STUDENTS' VIEWS AND EXPERIENCES IN INTERDISCIPLINARY GROUP WORK ON A COURSE COMBINING MATHEMATICS, ARTS, ARCHITECTURE, AND DESIGN

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ABSTRACT

Mathematics is everywhere. Therefore, it can also be studied from many perspectives, not just with pen and paper, starting from definitions and proceeding to proving theorems. In this article, the context for learning mathematics is an interdisciplinary university course at the intersection of mathematics, arts, architecture, and design. The course utilizes group work as the pedagogical approach; students are divided into heterogeneous, multidisciplinary groups at the beginning of the course, and they work in the same groups for five months. We present their views and experiences on the elements of successful group work in learning mathematics in an interdisciplinary course and examine the challenges encountered by students in their group work.

INTRODUCTION

Mathematics studies at the university level typically focus on sophisticated techniques essential for producing final, polished proofs. However, this approach may fail to reveal underlying ideas that are fundamental to true understanding, especially for those outside the natural sciences and engineering, who may not be familiar with the language used. Highlighting the visual ideas behind mathematical results could make the subject more inclusive, inviting students from all backgrounds. One way to provide opportunities for all students to engage is through interdisciplinary group work, which builds on the diverse knowledge and skills that students bring with them.

Group work, in general, is considered a viable way of studying university mathematics. It fosters higher quality learning and results in better learning outcomes than traditional lecturing, as observed, for example, by Freeman et al. (2014) and Springer et al. (1999) in their meta-analyses. Group work has become much more

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common in recent decades, and, for example, Sofroniou and Poutos (2016) provide a literature review on group work in mathematics, starting from the 1980s. The positive effects of group work in natural sciences, engineering, and mathematics are even greater for members of underrepresented groups such as gender minorities and ethnic minorities, as was observed by Springer et al. (1999). With group work and shared group goals also competition between individual students can be reduced, which can lead to more equal participation of women and other groups usually underrepresented in mathematics courses, since they more often suffer from very competitive classroom environments (Seymour et al., 2019).

Successful group work does not arise spontaneously, but requires adept guidance and facilitation (Reinholz, 2018; Oakley et al., 2004). Attention must be paid to group formation, and the groups should be guided to reflect on their own work. In this aspect, the establishment and discussion of group norms that regulate how the group members should interact with each other, hold significant importance (Reinholz, 2018).

Interdisciplinary group work in higher education is gaining traction due to the recognition that complex problems require diverse perspectives (Jaskyte et al., 2024; Uthrapathi Shakila et al., 2021; Choi & Pak, 2006). By interdisciplinarity, we mean a true integration of methods and knowledge from several disciplines. Choi and Pak (2006, p. 359) recommend defining multidisciplinarity and interdisciplinarity as follows:

> Multidisciplinarity draws on knowledge from different disciplines but stays within their boundaries. Interdisciplinarity analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole.

The benefits of group work alone are indisputable (Freeman et al., 2014; Springer et al., 1999), but with interdisciplinary group work, completely new dimensions of learning can be reached. Jaskyte et al. (2024) observe that task-oriented, cognitively diverse teams demonstrate higher team innovation performance, emphasizing the importance of diverse perspectives. According to Corbacho et al. (2021), participating in an interdisciplinary course influenced students' development in four key areas: teamwork, confident idea exploration with peers, personal growth, and the cultivation of relevant ethical, social, and professional perspectives. When collaborating in interdisciplinary groups, students often also face challenges, such as the unequal distribution of workload and tension arising from disciplinary differences (Uthrapathi Shakila et al., 2021).

Interdisciplinary group work in mathematics can provide subject learning opportunities also for advanced mathematics students, as the perspectives can differ significantly from those in traditional, calculus-oriented mathematics courses. The mathematical topics, such as symmetries and tilings, which lead to concepts like Kleinian groups and orbifolds, can be explored through making prototypes, conducting demonstrations, creating visualizations and using digital media or tools from crafts (Peltonen & Isoniemi, 2023). Traditional teaching encourages thinking about mathematics through manipulations (arithmetic, algebra), while this interdisciplinary approach emphasizes that mathematical perception can

also be developed through subjective ideas, which can then be formally expressed in the language of mathematics. Thus, the interdisciplinary approach not only invites students from other backgrounds to work with mathematics but also offers a completely new perspective to mathematics students themselves. As described by Kangas (2023), who was in the final phase of PhD studies in mathematics while taking part in 2015 on the course discussed here:

> I imagined I would learn more about art than mathematics - - I was wrong. - - Although I had always liked geometry and geometrical thinking, the course gave me a new, more visual dimension to mathematics.

