable to ask someone for help, or can this be done, or could you refer us to others who can help. I think that this is perhaps how I benefitted the most from the project'. [ENG1]

In the ENG groups, no student was assigned a predefined leadership role. In one group, one participant was elected to represent the group in meetings with other groups working on the same product. In the HEALTH groups, participants also managed to define a problem and develop a solution without predetermined organizational roles. Instead, the participants in this project had access to project management manuals and facilitators. In addition, one group devised a code of conduct for group interactions, which helped solve the misunderstandings that occurred. Clearly, the different disciplinary foci of the participants were noticed (different concepts, skillsets etc.) but did not seem to generate conflicts or significant misunderstandings. What seemed to gain currency and matter in decision-making processes was the participants' experience related to the healthcare practice, both in terms of internships and healthcare work.

> 'I think that we quickly realized who was doing which semester in their programs, who had more experience in relation to the healthcare system, So, maybe, the ones that were a bit ahead in their respective programs, their voices were perhaps a bit more influential than the ones who were less experienced. I think we nursing students, we were farthest towards completing our education, we were listened to a bit more compared to the others who had not done so much in terms of internships and did not know so much about that.' (HEALTH1)

Without predefined group roles, participants in the loosely structured groups designed their own collaboration structures. In the ENG multi-group projects,

students experience how complex technological products require a coordinated effort from the involved teams and some understanding of the 'foreign' discipline. Combining disciplinary perspectives to meet program expectations within a relatively short timeframe emulated interprofessional collaboration:

> 'I think that part of what we learn is like when we enter the labor market, what can we use others' education for. We know what others can do, and what we can do, and what the difference is. So, when we enter the labor market, you know, you have studied mechanics, then I have some idea of what that is. And when we are going to collaborate, you can imagine how the collaboration is going to play out. And again, that is preparation for the labor market.' (ENG2)

The ENG students also experienced challenges such as communication difficulties and disciplinary turf wars as the interviewed group gained enough understanding of another group's domain to ask critical questions and challenge the calculations done by that group.

In the GAME project, students were recruited into specific roles based on their disciplinary backgrounds. The project structure combined interdisciplinary collaboration and hierarchical relations between participants. Some were appointed 'leads' and 'directors' while others filled more operational roles as programmers and designers. Adopting these roles, participants were expected to complete a quality product within a short timeframe. Having completed the project, participants hesitate to describe the overall experience simply as 'good'. In hindsight, they characterize their experience as 'educational':

> 'Interviewer: Did you have a good experience?
>
> A: There were both good and bad experiences.
>
> B: Ups and downs.
>
> A: Yes, ups and downs, absolutely. There have been both good and terrible experiences, but overall, it has been an awesome experience.
>
> B: At least very educational
>
> A: Extremely educational, there were really a lot of learning experiences, for example when our [team role] suddenly had to take a break from it all. That was a kind of crisis situation, which we had to handle relatively fast.' (GAME1b)

Through the interdisciplinary collaboration participants experienced the importance of clearly defined project roles matching the discipline-specific skillsets of individual participants. Predefined roles made the participants

reflect on and discuss the role requirements and the available competences and knowledge resources and adapt the predefined role structure to these resources. In the beginning, leadership was understood as a question of logistics, planning, and coordination:

> 'like all the tasks we have on Trello where we have each our little block and then we assign ourselves to that and then we move them around so that everyone has an idea of where people are and what they're working on, but besides that we also have a weekly schedule where we have the daily goals and deadlines and meetings and whatnot on, and then we also have a production plan that spans over the weeks that we are working on a specific thing, where we have more clearly outlined and defined tasks with deadlines on.' (GAME1a).

However, towards the end, leadership is understood as the 'art' of knowing others' strengths and weaknesses and working 'with the person' to bring creative talents to fruition in the project. To practice this more advanced leadership approach, gaining an understanding of others' educational and disciplinary backgrounds is necessary. This complex understanding of leadership developed through the group's experience of collaboration issues related to the discrepancy between a particular (leading) role and the skillset of the person filling this role. Thus, advanced leadership involves combination of social skills (working with different personalities) and epistemic fluency ("recognition", "appreciation" and "understanding" different professional and epistemic communities (Goodyear & Zenios, 2007).

The leadership task was complicated by technological challenges. Access to the programmers' time had to be subject to project management control. 'Anarchistic' work processes, for example designers making unauthorized use of programmers' time, developed as a problem in the GAME project's initial phase because essential leadership tasks were not executed. As participants lost confidence in established collaboration structures, they started to 'silo' and focus excessively on limited parts of the design process. Correction of the role distribution and more confident leadership in the latter part of the process (referred to as 'ownership') instilled adherence to decision-making routines and eventually a less stressful working environment for all.

