MASTER THESIS

Challenges of interdisciplinary engineering education: A case study for the module Discrete Structures and Efficient Algorithms

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What a journey!

A challenging journey full of new learning experiences which even further developed my passion for applying and developing education. I must admit it was not always easy, but I am grateful for this opportunity. Pushing myself beyond limits helped me to shape my personal and professional goals. In this fruitful process, I have been surrounded by people to whom I am thankful. Without them, I would not be where I am now.

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Thank you all!

Abstract

Interdisciplinary education is a modern educational approach that is recently frequently used to shape university engineering curricula. It integrates insights and perspectives from different disciplines to tackle complex social challenges and helps students develop 21st century skills. However, many challenges related to the effective application of interdisciplinary education are yet to be tackled.

To identify those interdisciplinary challenges and perceived interdisciplinary values, a case study was performed within the module "Discrete Structures & Efficient Algorithms" at the University of Twente, in which bachelor students mainly from Applied Mathematics and Technical Computer Science worked on a shared team project. To identify the main interdisciplinary challenges within the module, a 4TU framework, which aims to align three levels of educational processes (vision, education, and facilitation) and to analyse and develop interdisciplinary education, was applied. Besides, the effect of the Covid-19 crisis, during which the module took place, on team collaboration was also investigated. All data were collected from students' surveys, staff interviews and the module documentation.

We found that both academic staff and students perceived interdisciplinary education valuable, as such experience broadens students' perspectives and may be beneficial in their future career. In this module, however, little attention was paid to develop an effective interdisciplinary experience. Notably, no learning outcomes existed that were directly related to interdisciplinary collaboration. Due to practical constraints (large student numbers), students support was redesigned (to "coaching for all") and turned out to be less optimal. Also, the ability of each participating programme to contribute equally to the project was imbalanced. Besides, the staff team showed low internal coherence and received minimal support on interdisciplinary education, therefore was not able to fully support the students. Consequently, we recommend implementing interdisciplinary learning outcome(s), support students' collaboration (staff training, an interdisciplinary workshop for students, coaching by teaching assistants). Also, the syllabi of both bachelor programmes need to be reviewed and staff teamwork can be optimized by organizing staff meetings.

Keywords: interdisciplinary, engineering curriculum, higher education

Table of content

1 Introduction

To overcome complex contemporary challenges which cannot be handled optimally within a single discipline, interdisciplinary education has been introduced (Lattuca, Knight, & Bergom, 2013). Interdisciplinary education aims to help students develop 21st century skills and integrate insights, knowledge and methods from at least two different disciplines to construct a new perspective on a topic (Czerniak & Johnson, 2014; Holley, 2017; Stentoft, 2017). It provides the students with an opportunity to see a problem from multiple perspectives and, consequently, expands their understanding of other points of view and the complexity of situations (Jones, 2010). Modern engineering education focuses on helping young engineers to develop interdisciplinary skills and be able to work with people that are both within (intradisciplinary) and outside (interdisciplinary) their own discipline (Barut, Yildirim, & Kilic, 2006; MacLeod & van der Veen, 2019). As a result, universities all over the world design new interdisciplinary programmes in which engineering students work on complex group assignments together with students from other disciplines (Klaassen, 2018; Stentoft, 2017). Although interdisciplinary engineering education is popular at university education, there are still some challenges that hinder its application (Klaassen, 2018).

In this study, a framework validated and established for the 4TU context is being applied for identifying and framing interdisciplinary challenges on engineering education within a case study. 4TU is a federation of four Dutch technical universities that aims to strengthen and pool technical knowledge (4TU, 2020). The framework will assist to identify those challenges in the module “Discrete Structures & Efficient Algorithms” at the University of Twente. In the module, second-year bachelor students of Applied Mathematics, Technical Computer Science, and other bachelor programmes (e.g. Advanced Technology; and Technology, Liberal Arts and Sciences) work together on a group project. The framework aims to align three levels of the educational process, namely *vision*, *education* and *facilitation*, to analyse and develop interdisciplinary education (Klaassen, de Fouw, Rooij, & van der Tang, 2019).