Interdisciplinary mathematics learning at the school level has been studied quite extensively, with a review on the topic provided, for example, by Doigt et al. (2019). However, almost all the cases presented in their work are limited to the STEM fields. While there is already some research on interdisciplinary group work in higher education, it is also mostly in fields that are traditionally considered close, such as mathematics, physics, and engineering, or related to problems arising from industry (see e.g. Uthrapathi Shakila et al., 2021). Not much is known about group work at the interface of mathematics and disciplines outside of natural sciences or engineering. We aim to investigate whether the same benefits and challenges arise in this setting or is there something that should specifically be paid attention to.

The research questions are the following:

1. What elements do the students consider important in successful group work at the beginning of the course and at the end of the course?
2. What kind of problems in group work do the students identify?
3. How do they describe the impact of the diverse disciplinary backgrounds of group members on their group work?

METHOD

Context

The context of this study is an interdisciplinary course on mathematics, arts, architecture, and design at Aalto University, Finland. The course is a part of Math&Arts Minor but can be also taken independently. According to the course syllabus, on this course the students gain tools to study and present mathematical ideas via artistic methods. Unlike traditional university mathematics courses, this course offers a broader perspective on mathematics, aiming to convey the essence of ideas rather than techniques. Central to the course is a research-oriented approach. The course addresses topics that can be approached without a standard mathematics student's background, such as rigid motions and conformality, which can be understood through common language concepts, and then explored further. The power of mathematics is exemplified through classifications, providing tangible examples of what mathematics can achieve. Such an approach is presented e.g., by Peltonen and Isoniemi (2023). The course is open to students from all study programmes, both with and without a mathematics

background. The course lasts 21 weeks, it is worth 15 ECTS and ends with a public exhibition (see the course timeline in Figure 1).

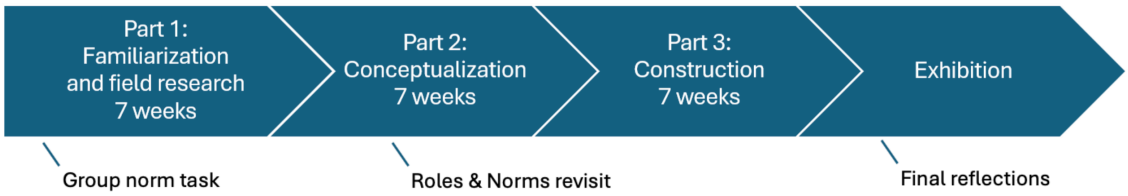

Figure 1: Timeline of the course

In the first part of the course, various topics, especially from low dimensional topology and geometry are presented and discussed through lectures, visitor talks by artists, designers, and architects and group assignments. In the academic year 2022–2023 these topics included e.g. configurations in 3 and 4 dimensions, transformations like folding, origami, and kirigami, as well as themes from geometry of surfaces and curvature. In the second and third part of the course, the student groups design and build a prominent, mathematically themed exhibition targeted to a wide audience, which is then showcased in a public venue. Through this project, the students deepen their understanding about the aspects of topology and geometry and find new interpretations of them.

The course is taught by a diverse team of instructors, each representing various disciplines, with a mathematician as the responsible teacher, who curates speakers for different sessions. Through collective agreement on overarching themes and strategies, the group of instructors and visiting specialists weave together disparate subject matters, creating a cohesive learning experience: despite presenting topics from their unique perspectives and specialized expertise, the team ensures cohesion and continuity throughout the course.

Students work in multidisciplinary groups of four to five students, to which the teachers divide them taking diversity e.g. of disciplines, languages, genders, and study phases into account. In forming the groups, the teachers make sure that there is at least one mathematics student, one art student and one engineering student in each group as well as both younger and older students, and that different genders and native languages are present in each group. Also, each group has at least one member, who is taking the whole minor in Math&Arts, and therefore has some experience in studying mathematics starting from concepts and ideas rather than equations and proofs. Motivational letters that the students provided when enrolling in the course are also considered in forming the groups to ensure variety of backgrounds and interests. Groups remain fixed for the length of the course, if nothing unexpected (such as a student dropping out) happens. Research findings support having such instructor-chosen groups of size three to five (Reinholz, 2018; Oakley et al., 2004).

The course and the final exhibitions have been presented in more detail by Peltonen (2016; 2019; 2023), and the aspects of facilitating group work in this setting by Kangaslampi (2023).

