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Learning to Collaborate in a Project-based Graduate Course: A Multilevel Study of Student Outcomes

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Abstract
The context of this study is an interdisciplinary project-based course at a large public university in Scandinavia. The course is taught annually to 3,300 graduate students from all fields of study, and learning to collaborate is a specified learning objective. Similar courses are widespread in higher education institutions worldwide, and empirical evidence of their impacts on students' skill development is needed. This study examined students' collaboration skill outcomes; whether outcomes vary by gender, academic achievement, field of study, course format (accelerated and semester based); and variations in outcomes across student groups and course classes. We used a pretest-posttest design in which 89% of students answered a self-report questionnaire about collaboration skills. The results indicate that the participating students' interdisciplinary, interpersonal, and conflict management skills improved significantly from the beginning to the end of the course ($p < .001$, $d > 0.4$). We also found that the accelerated course format positively influenced the students' conflict management skill outcomes and that the variability in the students' overall collaboration outcomes was related to their student group (not their course classes). Another important takeaway from our study is that the students' gender, academic achievement, and field of study showed little impact on their collaboration skills. The non-significance of the measured individual characteristics and the significance of the student group for students' collaboration outcomes are important reminders for teachers in higher education to guide and support both their students' learning and group processes in project-based courses.

Keywords Collaboration skills · Project-based learning · Graduate students · Multilevel regression

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Undeniably, collaboration skills are essential for students of higher education (HE), and the ability to collaborate is key to solving complex problems, innovating, and student employability (Organisation for Economic Co-operation and Development [OECD], 2021; Suleman, 2018). The current demand for collaboration skills requires universities worldwide to facilitate the development of such skills among their students (Williams, 2019), which is difficult in traditional instructor-centered university classrooms (Fisher & Newton, 2014). Project-based learning (PjBL), which is a form of student-centric collaborative learning whereby students work on projects with real-world problems, is a recommended approach to enable students' learning of collaboration (Fadel et al., 2015; Guo et al., 2020).

Interdisciplinary project-based courses are increasingly common in HE, and studies on such courses have indicated that they facilitate students' learning of collaboration skills (Chen & Yang, 2019; DeZure, 2017; Remington-Doucette & Musgrove, 2015). However, previous studies have not moved beyond the (often positive) effects to further examine relationships between student outcomes and other factors (Dettmers & Brassler, 2017; Konrad et al., 2021a). Research on student outcomes and gender is scarce and inconclusive, and few studies have investigated the impact of students' academic achievements on their outcomes in project-based courses. Another highly relevant relationship is between students' field of study and their collaboration skill outcomes, such as whether students in particular areas of study are more adept at collaborating.

In addition to student factors, students' collaboration skill outcomes are likely to be influenced by the fact that they are clustered in student groups and course classes. Educational outcomes commonly vary the most among individual students (Field, 2018); however, given the student-active and group-based nature of interdisciplinary project-based courses, determining the extent of this variability between student groups is particularly interesting. Studies have shown that student outcomes vary significantly across student groups in collaborative learning environments (e.g., Janssen et al., 2011), and student outcomes have also proven to vary between classes, as teachers play an important role in project-based courses (Sjølie et al., 2021). In addition, research has suggested that the course format, either accelerated or semester based, can influence student outcomes (Daniel, 2000; Seamon, 2004). Rather than investigating variations between students, groups, and classes (including teachers) separately, studies that examine how students' outcomes vary across students, courses, and group levels in collaborative learning environments are called for (Strijbos & Fischer, 2007). To bridge these gaps in the literature, we investigated the following research questions:

RQ1. Did the students' collaboration skills change from the beginning to the end of the course? Did these effects vary by gender, academic achievement, field of study, and course format?
RQ2. To what degree were the students' collaboration skill outcomes related to the course format, course classes, student groups, and individual factors?

To make a significant contribution to the current research on students' learning of collaboration in HE project-based courses, we investigated the outcomes of 3,300 students after an interdisciplinary graduate course at a large Scandinavian university. Thus, the study provides unique insights into students' collaboration skills, which can help universities better

plan and execute interdisciplinary project-based courses and facilitate the development of collaboration skills among their students.

Learning Collaboration Skills in Interdisciplinary Project-based Courses

Project-based courses have proven to effectively facilitate the development of collaboration skills across educational levels, including HE (Chen & Yang, 2019). In such courses, students collaborate on projects that resemble real-world activities and co-create products that are assessed at the end (Spronken-Smith & Walker, 2010). PjBL is an inquiry-based and student-centered approach based on the epistemic ideas of constructivism (Hmelo-Silver et al., 2007). In PjBL, students are presented with open-ended tasks and encouraged to set their own goals, use their previous understandings, collaborate, and negotiate (Boekaerts et al., 2000; Dillenbourg et al., 2009). Teachers are facilitators rather than experts who provide scaffolding and guidance, and assessments of project outcomes (Krajcik & Blumenfeld, 2005; Thomas, 2000). In interdisciplinary courses, students need to integrate different information, techniques, tools, perspectives, and skills as they collaborate on their projects (Dettmers & Brassler, 2017; Mansilla, 2017).

Researchers have found positive effects of project-based courses in several fields of study, including health (Wu et al., 2018), education (Frank & Barzilai, 2004), economics (Parrado-Martínez & Sánchez-Andújar, 2020), information technology (Crowder & Zauner, 2013), and engineering (Gavin, 2011; Oliveira & Cardoso, 2021). Although project-based courses in different fields have been extensively studied, studies on interdisciplinary courses have also been increasing. For example, Epstein et al. (2009) found that a vast majority of students reported that their teamwork skills improved after attending an interdisciplinary freshman course. Remington-Doucette and Musgrove (2015) found that students' interpersonal competencies increased in an introductory sustainability course with students from sustainability, business, and seven other majors. Vogler et al. (2018) studied another undergraduate course in which hotel/restaurant administration, computer science, and graphic design students identified teamwork/collaboration skills as the most relevant soft skill for their group's success. A recent study of five sustainability courses, which included natural science, social science, and economics students, found that students' interpersonal competencies positively developed from attending the courses (Birdman et al., 2021; Konrad et al., 2020, 2021b). Although the abovementioned studies investigated university students' interpersonal skills in interdisciplinary courses, only two of them examined graduate-level courses (Birdman et al., 2021; Konrad et al., 2020, 2021b) or applied quantitative approaches (Epstein et al., 2009; Remington-Deucette & Musgrove, 2015).