Vision refers to the main motivation for establishing interdisciplinary education. Implementing interdisciplinary education requires more effort, due to its complex nature (de Greef, Post, Vink, & Wenting, 2017) and required willingness to cross disciplinary boundaries (Borrego & Newswander, 2010). Interdisciplinary education is mostly applied by monodisciplinary people with some interdisciplinary experience (Blizzard, Klotz, Pradhan, & Dukes, 2012) and hence, their motivation and clearly specified learning activities and goals to achieve successful interdisciplinary programmes are essential. *Education* transfers the vision into practice (Klaassen et al., 2019). Several challenges concerning education can occur. First, the students may experience teamwork challenges, including, for instance, freeriding behaviour, misunderstanding (caused by using different terminology) or prejudice towards other disciplines. Second, strong constructive alignment (between learning goals, learning activities and assessment) is particularly important in interdisciplinary education. However, due to the complexity and diversity of interdisciplinary education, it is challenging for curriculum designers to align learning goals with valid and non-fragmented assessments (van den Beemt et al., 2020). *Facilitation* is usually understood in terms of support provided to academic staff as well as students. Notably, the essential support for both, academic staff and students, is usually underestimated by educational designers (Soares, Sepúlveda, Monteiro, Lima, & Dinis-Carvalho, 2013). As interdisciplinary education is a relatively new student-centred concept, involved academic staff might lack the necessary knowledge. This, in turn, can hinder the application of interdisciplinary education and decrease their willingness to cross disciplinary boundaries (van den Beemt et al., 2020). Therefore, providing teacher support (e.g. teacher training) is crucial (Gardner, Jansujwicz, Hutchins, Cline, & Levesque, 2014).

The module “Discrete Structures & Efficient Algorithms” was recruited by the Comenius project STRIPES2021; that aims to support teachers in redesigning interdisciplinary education, for several reasons such as: (1) imbalance in students’ numbers of participating bachelor programmes, (2) imbalance in their prior knowledge, and (3) assessment concerns. The goal of this study is to describe the main challenges of interdisciplinary engineering education that are experienced by the students and the involved academic staff in the module and draw several recommendations that can support the involved academic staff with the application of interdisciplinary education in the next years.

To achieve this goal, the following topics, based on the theoretical framework, are selected for investigation: (1) value of interdisciplinary education (*vision*). (2) perceived barriers (*vision*), (3) alignment between learning goals, learning activities and assessment (*education*), (4) team-work related challenges (*education*), (5) preparation and support of students and academic staff (*facilitation*). Additionally, the study will also investigate how the project teamwork in the module was affected by the Covid-19 crisis, due to which all educational activities at the University of Twente took place online from the 13th of March 2020.

2 Theoretical framework

2.1 Interdisciplinary learning

Interdisciplinary (ID) learning has been developed as a reaction to the complexity of current problems that cannot be optimally solved by using only intradisciplinary tools (Lattuca et al., 2013). ID learning aims to develop 21st century skills (collaboration, critical thinking, etc), integrates knowledge and methods from different disciplines to construct new perspectives on a common topic (Holley, 2017; Stentoft, 2017) and prepares students for real-world complex problems that cannot be solved by applying knowledge from one discipline only (Lattuca, Knight, Ro, & Novoselich, 2017). Moreover, viewing a topic from multiple different perspectives enables students to understand the complexity of situations and understand other points of views. This consequently expands their understanding of the topic (Jones, 2010). According to Stentoft (2017), ID learning focuses not only on what students learn but also on how they learn.

Unlike intradisciplinary approaches, the ID approach is relatively new and only a few resources on how to apply it in practice are currently available (Edelbroek, Mijnders, & Post, 2018). This, in turn, results in the fact that the term interdisciplinarity is still mistakenly used when practically applied. In practice, ID learning is more likely to be confused with multidisciplinary (Stember, 1991) or transdisciplinary learning (Menken & Keestra, 2016).