Interdisciplinary conceptual artifacts

Problem- and project-based learning requires that students engage in knowledge-building and develop conceptual artifacts (discussable and improvable ideas) in the process. Considering the investigated projects, the notion of an 'idea' means at least two things. On the one hand, following Bereiter, it refers to a product of thought processes, a mental artifact as opposed

to a product of material work processes. On the other hand, the notion of idea signals invention or innovation, referring to the *novelty* of the product. In these projects, the organizers expect interdisciplinary collaboration to hold a special potential for development of innovative ideas. The connection between innovation and interdisciplinarity plays out in different ways.

In the GAME project, the interdisciplinary setup emulated the standards of the game industry. Generating creative ideas is a routine task in game production and a sought-after skill in the industry. Consequently, idea generation is supported by the curriculum organization (no traditional semesters with exams) of one of the represented institutions, the school cultivating talents for the film and game industry. Most participating institutions, however, represented classic academic traditions involving formal curricula and exams. Participants point out how these epistemic traditions and their impact on students could explain collaboration issues in the project. As valuable as creativity is for game production, it must be combined with organizational skills in addition to competence in realizing ideas through various forms of advanced craftmanship (such as programming skills). In the end, the team generated an innovative game idea and realized it successfully. This was apparently related to thorough understanding of what individual team members brought to the table, and how these specific qualifications could contribute to the project. The epistemic leadership that it takes to enhance the potential of team members across a range of disciplinary backgrounds involves elements of epistemic fluency:

> 'you can only use others' competences effectively by actually knowing the person and finding out how this personality optimally works in relation to others. And that is something we have found out here. To take the same example, our [team role (leadership position)], brilliant and extremely creative, but a very bad leader, and that is the personality causing this, something with leadership, it is not competence, it has something to do with personality and - education. Some competences are highly attractive to the indie industry, but you cannot leverage these competences if you don't work with the person instead of against the person.' (GAME1b).

Similarly, the HEALTH teams addressed problems amenable to innovation. Insight into healthcare practice (professional and patient perspectives) was a valued resource in identifying the challenge and generating an idea for a potential solution. Despite the short timeframe, the HEALTH participants gained an insight into how different disciplinary and professional perspectives contribute to the identification of the challenge and its solution, which benefitted from academic members' attention to detail and practice-oriented participants' experience of patients' everyday life (e.g. patients with multiple

diseases needing to fit many hospital visits into their calendars). Innovative ideas result from the interplay of the represented knowledges and experiences: The health professionals' understanding of patient perspectives, professional ethical values, and academic participants' insistence on conceptual justifications and methodological awareness.

The experience of one of the ENG groups led to reflections on the nature of the product and interdisciplinary knowledge building. Each group was expected to complete a part of the product, matching the group's disciplinary specialization. Two aspects seem to influence the students' experience of contributing to interdisciplinary and innovative knowledge building. Firstly, while the group imagined constructing a physical product, it turned out that they were to do a virtual version of it instead. While this removed some time pressure, it also meant that the groups were less dependent on each other. Without a physical product, the boundary objects were the calculations resulting from simulations done by each group. That collaboration around a virtual product led to a 'weaker' experience of interdisciplinary collaboration became clear as the interviewed ENG group started to doubt the results they received from another group. While an experimental part involving the physical product could generate correct knowledge about the interaction between the two parts of the product, the students had to explain a potential misalignment between the two parts as a caveat in their project report, and at one point they characterize the entire process as '100% theoretical'. Secondly, the students also articulate what it would take to realize the idea that each group's knowledge product could be seen as a 'real' contribution to an overall project. To realize complex technological development projects, knowledge building should involve a coordinated effort across semesters and specializations integrating existing knowledge contributions.

Summary of findings

Across the interdisciplinary study activities, students report how they acquire elements from the disciplines that their fellow students bring into the investigated projects. Acquiring elements from a foreign discipline differs from being induced into a specific disciplinary universe through education. Learning elements from other disciplines happens for specific purposes in order to complete the task at hand. The participating students demonstrated a precise understanding of the contributions of specific disciplines to the task in front of them and of the boundaries of their own and others' disciplinary knowledge. In fact, disciplinary differences, not interpersonal or work ethics challenges, were used to explain collaboration issues during the work process. Furthermore, all participants emphasize the strengthening of social skills as the interdisciplinary nature of the tasks required outreach beyond their disciplinary

comfort zone. Finally, across groups participants recognize the relevance of the interdisciplinary experience for future work contexts.