Even though the results of the abovementioned studies on interdisciplinary project-based courses are encouraging, each study covered only a limited number of academic fields and humanities and health science students (e.g., Birdman et al., 2021; Guo et al., 2020). Only few studies have investigated students across a broad range of fields and examined whether students in particular areas are more adept at learning to collaborate. Furthermore, only a limited number of studies have extended beyond the finding of positive effects to investigate nuances or variations. One exception is the study by Dettmers and Brassler (2017). They found no improvement in students' interdisciplinary competences. They studied five

courses, which included social and natural science students, and suggested that conflicts and disagreements, difficulties in communication, inappropriate expectations, and underestimation of time and effort may explain why students could not collaborate better. On the basis of their unexpected findings, Dettmers and Brassler (2017) encouraged investigations into how student characteristics may be related to students' learning. This approach reminds that the positive effects of interdisciplinary project-based courses should be paid attention and encourages their thorough examination. Finally, many researchers have argued that becoming an effective collaborator is not intuitive and that merely exposing students to group work is insufficient. Becoming a good collaborator requires explicit and dedicated efforts, which means that students need support from their teachers to learn to collaborate (Sjølie et al., 2021). Teachers can support students by providing input on group theory, group skills training (e.g., exercises on listening and feedback), and group processing (e.g., reflection exercises) (Johnson et al., 2008; Rutherford, 2014). In contrast to traditional lectures, facilitating students' learning of collaboration requires teachers to meet students where they are and to scaffold students' group and learning processes (Kolmos, 2009).

Collaboration Skills and Course Format, Classes, and Groups

This study analyzed how course formats, classes, and student groups may influence student outcomes in project-based courses. Research that compared accelerated and semester-based course formats has found that accelerated formats are equal to or superior to semester-based ones (Carman & Bartsch, 2017; Daniel, 2000). In their study of courses across disciplines, Lee and Horsfall (2010) reported overall positive experiences and higher motivation among students in accelerated courses and that the format allowed for focused and uninterrupted learning experiences and highly intensified active learning cycles of theory, practice, and feedback (Lee & Horsfall, 2010). In addition, Picardo (2016) found that students in accelerated courses had better time management skills and access to course resources early, and avoided procrastination. Accelerated formats also have social benefits, as they can strengthen social learning experiences and provide an increased sense of community among students (Lee & Horsfall, 2010). Studies that reported equality of outcomes in the two formats have found that communication between students and teachers increased in accelerated courses and that students prefer this format better (Ferguson & DeFelice, 2010; Williamson, 2018). Nevertheless, accelerated courses still have problems, as they can be difficult for students because of time restrictions and increased stress and fatigue (Doggrell & Schaffer, 2016). Students have been less satisfied with their own achievements in accelerated courses (Daniel, 2000). In favor of semester-based formats, Faught et al. (2016) claimed that students learn more when they have more time to process what they learn. The relationship between student outcomes and course formats is an understudied area in project-based courses, where learning to collaborate is a specified learning objective.

In the course studied here, students were organized into classes of 30 students, one teacher, and two teaching assistants. Differences in the composition of the student group and teaching staff between classes concerning may cause class variations in student outcomes. Even though the teacher's role in project-based courses is more of a facilitator and orchestrator of learning rather than a traditional HE instructor (Dillenbourg et al., 2009), students need guidance and support from teachers to prepare them for collaboration (e.g.,

group skills training) and to talk and reflect on their collaboration (group processing) in such courses (Häkkinen et al., 2017; Sjølie et al., 2021). Investigating class variability is a starting point for learning more about how students' collaboration outcomes may be related to their classes and teachers.

In collaborative learning environments where students spend considerable time in their project group, student outcomes commonly vary between groups (Janssen et al., 2011). A condition that may influence outcomes is the interactions between group members. Interactions offer learning opportunities, even more so when students learn about communication and group theory beforehand, reflect on their interactions, and experiment to improve them (Konrad et al., 2021b). Students' learning also accelerates when they receive support, approval, and recognition from their group members (Johnson & Johnson, 2014). Students learn not only from engaging with their group but also from observing what others say and do (Bandura, 2006; Donnelly & Fitzmaurice, 2005). In other words, other students are important sources of learning for each other. Another factor that influences students' outcomes and learning is whether they feel safe in their group (Cörvers et al., 2016; You, 2021). When students feel secure, trust their group members, and feel that they can be open, they can focus on learning *without considering the consequences for their image in the eyes of others* (Tsuei et al., 2019).

The challenges that each group encounters and how they deal with these challenges may vary between groups and cause variations in student outcomes. Students in the same group are likely to share challenges, and in interdisciplinary groupwork, these challenges are commonly related to group dynamics, such as conflicts (Brandshaug & Sjølie, 2020). If students have the time, space, and will to engage constructively with disagreements and conflicts, such challenges may enable learning (Fam et al., 2020; Walker & Daniels, 2019). By contrast, conflicts can also lead to frustration and inhibit students' learning in project-based courses (Birdman et al., 2021). The openness of project tasks, the large responsibility placed on each group, and their interdisciplinary compositions also challenge students' learning in interdisciplinary project-based courses (Birdman et al., 2021; Hero & Lindfors, 2019).

Most previous studies have focused on HE courses, where students collaborate in monodisciplinary groups in non-project-based course, and have access to a smaller number of groups or classes. Therefore, research on variations in outcomes among individual students, groups, and classes in the context of interdisciplinary project-based courses is scarce.

Individual Student Factors

In research on learning and skill development, most variability in individual outcomes is commonly attributed to student-related factors (Field, 2018). Regarding gender, Remington-Doucette and Musgrove (2015) found that female students exhibited a larger increase in interpersonal competencies than males did after attending a sustainability program. The same study compared the competence development of students from several fields of study and reported no significant differences. Regarding students' academic achievement and collaboration skills, Ballantine and Larres (2007) found that students' interpersonal skills improved irrespective of their academic abilities after attending a course designed to enhance their generic skills (including collaboration). In studies that investigated collaboration skill outcomes in interdisciplinary samples of HE students, quantitative approaches were seldom applied, and differences between students from various fields of study were

rarely examined (e.g., Redman and Wiek, 2021; Vogler et al., 2018). Hence, we investigated (and controlled for) the relationship between students' collaboration skill outcomes and their genders, fields of study, and academic achievements.