Participants

The participants in the research were students enrolled in an interdisciplinary course on mathematics and arts. Altogether, 27 students consented to participate in the study, and 23 also provided their background information. Of these 23 students, 12 were women and 11 men. Their average age was 27 years (SD = 9.8 years), and their average year of study at the university level was 3.6 (SD = 2.1), ranging from the first to the 10th year. For 10 students, the native language was Finnish, for 4 students Swedish, for 3 students English and some other language for 6 students. The ethnic background of 14 students was Finnish, and non-Finnish for 9 students. About 40 % of the students studied arts, design, or architecture, another 40 % studied mathematics, physics or computer science, and the rest had some other major.

All participants gave their consent to participate in the research. The participants had the possibility to withdraw from the research at any time. The research plan was approved by Aalto University Research Ethics Committee.

Data

This study utilizes the students' reflections and their answers to one group work task as research data. The students wrote reflections weekly, but for this study their reflections were selected from two weeks: one round of reflections from mid-course (N=17), and final reflections after the course had ended (N=18). The length of the reflections varied from a few lines to a few pages, and the language was Finnish or English, depending on the student. Some reflections included photos or pictures, but they were omitted from the analysis. In addition to the reflections, the students' submissions to a group work on group norms and values were collected from four groups. The group work took place on the second week of the course, and the submissions consisted of pictures of an A0-size paper per group, where the group had collected their ideas. The data was pseudonymized to ensure confidentiality and was collected as part of course activities.

Analysis

The students' reflections and group work documents were analysed using content analysis and thematic analysis (Kallinen & Kinnunen, 2024). The documents were read several times for familiarization and to recognize parts, where the students discussed themes that were of interest to this research. Then these parts were extracted from the documents and entered into Excel spreadsheets for analysis. The text excerpts were divided into smaller parts before identifying common patterns and perspectives. Each excerpt was assigned preliminary codes based on the content. The codes were then examined and grouped into broader categories that emerged from the data. This process was iterative, with categories being refined and adjusted when new insights were gained. Final categories representing the key themes observed in the data were established after thorough examination and comparison. The content of the excerpts in each of the final categories was then analysed further to determine what features and issues the stu-

dents discussed and what observations they made. Additionally, the final categories were analysed to identify overarching themes reflecting the students' experiences.

RESULTS

Group work on group norms and values

In the second week of the course, the students were divided into the groups in which they would be working for the duration of the course. Their first assignment as a group was to get to know each other, invent a name for their group, and discuss group norms (instructions for the assignment "Getting started with the Groups!" are presented in the appendix). This assignment was based on the recommendations by Reinholz (2018) and Oakley et al. (2004) as well as the teachers' experiences. They collected the main points of their discussion into a free-form document, which was then analysed.

In four groups all students gave their consent to participate in the research, so here we present the views and topics they raised on group norms, core values and expectations. We consider these three areas at the same time, since some groups listed their views under group norms, while others presented them as core values or expectations.

The topics they raised were divided into seven categories using thematic analysis. The categories, the number of occurrences of comments in the group work, and the groups presenting ideas in each category are presented in Table 1.

Table 1: Categories of group norms, core values and expectations.

	Category	Examples	Groups
1	Creating a supportive and inclusive environment	"Be flexible and amicable", "Respect everyone's opinions	A, B, C, D
2	Encouraging individuality and creativity	"Bring your crazy ideas in", "Step out of comfort zone"	A, B, C, D
3	Effective communication practices	"Proactive communication", "Understanding and listening to others"	A, B, C
4	Having fun	"Joyful creation"	A, C, D
5	Commitment to participation	"Active participation", "Mindful time management"	A, C, D
6	Commitment to excellence	"Do the best you can!"	B, D
7	Supportive decision-making culture	"Make the decision", "Transparency"	A, C

Two categories, "Creating a supportive and inclusive environment" and "Encouraging individuality and creativity", were recognized from the norms and values of all four groups. The former was presented in group norms for example, as "Be flexible and amicable", "Respect everyone's opinions" and "Encourage". This category also encompassed the highest number of observations made by the groups. The latter category was presented e.g. as "Bring your crazy ideas in",

"Step out of comfort zone" and "Limitlessness". Three other categories were recognized in the norms and values of three of the four groups. These were "Effective communication practices", "Having fun" and "Commitment to participation". Two groups also made observations categorized as "Commitment to excellence" and "Supportive decision-making culture".