Discussion and concluding points

This interview study investigates *the cognitive, social, and epistemic gains that students experience when participating in interdisciplinary study activities.* With the caveat that the interviewed participants may have had a more positive experience than their peers, the study illustrates what students *can* gain from interdisciplinary collaboration in terms of cognitive, social, and epistemic aspects. The participants experienced how being part of more diverse learning environments gave access to acquiring an in-depth understanding of 'foreign' concepts and methods that helped generate a more complete understanding of innovative products (ENG projects). The participants also gained experience of how one can effectively pick up needed skills by collaborating with peers who have expert knowledge in a different field, for example design or programming. Generally, working in interdisciplinary projects gave participants a concrete experience of working – under time pressure – with tasks that required the pooling, integration, and development of different types of knowledge within an environment expecting innovative ideas and quality solutions. The participants were aware of how much such situations resemble contemporary labor market conditions.

At the same time as participants characterize the interdisciplinary collaboration experience as rewarding, educational, and even 'awesome', they also shared less optimal experiences. Some interviewees would have preferred more involvement of external partners, and the shift from physical to virtual product in one of the ENG groups was a disappointment. Other participants describe their experience as both good and bad and at times extremely challenging. At the same time, the participants are aware that they have learned so much from the experience *because* it has been challenging. The ENG students were slightly dissatisfied with the '100 % theoretical' product because it would be *more* challenging to do a physical product. These points bring associations to Barrett's concept of 'hard fun' as a core PBL concept (2012).

The organizers of the investigated projects structured the student collaboration differently. In the GAME project, participants were recruited into predetermined roles, in the HEALTH projects participants collaborated as equals without a defined authority structure but with access to process facilitators, and in the ENG projects the organizers relied on students' already existing organizational skills. The importance of leadership and coordination processes is evident in all projects both in the self-structured HEALTH and

ENG projects and in the explicitly structured GAME project where managing the role structure became essential for successful project completion. In the HEALTH projects leadership appears to happen as collectively accomplished tasks where practical experience counts as much as academic knowledge in the process of giving the project purpose and direction (sensemaking and sense-giving).

Which factors contributed to students' experience of cognitive, social and epistemic gains? With the concept of hard fun, we can – tentatively - list a few connections between the experienced gains and the framework set up for the interdisciplinary study activity. Barrett (2012) argues that for an activity to qualify as hard fun, it should have the following characteristics: it must be a difficult task in itself; it should demand a high activity level, and it should contain transformative potential. These characteristics seem to apply to the activities investigated. Table 2 illustrates how particular types of 'hard fun' challenges seem to relate to the students' experience of cognitive, social, and epistemic gains.

Type of gain	**Challenging factors contributing to the experience of 'hard fun' (Barret, 2012)**
Cognitive gains: Mastery of others' knowledge (e.g. select concepts and methods) Acquisition of new skills through peer-learning	Intra-group interdisciplinarity and/or necessity of outreach beyond one's own discipline (connected to task difficulty)
Social gains: Confidence with outreach Developing skills in leading and/or coordinating groups representing diverse skillsets and knowledges	Intra-group diversity and/or intergroup diversity requiring coordination and leadership contribute to an activity's transformative potential Urgency/time pressure contributing to a high activity level Pre-defined (but negotiable) organizational roles as a productive challenge
Epistemic gains Understanding and appreciating 'foreign' knowledge as essential to the common project. Skills related to knowledge integration to achieve the group goal.	Expectation of innovative products/ideas Accomplishing the set task requires integration (not just juxtaposition) of knowledge from different disciplines.

Table 2. Challenges and gains.

In the ENG projects students needed to move from basic understanding to advanced insight and acquire knowledge above their academic levels, and the GAME students describe expectations as mirroring professional standards. All groups describe the necessity of a high level of activity and a sense of urgency and engagement. All interviews contain transformation stories related to stepping out of one's comfort zone, for example reaching out to 'strangers', coordinating contributions, and telling others what to do to make the project succeed. Clearly, more research is needed to arrive at a thorough understanding of the connection between activity/task characteristics and learning gains in interdisciplinary student collaboration. What this study has demonstrated is that investigating interdisciplinary student collaboration requires interdisciplinary research approaches to capture the multi-faceted and complex experience that such collaboration involves. In this study, a combination of cognitive, social, and epistemic concepts was instrumental in capturing students' gains from interdisciplinary projects. That the concept of hard fun seemed to be highly applicable as well, indicates that future research should pay more attention to *affective* factors as well, both to qualify the experience of fun but also to learn more about potential problematic implications of high-challenge student projects such as higher levels of stress and group tensions.

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