The preceding section provides an empirical backdrop for our study, as we investigated students' collaboration skill outcomes in a project-based course with students from five fields across the whole university. We examined the relationship between students' collaboration skill outcomes and the selection of individual and course-related variables. The course we studied allowed us to determine how student outcomes vary between course formats (accelerated or semester based), classes (with different teachers), student groups, and individuals. At the individual level, we examined the relationship between student outcomes and gender, field of study, and academic achievement. A conceptual understanding of collaboration skills is needed to fulfil these aims.

Definition of Collaboration Skills

The collaboration skill domain is characterized by ambiguity and is part of numerous frameworks and instruments. Collaboration skills have been given different labels, including social, emotional, interpersonal, team/groupwork, and relationship skills. They are taught across educational levels and investigated within different disciplines. The collaboration skills used in this study are best described by separating the two words of the term: collaboration and skills. Collaboration describes the process of building and maintaining a shared conception of a problem or task, distributing responsibility across members of a group, sharing expertise, and mutually constructing and negotiating cognition (Roschelle, 1992). Skills describe the "ability and capacity to carry out processes and be able to use one's knowledge in a responsible way to achieve a goal" (OECD, 2019, p.2).

By combining the two, our conceptual understanding of collaboration skills becomes *students' abilities and capacities to carry out collaboration processes and to use their knowledge about collaboration responsibly to achieve a goal*. In a project-based course, the goal can differ; for instance, it can be to complete the project on time or to achieve a top grade.

Collaboration skills include several skill dimensions that are combined for different purposes, such as policymaking, evaluation, assessment, or research. Different categories have been proposed, and the number of collaboration dimensions ranges from 2 to 8 (Lai et al., 2017). Interpersonal and conflict management skills are the most common dimensions, and leadership, responsibility, feedback, communication, and problem-solving are also often included. Interdisciplinary skills have been included in more recent domain descriptions (Brundiers et al., 2021; Center for Curriculum Redesign, 2019). The large variation in collaboration skill dimensions can be considered functional because of variations in the contexts, goals, and processes in which they are used. However, this conceptual ambiguity may be problematic when conducting research on collaboration skills, as it challenges content validity and may lead to misinterpretations of the findings. Therefore, transparency is key to the study and measurement of collaboration skills.

The previous sections provide a backdrop for our study, as we investigated students' collaboration skill outcomes in a project-based course with students from five fields of study across the whole university. In the following section, we present the details of our methods.

Methods

Purpose of the Study

The purpose of our study was to investigate the effects and variations in students' collaboration skill outcomes in a graduate course. We set out to examine the relationship between students' collaboration skill outcomes and a selection of individual and course-related variables. The course we studied allowed us to determine how student outcomes vary between course formats (accelerated or semester based), classes (with different teachers), project groups in which students collaborate, and individual factors such as gender, field of study, and academic achievement. The studied course provided a unique opportunity to investigate variations in outcomes among students attending the same project-based course across the whole university.

We investigated three dimensions of collaboration skill outcomes: interdisciplinary, interpersonal, and conflict management skills. This decision was based on the prevalence of these dimensions in previous collaboration frameworks and research, and their relevance to the investigated project-based course. Interdisciplinary skills were selected because the course included students from all faculties and fields of study at the university, and because interdisciplinary skills are part of the course learning objectives and therefore deliberately trained. Interdisciplinary competence refers to the understanding of different disciplinary knowledge, methods, expectations, and boundaries (Lattuca et al., 2013). Interdisciplinary groupwork not only introduces students to the challenges of interdisciplinary communication but also helps to reduce their stereotypes of those working in other disciplines (Luthje & Prugl, 2006). Interdisciplinary skills include knowing how to draw on others' disciplinary perspectives and integrating different insights to reach a goal (Klein & Newell, 1997). Recognizing how others' skills and knowledge complement and overlap with their own is another vital skill in this dimension (MacDonald et al., 2010). Interdisciplinary skills also include knowing how to utilize one's own and others' skills and perspectives (Center for Curriculum Redesign, 2019), presenting one's expertise to others, and asking questions to students from another field (Muukkonen et al., 2019).

Interpersonal skills were included because they are part of most collaboration skill domains and facilitate group functioning and efficiency (Prichard et al., 2006). Specific skills in this dimension include knowing how to conduct active steps to ensure that everyone feels supported and contributes and how to empathize with others (Center for Curriculum Redesign, 2019). Showing active interest in others' concerns (Boyatzis et al., 2015), providing emotional support, and giving positive feedback (Cumming et al., 2015; Johnson & Johnson, 2017) are other essential interpersonal skills.

The third dimension, managing disagreement and conflicts, was chosen because conflicts are often challenging for students in project-based courses. However, conflicts also provide important arenas for skill training and learning (Konrad et al., 2020; Lee et al., 2015) because regardless of students' expertise, they must handle conflicts repeatedly in group after group (Center for Curriculum Redesign, 2019). Conflict management skills include knowing how to prevent, face, and resolve conflicts and disagreements (OECD, 2018). Other skills in this dimension are knowing how to bring conflicts or disagreements into the open, addressing them in a respectful manner, talking openly with those who are involved,

and when necessary, de-escalating emotions in a situation (Boyatzis & Goleman, 2007; MacDonald et al., 2010).

Prior Surveys

Interdisciplinary, interpersonal, and conflict management skills have been measured in previous studies using self-reports, teacher reports, peer reports, and performance-based measures (Griffin & Care, 2015; Meijer et al., 2020). However, psychometric information on validity and reliability was often not included in these studies (Guo et al., 2020; Valentine et al., 2015). In addition, many studies have investigated collaboration skills as part of other domains instead of "zooming in" on collaboration skill dimensions (Mahoney et al., 2018). For example, our three dimensions have been measured as part of social and emotional skills and intelligence, interprofessional competencies, knowledge work competencies, and groupwork skills, whereas some measures include single items and others scale variables.