In the middle of the course, the students were asked to revise their group norms and distribute roles to the group members for the final project they were starting to work on. They were asked to discuss whether they still agree with the norms they chose at the beginning of the course, or if they would like to add or change something. Then they were asked to discuss the final project and consider what kind of responsibilities they can identify and how they would like to assign roles among the group members. Such an exercise has been recommended, for example, by Reinholz (2018) and Oakley et al. (2004).

In their weekly reflections, two students from group A, four from group B, two from group C, and three from group D shared their thoughts on this group exercise. In group A, one student observed difficulties in their group related to uneven workloads, timing issues ("deadlines come as surprises"), and lack of progress on tasks. Another reported that the group was working through the roles they had started taking. They also mentioned not feeling a sense of belonging with their group. In group B, the students had confirmed their group norms, and they hoped that dividing roles would help address uneven workloads (two students) and improve organization (three students), as they had noticed uneven commitment and difficulties in finding common time to work.

In group C, two students thought that the group work was going well but emphasized the importance of specific roles. They also noted that the timing of their work needed adjustment and decided to have weekly meetings. Three students from group D wrote that the group work was going well and that it was a good time to discuss group dynamics. One student mentioned that dividing roles would have clarified expectations for each member, but other group members did not want to divide roles.

Final reflections

In the final reflections, the students (N=18) reflected on their experiences during the whole course. The parts where students discussed group work or things related to their group were collected for analysis.

The first aspect to be noted from the final reflections was that the students considered the diversity of the groups to be very important. Altogether, twelve students clearly emphasized the importance of having members with different backgrounds working in the team. The students were able to describe in detail what each group member brought to the project. Eight of them noted that the unique skills and expertise of the team members were crucial for the success of their group work:

> I think our team also succeeded due to the individual qualities each of us brought with us to the project. (Student 14)

Another eight students pointed out that each group member was important, and the group work they did would not have been possible if any one of them had not been a part of the group:

> I do not think that we would have been able to create this amazing work if one group member had not participated. (Student 8)

The norms and core values that emerged from the first group work were also visible in the students' reflections. Communication was recognized as one of the key factors in the groups' success (8 students), as was the supportive and inclusive environment (6 students):

> By establishing clear objectives, dividing tasks efficiently, and maintaining open lines of communication, our group fostered a positive and productive environment. (Student 10)

Table 2 presents, for each category, the number of students who, in their reflections, believed that something relevant to that category contributed to the success of their group's work. "Having fun" was, in the end, not visible as a norm or value in the reflections though many students indicated that they enjoyed working with their group or in the course in general.

Table 2: Occurrences of group norm and core value categories in students' final reflections

	Category	Students
1	Creating a supportive and inclusive environment	6
2	Encouraging individuality and creativity	9
3	Effective communication practices	8
4	Having fun	-
5	Commitment to participation	5
6	Commitment to excellence	2
7	Supportive decision-making culture	1

Ten students reflected on the problems and challenges they faced as a group. Most of these were similar to those that had already arisen in the mid-course reflections, such as finding common time to work or working just before deadlines (4 students), uneven workload or commitment (3 students), and a lack of communication or organization within the group (2 students). In addition, five students reflected on problems caused by the different kinds of personalities in the group:

> Our group had a bit of chaos going on due to the different personalities and tempers. (Student 24)

> It was a new experience for me to work under such conditions and adapt to the diverse personalities within our group, including one person who talked a lot and another who remained more reserved. (Student 27)

> There was also learning in group work, and for me, for example, there was something to learn in how others were not as precise in everything as I was. (Student 15)

The students did not reflect much on how they were able to solve these problems, but two clarified, that the group members were simply very determinate to make things work regardless of scheduling issues and other difficulties, and two others pointed to effective communication as the saviour.

> However, we were able to overcome these challenges through compromise, open communication, and creative problem-solving. (Student 1)

> I think overall we managed to succeed through sheer willpower. (Student 13)

Two students also recalled in the final reflections the group task from the beginning of the course, where groups' norms and values were discussed. They felt that these discussions had helped them work better as a group.

> I liked the exercises to decide how the group was going to work together as a team, I think that was super important for the whole process even though some of the groups didn't really get why we were doing it. (Student 27)

> This class also taught us important team management skills, as we set our objectives and rules from the very beginning, which allowed us to work efficiently throughout the semester. (Student 14)

DISCUSSION

The aim of this study was to explore students' views and experiences in interdisciplinary group work on a course combining mathematics, arts, architecture, and design. At the beginning of the course, the students assumed that the conditions for the success of the group work would be a supportive and inclusive environment that encourages individuality and creativity, effective communication within the group, and commitment to the group work. They also indicated that they aimed to have fun while studying on this course. According to the final reflections, the diversity of the group was the key to success in this interdisciplinary course and its final project. The same norms and core values from the beginning of the course were also highlighted in the final reflections, but the importance of effective communication alongside an inclusive atmosphere was emphasized even more, as these were needed to benefit fully from the diversity of the group.