Multidisciplinary learning involves people from different disciplines that work together towards a shared goal by approaching it from different angles and disciplinary perspectives. However, there is only little integration (work side by side) and a new integrated solution is less likely to emerge (Borrego & Newswander, 2010; de Greef et al., 2017). Unlike in multidisciplinary learning, the key concept of *interdisciplinary learning* is intersection and integration of knowledge, methodology and language from different disciplines (de Greef et al., 2017; Klaassen et al., 2019). Students learn through sharing perspectives from different disciplines, integrating them and constructing a new solution to complex problems which would not be possible in monodisciplinary settings. (McNair, Newswander, Boden, & Borrego, 2011). *Transdisciplinary learning* crosses not only disciplinary boundaries but also academic boundaries. The integration process involves people from academic (e.g. students) but also non-academic (e.g. patients, entrepreneurs) environments. The involved disciplines enhance their learning by using their skills and knowledge in collaboration with external stakeholders to solve real-life problems (de Greef et al., 2017; English, 2016). The involved two or more parties create unity beyond their disciplines (Jensenius, 2012)

Overall, in practice, multidisciplinary, interdisciplinarity, transdisciplinary approaches are sometimes used interchangeably. It is clear from the above statements that they differ in the extent to which the work of the involved parties is integrated – from low integration (multidisciplinary) to high integration (transdisciplinary) and by whom they are integrated (de Greef et al., 2017). The conceptual differences of the approaches can be seen in Figure 1.

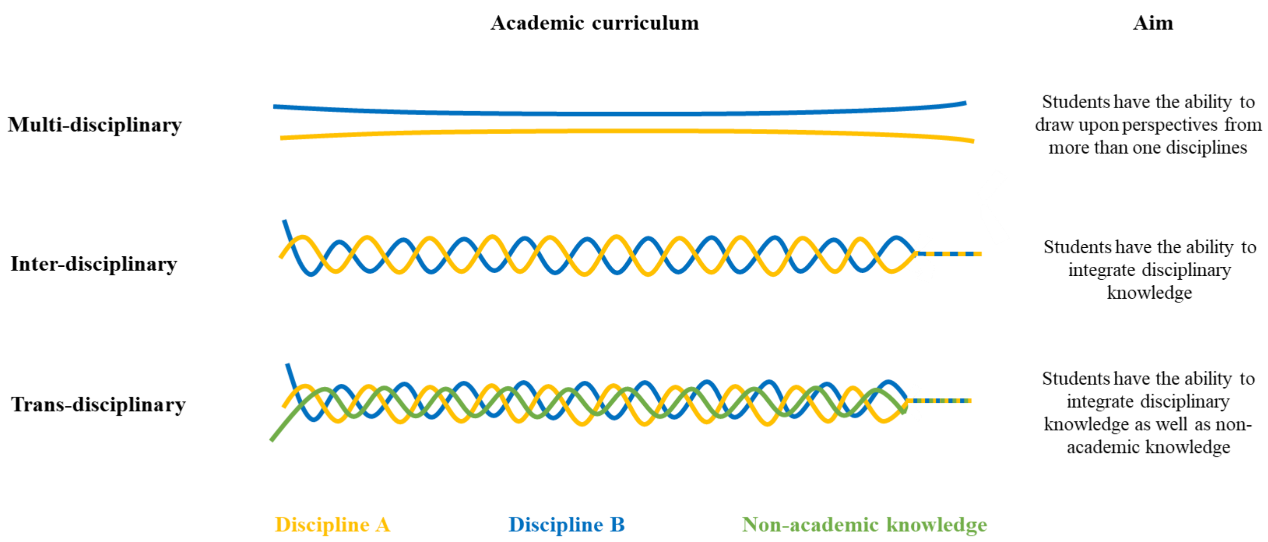

Figure 1: Three disciplinary approaches distinguished by degree and method of integration: Adapted from de Greef et al. (2017)

2.2 Interdisciplinary engineering education

Future world challenges, such as mass migration, cybersecurity, infrastructure, changing climate or energy transition, are very different from those that the world faced in the 20^{th} century (Kamp, 2016). On top of that, the current world is changing due to the massive growth of technology, for instance, artificial intelligence. Accordingly, there is a clear need to prepare future engineers, whose main domain is technology, for the world of technical innovations and complex social problems. This requires an extensive transformation of higher engineering education.

"Nowadays we attempt to educate 21st-century engineers with a 20th-century curriculum taught in a 19th-century institution." (Grasso & Burkins, 2010)

The focus of higher education nowadays is shifted towards ID learning and ID research (Klaassen, 2018). This is a clear indication that the current goal of scientific and engineering training is ID skills (MacLeod & van der Veen, 2019) and, therefore, implementation of interdisciplinarity in engineering education is sought. The aim of interdisciplinary engineering education (IEE) is to teach students to combine insights, theories and methods, from different disciplines in a single context (Lattuca, Voight, & Fath, 2004), be able to operate across boundaries of their own field (Klaassen et al., 2019) and have a mindset beyond technical expertise (Kamp, 2016). A boundary represents a limit of one's ability (Akkerman & Bakker, 2011). Crossing boundaries at higher education requires effort, as university education is mostly based on specializations within specific fields (de Greef et al., 2017).