Current Survey

In the development of our instrument, we were inspired by the four-dimensional education framework (Center for Curriculum Redesign, 2019) and the following instruments: the Interprofessional Collaborative Competencies Attainment Survey (Violato & King, 2019), the Emotional and Social Competency Inventory University edition (Boyatzis & Gaskin, 2010), the Groupwork Skills Questionnaire (Cumming et al., 2015), and the Collaborative Knowledge Practices Questionnaire (Karlgren et al., 2019). We selected these instruments because validity and reliability information were published, and they fit our context and could be used for repeated-measures research. Items were adjusted, and new ones were added to adhere to the theoretical understanding of each dimension to ensure content validity. Each scale in our instrument was constructed with four or five statements rated using a 5-point Likert scale defined as follows: very low (1 point), low (2 points), medium (3 points), high (4 points), and very high (5 points).

The questionnaire was developed specifically for this study, and collaboration skill development was one of its many topics. First, questions from previous research on collaboration skills were reviewed and adapted to our context. Second, each question was critically examined to avoid overlaps between skill dimensions, social desirability and common method bias, and normative formulations (indicating wrong/right) and to ensure that the questions were meaningful for the students (cf. Podsakoff et al., 2003). Third, English and Scandinavian language versions of the questionnaire were developed and tested by academics and practitioners. Native speakers of both Scandinavian and English languages (and neither) contributed to this phase of development. Two pilot studies were conducted to address potential sources of bias. First, six students who attended the investigated course in 2020 reviewed the questionnaire online and gave written feedback. Second, we observed 20 graduate students discussing the questionnaire in groups and plenaries for 45 min. Most students completed and evaluated the Scandinavian language version, whereas others reviewed the English version. The important takeaways from the pilot study were feedback on questions that were difficult to understand, articulating or phrasing single questions, question order, and response scales.

Factor Analysis

To test our theoretical model of the three latent factors and to determine the extent to which each variable in our dataset was associated with a common factor, we used factor analysis. Table 1 presents three collaboration factors in the posttest data, and the same three collaboration factors were also found in the analyses of the pretest data. The three factors explained 61% of the variance, which is acceptable. We used Kaiser's criterion that only factors with eigenvalues > 1 should be retained for interpretation (Field, 2018). This rule is somewhat arbitrary because it could distinguish between factors with eigenvalues just above and just below 1. However, the scree plot showed that in this analysis, the next factor (number 4) had an eigenvalue of 0.7 (and would only increase the explained variance to 0.66). Thus, the empirical analysis results support a three-factor model. Also of relevance is the finding of the three factors that is consistent with our theoretical understanding.

The initial model included 14 collaboration skill items, and the final factor model included 13 items. One item (managing disagreement by lightening the mood) was removed because of a low factor loading (< 0.4 on its primary factor), and this item negatively influenced the alpha value. The 13 items included in the final factor model had factor loadings

Table 1 Results From a Principal Axis Factoring and Internal Consistency Measures of 13 Collaboration Skill Items in the Posttest Data

Collaboration skill item	Factor loading		
	1	2	3
Factor 1: Interdisciplinary skills			
Presenting your expertise to students of another field	**0.74**	0.06	0.06
Asking questions relating to the practices of students in another field	**0.67**	0.03	0.02
Describing your contributions to the team	**0.62**	0.03	0.03
Actively contributing to the utilization of each team member's skills	**0.56**	0.12	0.09
Describing the contributions of your team members	**0.47**	0.17	0.09
Factor 2: Interpersonal skills			
Providing emotional support to your team members	0.08	**0.81**	0.01
Showing that you care about your team members	0.05	**0.71**	0.04
Being sensitive to the feelings of other students	0.04	**0.69**	0.04
Being there for your team members when they need you	0.08	**0.62**	0.01
Giving positive feedback to other students	0.10	**0.57**	0.05
Factor 3: Conflict management skills			
Managing disagreement by bringing it out into the open	0.05	0.04	**0.86**
Managing disagreement by openly talking about it with those involved	0.03	0.02	**0.84**
Trying to resolve conflict instead of allowing it to fester	0.05	0.08	**0.62**
Eigenvalue	5.3	1.5	1.1
% of variance	41	51	61
Cronbach's alpha	0.79	0.83	0.79

Note. $N = 2{,}972$. "Pattern matrix" from principal axis factoring with an oblique rotation (direct-oblimin) of the posttest data. Factor loadings > 0.30 are in bold. Kaiser-Meyer-Olkin (KMO) value, 0.91; Bartlett's test of sphericity χ^2 (91) = 14,410, $p < .001$

ranging from −0.86 to 0.47, which are satisfactory considering the rule that items should load onto their primary factors > 0.4 (Guadagnoli & Velicer, 1988). Moreover, the reliability analysis of each factor showed that the alpha value decreased when an item was deleted.

First, interdisciplinary skills referred to the students' ability to utilize the skills and perspectives of others. The bivariate correlations were of medium strength, and the scale had a satisfactory alpha of 0.79 (Field, 2018). The scale was designed to combine the five statements into one variable, which was then divided by 5 to obtain the average score for each respondent.

Second, interpersonal skills referred to the students' ability to empathize with and actively support group members. The scale consisted of five statements and tests that showed that the bivariate correlations were of medium strength and that the scale had a satisfactory alpha value of 0.83 (Field, 2018). The scale was designed to combine the five statements into one variable, which was then divided by 5 to obtain the average score for each respondent.

Third, conflict management skills referred to the students' ability to navigate and resolve interpersonal conflicts and disagreements. The scale consisted of three statements and tests that showed that the bivariate correlations were of medium strength and that the scale had a satisfactory alpha value of 0.79 (Field, 2018). The scale was designed to combine the three statements into one variable, which was then divided by 3 to obtain the average score for each respondent.

The correlations between the three collaboration skill scales were of medium strength (Pearson's $r = .52–0.56$).