The students also discussed challenges in their group. The most common problem was finding suitable times for all to work on the course projects. This was perhaps due to how the course was organized; the course meetings were held twice a week, but the students were expected to work in their groups also outside of these meetings as well. Students coming from different stages of various programmes can have highly incompatible timetables making this part troublesome. Earlier studies have not observed a challenge with finding common time; maybe the work scheduling was done in advance by the teachers. Other challenges included an uneven workload or commitment, which have been observed also in previous studies, both on mathematics group work and interdisciplinary group

work (Uthrapathi et al., 2021; Sofroniou & Poutos, 2016). Some students also experienced difficulties in their groups due to the different personalities and working habits. Even when the diversity caused some tension, the students considered the diverse skills and knowledge from their group members to be crucial to their group's success. The group would not have been able to create a similar mathematical artefact, if even one of the group members had not been participating.

Students listed effective communication as one of the group norms at the beginning of the course. Open communication was also seen at the end of the course as one of the crucial elements contributing to successful group work and overcoming challenges within the group. It would be interesting to further investigate how interdisciplinary student groups engage in discussions while working together on mathematical concepts. Perhaps challenges to understanding arise from both the students' diverse backgrounds, manifested in different speech patterns and the use of various concepts, as well as the unique characteristics of mathematical discourse. Sjöblom and Meaney (2021) present a framework of "productive listening" through which it is possible to understand the complexity of listening in group work on mathematical problem-solving. Their framework includes both the purpose of listening, which is also connected to problem-solving stages, and social aspects, related to the group respecting the speaker's contribution, seeing the speaker as valuable, and feeling that one's own contribution would be listened to.

This also emphasizes the importance of an inclusive atmosphere, which was considered one of the key elements for successful group work by the students, as well. This is consistent with earlier studies on interdisciplinary group work. For example, Corbacho et al. (2021) observed that for a learning community to emerge, the students had to develop a sense of relatedness and trust with those from different academic backgrounds. Jaskyte et al. (2024) also highlight the importance of the working atmosphere in interdisciplinary group work and emphasize that the team leaders should foster an environment of psychological safety within the group. This poses a challenge to the instructors: how to facilitate group interaction at the very beginning so that an inclusive and supportive environment is created, where everyone feels that their input is valued.

Thus, successful interdisciplinary group work in mathematics, arts, architecture, and design shares many of the features observed earlier in both mathematics group work and interdisciplinary group work. However, perhaps related to the course implementation, the difficulty of finding sufficient working time also emerged and should be addressed. The students also perceived the importance of effective communication and an inclusive working atmosphere to be even greater than in previous studies.

Since diversity was observed by the students to be both crucial for success and a source of challenges, we recommend open-minded discussions with teachers and researchers from different disciplines when planning an interdisciplinary course. Achieving the necessary diversity in student groups can occur naturally if no single discipline dominates and the course is appealing and inviting to students

from diverse backgrounds. However, reconciling the traditions and perspectives of different disciplines is not straightforward, as noted, for instance, by Peltonen & Luotoniemi (2023). Communication among teachers is essential, as it facilitates the examination of familiar issues from diverse viewpoints. Establishing a common language is also vital, since the same terms may carry different meanings and interpretations across disciplines. Time constraints often impede thorough discussions and the ability to break away from established roles, both for teachers and students. Concrete small-scale workshops can serve as a productive starting point for deeper dialogue between disciplines.

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APPENDIX

Instructions for the group work on group norms and values:

Getting started with the Groups!

- Introduce yourselves briefly: Name, background, areas of interest, … Hint: You can in addition agree on a separate meeting outside the course meetings to get to know your colleagues better.
- Invent a name for your group
- Discuss and write down your Group Norms (guidelines on how you will work as a group). You can consider e.g. the following questions, but feel free to discuss other aspects as well.
    - How do you keep in contact? (Teams, Signal, …) How fast are others expected to react to messages?
    - Where do you store your electronic material? (Teams, OneDrive, DropBox, ...)
    - What do you expect from the group members?
    - How do you make sure that everyone's opinions will be heard?
    - What are your group's core values?
    - What are your group's goals?

Prepare a 3-minute presentation of your Group and your most important Group Norms.