Even though IEE is broadly discussed at university education, there are currently only a few practical frameworks on how to build ID engineering curricula (Klaassen, 2018). This is due to the lack of concrete insights on ID education as well as due to unclear indication in the current literature whether ID education involves only different domains (e.g. social science and engineering) or also domains that are closely related (e.g. computer science and applied mathematics) (Gantogtokh & Quinlan, 2017; Klaassen et al., 2019).

The IEE framework (Figure 2) used in this research was established for and validated in the 4TU context. 4TU is a federation of four Dutch technical universities, namely Technical University Delft, Eindhoven University of Technology, University of Twente and University of Wageningen, that are "jointly committed to strengthening and pooling technical knowledge" (4TU, 2020). As proposed in the framework, IEE aims for an alignment between (1) *vision*, (2) *education* and (3) *facilitation.* These three levels of educational processes together assist to analyse ID courses and curricula (Klaassen et al., 2019; Parks & Quain, 1986) and will be used for this case study.

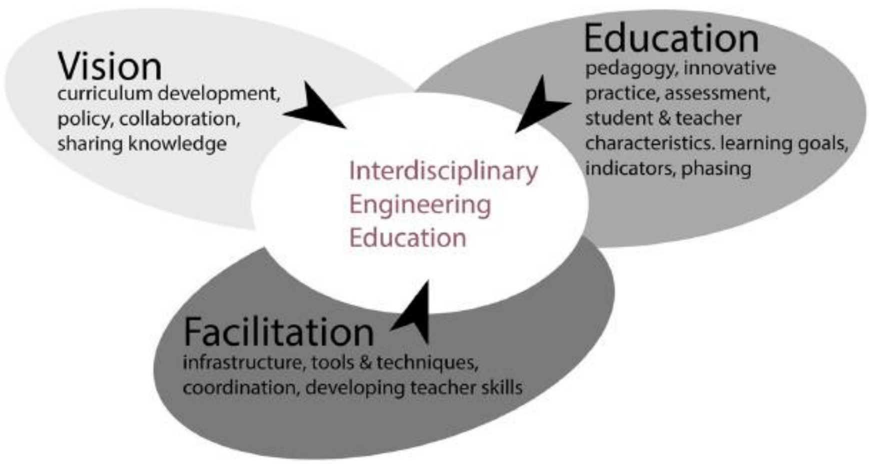

Figure 2: Framework for Interdisciplinary Engineering Education (4TU Centre for Engineering Education). Retrieved from: Klaassen, De Fouw, Van Der Tang, & Rooij (2019)

Vision describes the main reasons for establishing IEE programmes and identifies their goals. In the literature review of van den Beemt et al (2020), four main motivational factors for IEE were detected: (1) learning to solve complex real-world problems, (2) developing entrepreneurial competencies, (3) developing socially aware engineers, (4) improving current disciplinary programmes. *Education* facilitates the transfer of the vision into practice (Klaassen et al., 2019). This educational process involves constructive alignment between learning goals, learning activities and assessment tools and it also investigates students-related characteristics, such as group composition. *Facilitation* contributes to the alignment of vision and education by providing the necessary support for keeping the education running (e.g. scaffolding). Due to institutional constraints, such as departmental structure at universities, facilitation plays an important role in providing IEE (van den Beemt et al., 2020) and engages in a support of crossing disciplinary boundaries (Klaassen et al., 2019).

2.3 Challenges of interdisciplinary engineering education

This section is mainly based on the literature review of van den Beemt et al (2020) in which they analysed 99 selected studies (according to inclusion criteria, study characteristics, appraisal, and synthesis of results) published between 2005 and 2016. In their review, the challenges are divided into three main categories: vision, learning and support. However, for the purpose of this work, we will stick to the categorization introduced in IEE framework which was introduced in the previous section. Therefore, the three main categories will be *vision*, *education* (instead of teaching) and *facilitation* (instead of support).

2.3.1 Vision

The main challenge concerning vision of IEE was detected by van den Beemt et al. (2020) and is namely the complexity of ID education.