The Course

We used data from a survey conducted in 2021 in an interdisciplinary project-based course at a Scandinavian public university with 43,000 students. The course had 7.5 ECTS (European Credit Transfer and Accumulation System) credit points, which is equivalent to 3.75 U.S. credit points. Learning to collaborate was a specified learning objective, and 3,249 students attended the course as a compulsory part of their full-time graduate degrees. In the course, each student was a member of an interdisciplinary student group that was part of a course class. The course included 633 groups and 112 classes in total. The average class size was 29 students (range, 10–53 students), and the average group size was 5 students (range, 3–10 students). Each class had a broad theme predefined by its teacher, under which the students defined their own projects. Prior to the course, the students chose their course class based on its theme. Some examples of broad themes are plastic-free oceans, innovation in health care, future jobs, and responsible AI and welfare.

In each student group, students from three or more fields of study collaborated on the same project and wrote two reports: one analyzed their collaboration, and another described the results of their project. Each report accounted for 50% of the group's joint grades (A–F). Of the students, 67% followed the course in an accelerated format (15 consecutive days), while 33% followed a semester-based format (1 day per week for 15 weeks). Both formats had the same course plan and included the same compulsory activities. Activities included formulating a collaboration agreement, mapping individual and group competencies, giving/receiving feedback, and daily individual and group reflections. All teaching and course activities were held online because of the COVID-19 pandemic.

Table 2 illustrates the graduate course design, assessment, and two formats. Both course formats applied similar designs and assessments, but their duration and number of students, groups, and classes varied.

Participants

The students who attended the abovementioned course were from all fields of study at the participating university: Information Technology and Engineering; Humanities and Social Sciences; Economics and Management; Natural, Medical, and Health Sciences; and Architecture and Design. Of the students, 89% were citizens of Nordic countries; 3%, other European countries; and 6%, Asia; 1%, Africa; and 1%, Oceania and the Americas. 30% of the students had 2 or more years of work experience, while 70% had 1 year or less. The course included an almost equal to equal number of male and female students, and 55% of the students reported B grade point averages (GPAs) in their undergraduate studies. The largest field of study represented in the course was IT and engineering (44%), and the number of students from each field of study was not equally distributed between the semester-based and accelerated course formats. Table 3 summarizes the characteristics of the participating students.

The abovementioned variables were used as independent variables in our analyses, where we investigated whether gender, field of study, and academic achievement were linked to students' collaboration skill outcomes. We analyzed whether gender differences occurred because research that compared collaboration skill outcomes of males and females in settings like that in present study was inconclusive and scarce. Our study was also a unique opportunity to investigate the variations between students from five fields of study who were attending the same project-based course. In addition, we were curious to explore the relationship between students' GPA and collaboration skill outcomes in our sample, as only a few previous studies have examined this factor in project-based courses. As the course

Table 2 Overview of the Graduate Course and Comparison of Course Formats

Course	3.75 credits (7.5 ECTS). Compulsory for 3,249 first-year graduate students	
Design	Project-based learning approaches, curriculum on group theory, and project development Examples of activities: collaboration agreement, feedback, and reflection exercises Teacher training on facilitation and group processes[a]	
Assessment	Group grade (A–F) based on one project and one group process report (50/50 count) Due 1 week after the last day of the course	
Formats	**Semester-based format**	**Accelerated format**
Participants	2,178	1,071
Groups	425	208
Classes	75	37
Duration	15 weeks, from January to May Every Wednesday Students had three to four courses	15 days in January Monday to Friday Students had no other courses

Note. The students' fields of study decided which course format they could attend. For example, IT and engineering students attended the semester-based format, and students from architecture and design could choose either format

[a]The teachers completed a 3-hour online course on group theory and attended a 2-day training seminar on facilitation and group processes before teaching the course

Table 3 Participant Characteristics (Independent Variables)

Characteristic	Full sample		Course formats	
	n	%	Semester based n	Accelerated n
Gender				
Female	1,415	45	805	610
Male	1,740	55	1,309	431
Total	3,155	100	2,114	1,041
Field of study[a]				
IT and Engineering	1,392	44	1,289	103
Humanities and Social Sciences	499	16	119	380
Economics and Management	449	14	312	137
Natural, Medical, and Health Sciences	607	19	299	308
Architecture and Design	228	7	101	127
Total	3,175	100	2,120	1,055
Academic achievement[b]				
A	264	9	157	107
B	1,694	55	1,126	568
C and D	1,092	36	732	360
Total	3,050	100	2,015	1,035

Note. The values presented are based on the participants' answers on the pretest survey

[a]The faculty in which a student's graduate program was organized at the participating university

[b]Students' self-reported grade point average (GPA) in their undergraduate studies

format the students' attended was decided on the basis of their fields of study, both variables were important to add to our analyses.

Furthermore, we investigated different course characteristics that could be related to students' collaboration skills. We found the relationship between course formats and collaboration skills to be an understudied area in HE project-based courses.

Data Collection

Data were collected using a questionnaire administered as part of the course's annual student survey on days 4 and 14 of the course (in both formats). All students were invited to answer the survey and were given time to respond online during a class lecture. On the basis of the observations from five classes, the students spent 15–20 min answering the survey. A total of 3,326 students were asked to answer the survey, and 2,921 students responded, with a response rate of 89%. All student responses were included in the analyses, as >90% of the students completed all the questions. In the overall student survey, 5% (pretest) and 7% (posttest) of the data were missing, and 6% (pretest) and 8% (posttest) of the data for our three skill variables were missing. As for our independent variables (in Table 3), between 2% and 4% of the data were missing.

Data Analyses

Paired *t* tests and Cohen's *d* were used to analyze whether the students' collaboration skills changed from the beginning to the end of the course. We investigated whether all groups of students who participated in the course benefitted equally; therefore, we also compared the results between the female and male students, between the students with high and low GPA,

between the students from different fields of study, and between the students who participated in semester-based and accelerated course formats.

Multilevel regression analyses were used to determine the extent to which the class, student group, course format, and individual factors (gender, field of study, and academic achievement) were related to students' collaboration skills. Multilevel models accounted for the nesting of participants in groups and classes, allowing the dependent variables to vary across three levels (random intercepts and fixed slopes). Student group (n = 633) and course class (n = 112) identificatory variables were added to investigate level 2 (group) and 3 (class) variations in students' collaboration skills. We performed this because students in the same group and class were not independent of each other (Field, 2018): students in the same class shared plenary learning experiences and had the same teacher, and students in the same group shared (positive and negative) experiences through group exercises, meetings, and group interactions.

Results

Table 4 presents the results of the paired *t* tests for comparison of the participants' means from the pretest to the posttest for the three collaboration skill scale variables. The mean differences were between 0.31 and 0.39, and the effect sizes (*d*) were between 0.52 and 0.69. This finding indicated medium to large effect sizes for all three skill scales (Calin-Jageman & Cumming, 2019) and that the participating students' collaboration skills on average changed significantly from the pretest at the beginning of the course to the posttest at the end. Non-parametric tests based on medians were also conducted, and the results from the paired *t* tests were confirmed. The Pearson's *r* correlations for the participants' reported skills at the pretest and posttest were medium (0.47, 0.59, and 0.41), which was as expected in repeated-measures research (Bonate, 2000).

Table 5 shows the results of the paired *t* tests for comparison of the participants' means from the pretest and posttest in groups divided by gender, GPA, field of study, and course format. The results indicated a statistically significant difference ($p < .001$) and medium-to-large effect sizes for all the investigated groups.

The female and male students displayed similar results in their pretest and posttest scores for all three skill scale variables. Students with different GPAs also showed similar results. The only exception was that the students with a GPA of B had a greater change in interdisciplinary skills from the pretest to the posttest. Differences between the pretest and posttest skills were also similar for the students from different fields of study; however, some fields were distinct: Humanities and Social Sciences had a particular positive change in interdis-

Table 4 Comparisons of Interdisciplinary, Interpersonal, and Conflict Management Skills Reported at the Pretest and Posttest

	Pretest mean	Posttest mean	Mean difference	*p*	Cohen's *d*	Pearson's *r*
Interdisciplinary skills (1–5)	3.37	3.76	0.39	<0.001	0.69	0.47
Interpersonal skills (1–5)	3.76	4.07	0.31	<0.001	0.52	0.59
Conflict management skills (1–3)	3.59	3.95	0.36	<0.001	0.65	0.41

Note. $N = 2{,}921$

Table 5 Comparisons of Collaboration Skills in the Pretest and Posttest for the Groups of Participants

	Interdisciplinary skills		Interpersonal skills		Conflict management skills	
Group characteristic	Mean difference	Cohen's *d*	Mean difference	Cohen's *d*	Mean difference	Cohen's *d*
Gender						
Female	0.41**	0.72	0.32**	0.65	0.37**	0.51
Male	0.37**	0.66	0.31**	0.56	0.35**	0.49
Grade point average						
A	0.36**	0.60	0.26**	0.47	0.39**	0.50
B	0.40**	0.72	0.33**	0.64	0.37**	0.50
C and D	0.39**	0.68	0.30**	0.57	0.34**	0.48
Field of study						
IT and Engineering	0.40**	0.69	0.33**	0.59	0.38**	0.52
Humanities and Social Sciences	0.41**	0.78	0.30**	0.63	0.29**	0.40
Economics and Management	0.34**	0.56	0.25**	0.51	0.30**	0.43
Natural, Medical, and Health Sciences	0.41**	0.69	0.35**	0.66	0.38**	0.55
Architecture and Design	0.37**	0.67	0.28**	0.55	0.45**	0.64
Course format						
Accelerated	0.43**	0.76	0.36**	0.71	0.40**	0.56
Semester based	0.37**	0.66	0.30**	0.55	0.35**	0.47

Note. $N = 2{,}921$. $^{**}p < .001$

ciplinary skills; Natural, Medical, and Health sciences had notable changes in interpersonal skills; and Architecture and Design had notable changes in conflict management skills. The students in the accelerated format had a greater change from the pretest to the posttest in all three collaboration skills than the students in the semester-based format.

Table 6 provides the results of the multilevel regression analyses performed to investigate the relationship between the students' collaboration skill outcomes and course characteristics and individual factors. As the course format that the students attended were decided on the basis of their fields of study, we included interaction variables to distinguish the effects of the course format from those of the student characteristics at the course level.

The most important finding in Table 6 is that the group-level variation was substantial for all collaboration skills, whereas the class level was of less importance. Most of the variance in collaboration skills was accounted for by individual-level factors (85–89%), but a significant student group-level effect (9–13%) and smaller class-level effect (2%) were also found. The significance of the group level for the student outcomes suggests that adding group-level variables and random slopes could have further improved the model. However, we decided not include these to because each student group included only a few students and we had no group-level variables available. At the class level, the effects were < 2%, which indicates that the clustering of the students in course classes was not substantial. Therefore, it was not meaningful to examine additional variables or add random slopes at the class level (cf. Muthen and Satorra, 1995).

A second notable finding was that the conflict management skill outcomes of the students in the accelerated course format were significantly higher than those in the semester-based format after controlling for the other variables. The accelerated format did not have signifi-

Table 6 Multilevel Regression Analyses for Predicting Students' Collaboration Skill Outcomes

Effect	Interdisciplinary skills	Interpersonal skills	Conflict management skills
	Estimate (SE)	Estimate (SE)	Estimate (SE)
Fixed effects			
Intercept	1.97** (0.07)	1.77** (0.06)	2.44** (0.07)
Pretest skills	0.53** (0.02)	0.60** (0.02)	0.41** (0.02)
Gender			
Female	–0.02 (0.02)	0.07** (0.02)	–0.02 (0.02)
Grade point average			
A	0.06 (0.03)	–0.02 (0.03)	–0.04 (0.04)
B	0.05* (0.02)	0.02 (0.02)	–0.04 (0.03)
Field of study			
Humanities and Social Sciences	–0.04 (0.05)	0.02 (0.05)	–0.03 (0.04)
Economics and Management	–0.08* (0.03)	–0.06 (0.03)	–0.07 (0.04)
Natural, Medical, and Health Sciences	–0.03 (0.03)	–0.05 (0.03)	–0.07 (0.04)
Architecture and Design	–0.02 (0.05)	0.00 (0.05)	0.05 (0.06)
Course format			
Accelerated	0.11 (0.06)	0.09 (0.06)	–0.21** (0.07)
Interaction effects			
Humanities and S. Sciences × Accelerated	–0.01 (0.08)	–0.02 (0.07)	–0.14 (0.10)
Economics and M. × Accelerated	–0.05 (0.08)	0.02 (0.07)	–0.09 (0.09)
Natural, M. and H. Sciences × Accelerated	–0.05 (0.07)	0.08 (0.07)	–0.06 (0.09)
Architecture and Design × Accelerated	–0.07 (0.09)	0.02 (0.09)	–0.11 (0.11)
Random effects			
Variance components			
ICC% student level	87	89	85
ICC% group level	11	9	13
ICC% class level	2	2	2
Total variance	26	21	38