Complexity

ID programmes are more complex in comparison to intradisciplinary ones and their practical application is more difficult and challenging. Ability to communicate, willingness to cross boundaries and work as a team are required skills for successful implementation of IEE (Borrego & Newswander, 2010). De Greef et al. (2017, p. 32) claim that *"most educational designers are usually good at collecting different disciplinary insights into their programme, the next step – embedding integration in education – is often a challenge".* This often results in ID educational programmes that lack the required integration. Besides, it is also desired that ID education is implemented by those with ID experience. However, in practice, ID education is often applied by monodisciplinary people with no or limited ID experience (Blizzard et al., 2012) which may be resistant to ID application.

Overall, an unclear vision for establishing IEE can result in vague learning activities and learning goals that are misaligned. To investigate the barriers of motivation and goals of IEE, it is essential to obtain information on the perception of involved academic staff.

2.3.2 Education

In terms of *education*, IEE needs to tackle possible challenges, including students, such as teamwork, and learning goals, activities and assessment (van den Beemt et al., 2020).

Teamwork

Learning based on teamwork (e.g. project-based learning) is broadly used in IEE (MacLeod & van der Veen, 2019). Teamwork challenges that commonly occur in monodisciplinary settings are also present in ID settings (Borrego, Karlin, Mcnair, & Beddoes, 2013). Such challenges are the following: (1) lack of trust; (2) social loafing: a team member unintentionally invest less energy; (3) free-riding: a team member intentionally does not participate; (4) shared mental models: having a shared understanding, a group level system of encoding, storing and retrieving information; and (5) interdependence: the extent to which team members depend on each other (Decuyper, Dochy, & Van den Bossche, 2010).

The above-mentioned teamwork challenges might be even more present in ID settings due to, for instance, *misunderstandings* caused by speaking different languages/using different terminology or *prejudice* towards other disciplines. It is necessary for involved academic staff to be aware of such potential teamwork problems and support students' project groups to reach desired learning goals (McNair et al., 2011). This can be done by, for instance, maintaining trust among team members (Borrego et al., 2013).

Misunderstanding: Even in our day to day communication misunderstandings commonly arise. The possibility of misunderstanding increases in ID settings in which different jargon is often used by different disciplines. Moreover, terminology or phrases can have different semantic meaning for different disciplines. There is no doubt that engineering curricula mainly focus on building up the technical abilities of students and communication and teamwork skills development are omitted (Kashefi, Ismail, & Yusof, 2012). Consequently, engineering students and graduates lack effective communication skills and such a factor might play a key negative role in the communication within project teamwork.

Prejudice: Prejudice can be defined as an unfair or unreasonable opinion about others which is predominantly based on insufficient knowledge ('Cambridge Dictionary', 2020). Prejudice in ID education can be based on judging others from the perspectives of our own discipline but also based on our personal beliefs and mindset. Prejudice can hinder the effectiveness of collaboration (Lattuca et al., 2004). Thus, it is crucial for students to be aware of their own prejudice in order to successfully cross disciplinary boundaries and value insights of other team members.

Learning goals, activities & assessment

An important factor in education is the strong constructive alignment between clearly specified learning goals, learning activities which lead to intended learning goals and well-designed assessment tools (Biggs, 2003). According to van den Beemt et al. (2020), constructive alignment is particularly crucial in ID settings in which learning goals and activities might first seem to be unclear and unstructured. In practice, achieving such an alignment is very challenging for curriculum designers, due to the ID nature of the programmes.

Learning goals: ID courses or modules should state intended learning goals which motivate the students to collaborate with students from other disciplines and learn from and about them (McNair et al., 2011).

Learning activities: Assignment and learning activities need to be thoroughly constructed and allow all project members to have a balanced contribution (van den Beemt et al., 2020) by, for instance, considering prior knowledge of students. Besides, ID assignments usually contain broad or open-ended problems that the students are asked to solve. According to findings of several research papers, students in ID settings prefer assignments that are well-defined and less open-ended (Gómez Puente, Van Eijck, & Jochems, 2013) and related to real-life problems thanks to which students expand their understanding (Brundiers, Wiek, & Redman, 2010).