Note. N=2,921. The reference categories were male; C and D grade point average; IT and engineering; semester-based; IT and Engineering × Accelerated. SE=standard errors are in parentheses. ICC=Intra-level correlation coefficient. Estimates of covariance parameters for residuals and intercepts are provided in Appendix 1. *p<.05. **p<.01

cant relationships with interdisciplinary and interpersonal skills. Moreover, the effect of the accelerated format depended only to a small degree on the field of study.

Regarding the individual factors, gender, GPA, and field of study had no particularly strong relationship with students' collaboration skill outcomes. The female students had statistically higher outcomes on interpersonal skills than males, students with B GPAs had somewhat higher skill outcomes on interdisciplinary skills than students with C/D GPAs, and Economics and Management students had the lowest outcomes on interdisciplinary skills.

The effects of the students' collaboration skills at the pretest were statistically significant (p<.01) for all three skill scales. This dependent relationship was expected and investigated for control purposes.

Discussion

This study investigated whether students' collaboration skills changed from the beginning to the end of an interdisciplinary project-based course and whether collaboration skill outcomes were related to course and student characteristics. Our survey instrument was reliable for measuring the three dimensions of collaboration skills (interdisciplinary, interpersonal, and conflict management skills) and robust for use in our large interdisciplinary student sample. The questionnaire was validated through the review of collaboration instruments, the different pilot studies among students, factor analysis, and the measurement of internal consistency. In line with our theoretical understanding, three collaboration factors were identified.

Three main findings were obtained. First, most students' collaboration skills changed from the beginning to the end of the course. Significant changes and medium effects were found among the students from both genders, students with low and high grades, and students from different fields of study. Second, the conflict management skill outcomes of the students in the accelerated course format were higher than those of the students in the semester-based format. As for interpersonal and interdisciplinary skill outcomes, we did not find significant differences between the students in the two formats. Third, the student group level had a substantial impact on the collaboration skill outcomes. All the students performed their project and shared experiences in a group with 4–6 students, and the students' collaboration skill outcomes were clearly related to their student group.

Overall Change in Collaboration Skills

Our first finding indicated that *the course successfully facilitated the development of collaboration skills* in most students. This is supported by several other studies. The review by Guo et al. (2020) of studies on PjBL in HE, the empirical studies by Epstein et al. (2009) and Remington-Doucette and Musgrove (2015) from interdisciplinary undergraduate project-based courses, and the investigations by Birdman et al. (2021) and Konrad et al. (2020) of graduate students in international sustainability programs. Considering the findings from previous studies and the fact that the course applied the recommended project-based approaches (Fadel et al., 2015; Guo et al., 2020), the consistent medium-to-large effects we found must probably be expected: learning to collaborate was part of the learning objectives; teachers facilitated and guided students; student groups completed compulsory group activities (e.g., giving/receiving feedback and group and individual reflections); and students were assessed on a report where they analyzed their collaboration.

Change in Collaboration Skills and Implications of Course Format

Our second finding indicated that the *students who were attending the accelerated course format improved their conflict management skills more* than did the students in the semester-based format. We investigated two course formats in which the students in the accelerated format met every day for 15 consecutive days. By contrast, in the semester-based format, the students met for 1 day a week for 1 semester (15 weeks). After we controlled for the students' skills at the beginning of the course, gender, field of study, and GPA, we found that the accelerated course format positively predicted the students' conflict management skill

outcomes but was not related to their interpersonal and interdisciplinary skill outcomes. As regards to the benefits of the accelerated format on the students' conflict management outcomes, researchers have proposed possible explanations. First, the benefits of accelerated courses were confirmed in Carman and Bartsch's (2017) quantitative study of a graduate course and Picardo's (2016) study among undergraduate students, which suggested that students learn more and are more motivated when they are closer to their deadline. In addition, Lee and Horsfall (2010) reported that students experienced an increased sense of community with and responsibility to their peers and that they were able to immerse themselves in a single topic when the timeframe of the course was shorter. As for conflict management skills, it may be that the students in the accelerated format took the time, space, and will to engage constructively with potential conflicts because their project period was shorter, uninterrupted, and denser (cf. Fam et al., 2020; Walker and Daniels, 2019). It may also be that students are more likely to address *and* learn from conflicts (cf. Konrad et al., 2020) when their project period is shorter. Our overall findings regarding the course format are in line with Daniel's (2000) review of HE courses across disciplines and nations, which concluded that most courses, regardless of discipline, could be appropriately taught in a time-shortened format. Thus, our study makes an important contribution to the research on course formats, as the relationship between students' outcomes and course format has not been previously investigated in project-based courses.

The Impact of the Group Level on Collaboration Skills

Our third finding showed that a substantial part of the variability in the students' skill outcomes was attributed to their student group. This finding confirms that students' learning is linked to their student group, as suggested by Janssen et al. (2011). One possible reason for this feature may be that students spend a lot more time with their group than with their class in the studied course. The group is where students interact and experience, practice, and experiment to learn how to collaborate (Konrad et al., 2021a). Another point is that students' learning from observing others relies considerably on what the other students in their group say and do (Bandura, 2006; Donnelly & Fitzmaurice, 2005). Students' skill outcomes may also be influenced by the support and recognition they receive from their group members; for example, *did they feel secure and trust their group?* (Cörvers et al., 2016; You, 2021). Presumably, the groups differed in terms of whether they experienced disagreements and conflicts. In other words, some students may have experienced conflicts and had an arena for training and experimenting with conflict management but others may not (Konrad et al., 2020; Lee et al., 2015). To further explore the group's influence on students' collaboration outcomes in future studies, we encourage investigations using qualitative approaches that focus on what differences between groups may cause some groups to do better than others. Adding group-level variables such as shared goals, psychological safety, and/or group efficacy should be considered in future studies.