Assessment: Van den Beemt et al. (2020, p.24) in their literature review concluded that: *"Assessment in general is considered under-developed and underdiscussed in interdisciplinary educational contexts."* Such a statement is supported by the fact that only 15 % of reviewed articles by van den Beemt et al (2020) focused on assessment. Based on this information, it can be assumed that there is currently not much attention paid to what effective assessment in ID education looks like.

2.3.3 Facilitation

Two main topics in relation to challenges of facilitation of IEE emerged: (1) teacher and student support and (2) institutional barriers. More attention to students' support will be given in separate section 2.5.

Teacher support

A prerequisite for successful implementation of IEE is creating a safe environment in which students feel comfortable to express ideas (psychological safety), having a feeling of self-efficacy and having the right mindset. It is crucial to maintain a high level of trust between students, but also between students and teachers (Borrego et al., 2013; de Greef et al., 2017). However, the question is how to effectively create such an environment that promotes learning through the psychological safety of those participating in it.

ID education is an innovative, student-centred approach, as opposed to the classical teacher-focused approach, and, therefore, ID education may be an unfamiliar concept to most of the teachers. Teaching in ID programmes might be, on one side, inspiring, but on the other side, challenging. As reported in multiple studies, insufficient teacher support and lack of training hinder the application of ID education (e.g. van den Beemt et al., 2020; Gardner, Jansujwicz, Hutchins, Cline, & Levesque, 2014). Additionally, the lack of ID experience and knowledge regarding the application of ID education may decrease motivation to invest in delivering such education (Gardner et al., 2014). Such challenge can be overcome by providing teacher training (or any type of support) on topics such as ID education, student's skills development, coaching and supervising in ID settings, etc (Gardner et al., 2014).

"Teachers are role models. If students are expected to acquire interdisciplinary skills such as critical thinking, collaboration and reflection, teachers should have developed these skills as well". (de Greef et al., 2017, p. 92)

Moreover, those who lack ID experience are less likely willing to cross institutional boundaries. Insufficient need to collaborate with staff from other departments/faculties may cause communication barriers and consequently block ID education development. To fully integrate an ID programme, connecting involved teachers (most importantly those from different departments), motivating them to openly communicate and share insight is vital (de Greef et al., 2017; Menken & Keestra, 2016).

Institutional barriers

Departmental and faculty structure at universities are seen as factors that also hold back an application of IEE. Consequently, academic staff might stay in their comfort zone and focus only on monodisciplinary education, rather than cross institutional boundaries (McNair et al., 2011).

2.4 Educational formats in interdisciplinary engineering education

Project-based learning (PjBL) is nowadays broadly used educational format in ID education in which open projects are the central point (MacLeod & van der Veen, 2019). Students learn to develop their collaborative and problem-solving skills with people from other disciplines and get familiar with them (T-shaped) (Craig, 2019). By integration of different knowledge and views, as a team, they are actively engaged in tackling open real-world problems (MacLeod & van der Veen, 2019). In PjBL, motivation plays an important role in making students responsible for their own development. In 2013, an innovative educational curriculum (see more in section 3.2) at the University of Twente was introduced in which PjBL in thematic modules is used.

Nowadays, another innovative educational format gains its attention in ID education – *challenge-based learning* (CBL) in which all involved stakeholders learn together with the students. In CBL, general themes are offered to the students from which they identify a challenge they want to investigate and formulate sustainable solutions (Kohn Rådberg, Lundqvist, Malmqvist, & Hagvall Svensson, 2020). CBL plays an essential role in the educational vision of the University of Twente for the next ten years (see more in section 3.1) and several pilot courses and programmes (e.g. Autumn Challenge programme) are currently running. CBL can be considered as a further step towards student self-regulated learning and towards implementing sustainability in engineering education (Enelund, Knutson Wedel, Lundqvist, & Malmqvist, 2013).

2.5 Scaffolding in interdisciplinary engineering education

Even though students support in ID education, particularly in PjBL, is seen to be essential (MacLeod & van der Veen, 2019; Stentoft, 2017), it is still underestimated by ID curricula designers (Soares et al., 2013). Scaffolding (temporary support provided to students throughout educational process) in ID education adds complexity to the learning process and requires the development of innovative supporting mechanisms. Overall, there are only a few empirically validated mechanisms that know how to support ID education and, thus, more empirical research into ID PjBL is required (Stentoft, 2017).