We found minimal variation in the students' collaboration skills among the 113 course classes, which suggests that students' collaboration skills were successfully and equally developed across classes. The role of the teacher as a facilitator might have reduced the influence of teachers on their students' outcomes (Krajcik & Blumenfeld, 2005; Thomas, 2000). By contrast, researchers have agreed that teachers play a key role in project-based courses, as exposing students to collaboration is insufficient (Häkkinen et al., 2017; Sjølie

et al., 2021). Another possible reason for the equality between classes is the course design, in which all teachers followed the same course plan and facilitated the same compulsory activities among their groups of students. Future research must investigate the relationship between teachers, course design, and student outcomes in similar courses.

The collaboration outcomes we measured varied the most among the individual students, which was expected (cf. Field, 2018). In addition, we found that the *female students had a larger change in their interpersonal skills* than the male students, which is in line with Remington-Doucette and Musgrove's (2015) results from their pretest/posttest study in a sustainability course. However, Ballantine and Larres's (2007) quantitative study in a final-year undergraduate course did not find significant differences in outcomes between male and female students or between more and less able students (based on their GPAs). This latter finding supports our findings that the relationship between students' collaboration skill outcomes and their GPA was not significant. As for the students' field of study, our research provides a unique contribution by examining a large sample of students from all fields of study at one university, including the humanities and health sciences (cf. Birdman et al., 2021; Guo et al., 2020). Therefore, our finding on the non-significant relationship between students' collaboration skill outcomes and their field of study is worthy of attention. We encourage future studies on interdisciplinary project-based courses in HE to include further individual student characteristics such as students' openness and diligence, as proposed by Spelt et al. (2009).

The variations in outcomes at the student level may also be influenced by the context we investigated: students' abilities to learn and the previous understandings with which they enter the course are likely to vary and affect their development of collaboration skills in the investigated course (Boekaerts et al., 2000; Dillenbourg et al., 2009). Considering the interdisciplinary characteristics of the course, students can differ in how they apply and handle different information, techniques, tools, perspectives, and skills (Dettmers & Brassler, 2017; Mansilla, 2017). The latter impact of the interdisciplinary context remains to be examined, as this factor was not within the scope of our study.

Implications for Theory and Practice

The presented research has three implications. First, teachers, planners, and administrators can consider the characteristics of the investigated course when they plan future project-based courses, for example, to include learning to collaborate in learning objectives, implement compulsory group activities (feedback and individual and group reflections), provide teachers with course plans, and have students analyze their collaboration as part of the assessment. The results regarding course formats may also be useful to consider. Second, the findings on the significance of the group (and not so much the class) may serve as a reminder for teachers in project-based courses to guide and support their students and groups to help them feel safe and build trust among group members to facilitate learning. Third, our instrument can be used to measure students' collaboration skills in three dimensions. It exemplifies how interdisciplinary, interpersonal, and conflict management skills can be operationalized and understood and may provide some clarity to the ambiguous domain of collaboration skills. We welcome further development and use of our measures in future courses, both for research and teaching purposes (e.g., as a rubric).

Limitations and Further Research

The main strengths of our study are the large interdisciplinary sample (3,326 students from five fields of study) and the high response rate (89%). We had access to an entire cohort of graduate students at a large university. However, this advantage is also a limitation, as it left us without a control group, as no comparable control courses or cohorts were available.

A methodological limitation was the use of self-reports, which assumed that respondents answered the questionnaire accurately (Groves et al., 2013). Therefore, the results were likely influenced by students' biases (Schlösser et al., 2013). We measured students' collaboration skills at the beginning and end of the course, and long-term measurements were not applied. By using long-term measures and peer reports, teacher reports or behavioral indicators must be considered in future studies. We encourage both quantitative and qualitative research to further substantiate the ecological validity of our results.

We did not attempt to build a full explanatory model of students' collaboration skill outcomes and did not include variables at the group level or random slopes. Therefore, we encourage further research that expands our model with, for example, group variables on interactions, safety, challenges, or conflicts. As for individual-level variables, we present zero findings and hope that future studies will include more variables on this level, such as personality, self-efficacy, and mindset.

Even though we opted to study three dimensions of collaboration skills, studies that thoroughly investigate each of the interdisciplinary, interpersonal, and conflict management skills are necessary. We particularly encourage research that further explores the relationship between students' conflict management skill outcomes and course formats. Using multiple methods to study factors, such as interdisciplinary skills, more thoroughly may build a more comprehensive understanding of students' learning in this dimension. At the same time, we recognize the need for research that explores and enhances our understanding of the large collaboration skill domain.

Conclusion

This study examined students' learning in a large interdisciplinary graduate course with two formats: accelerated (15 consecutive days) and semester based (1 day/week for 15 weeks). Using a pretest-posttest study design, we investigated whether students developed collaboration skills (interpersonal, interdisciplinary, and conflict management skills) in the course. Our findings indicate that the students' collaboration skills improved significantly and varied between individual students and student groups (not classes) and that the students' gender, academic achievement, and field of study did not predict their collaboration outcomes. However, the accelerated format did positively impact the students' conflict management skills. Our study has significant value to HE as it (1) investigated an interdisciplinary project-based course with 3,326 graduate students from across the whole university, (2) employed and validated a collaboration skill survey instrument, and (3) accounted for the non-independence between students, student groups, and course class in analyzing students' outcomes.

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Availability of Data and Materials Participation in the survey was voluntary, and participants' confidentiality was protected. The data collection was approved by the Norwegian Data Protection Services (reference number 628979). The data that support the findings of this study are available from The Experts in Teamwork Academic Section at the Norwegian University of Science and Technology (NTNU) but restrictions apply to the availability of these data, which were used in agreement with the head of the section for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of The Experts in Teamwork Academic Section, as part of the Department of Industrial Economics and Technology Management at NTNU.

Declarations

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article, and no funding was received to assist with the preparation of this manuscript.

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