Firstly, supervision of project groups is one of the proposed scaffolding strategies that facilitate ID learning (Nash, 2011). Regular supervision guides the project group via the learning process and shapes the project in such a way that the contribution of all participants is required for successful completion (MacLeod & van der Veen, 2019). Besides, McNair (2011) points out the importance of providing balanced tasks for all involved disciplines. However, in practice, there is a clear challenge in all the aforementioned points. In education, we aim to provide a relative balance in tasks, but it is important to be aware that this does not reflect real-life settings and, therefore, it is not always possible to achieve it. Secondly, the organization and implementation of learning activities in PjBL must provide a structure that motivates and supports the students (Borrego et al., 2013). Students appreciate project tasks that are directly related to real-world problems or activities that include role-based learning within their group (van den Beemt et al., 2020).

3 The case description

In this section, we provide three different levels of background information in order to understand better the research questions that are presented in section 4. The goals and objectives of the University of Twente, the current bachelor educational focus and the module under research are presented here.

3.1 The University of Twente

The University of Twente was established in 1961 as the Twente Technical College, as the third technical institution in the Netherlands. The first 200 students began their studies in 1964. Since then a lot has changed. In 2019, about 11,000 students were enrolled in all (and not only technical) bachelor and master's programmes at the University of Twente (University of Twente, 2020a). The University of Twente is a pioneer in fusing technology, science and engineering with social sciences to prepare students for today's challenging world (University of Twente, 2020a). This is expressed by the university motto: "Hight Tech Human Touch". In 2019, the University of Twente released the document Shaping2030 in which the new mission, vision and strategy for the coming decade were introduced, as a reaction to technological opportunities on one hand, and complex social challenged on the other hand. The mission of the University of Twente is:

"The University of Twente is the ultimate people-first university of technology. We empower society through sustainable solutions." (University of Twente, 2019).

Aligned with the mission of the university, the vision is focused on contributing to a fair, sustainable, and digital society between now and 2030. To realize the vision, three main strategic goals have been set: (1) shaping society (e.g. challenge-based research education and learning), (2) shaping connections (e.g. partnership with EdTech companies), (3) shaping individuals (e.g. ambitious programmes for academic, social entrepreneurs) (University of Twente, 2019).

3.2 Twente Educational model

The current educational curriculum at the University of Twente was redesigned between 2010 – 2013, as a reaction to the rapidly changing world and changing requirements for the future labour market. The main drivers for developing new educational curriculum were: (1) providing effective learning (e.g. team-based learning), (2) a reduction of dropout rates, and (3) ID approach in education (Visscher-Voerman & Muller, 2017).

The Twente Educational model (TOM, in Dutch: Twente Onderwijs Model) was introduced in September 2013 (Craig, 2019). All bachelor programmes (3-year degree) at the University of Twente consist of 12 interrelated modules (Figure 3) that complement one another (Craig, 2019). A module is an educational unit that lasts one quarter and after a successful completion a student earns 15 European Credit (ECTS) (Visscher-Voerman & Muller, 2017). Modules are either provided only to one bachelor programme or are shared between two or more programmes.

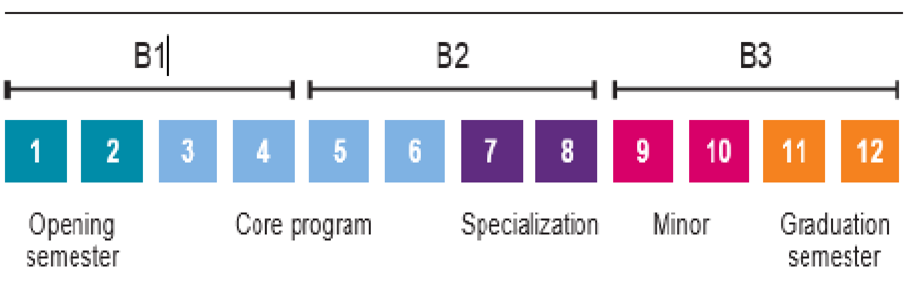

Figure 3: Structure of bachelor programmes at the University of Twente. Retrieved from Visscher-Voerman & Muller (2017)

The central point of each module is a project that addresses real-world topics. All students work in teams. In each module, students learn how to collaborate and combine aspects of science, technology, and society. Students are also challenged and, to a certain extent, responsible for their own development (student-driven learning) (Visscher-Voerman, 2017).

3.3 Module 7: Discrete Structures & Efficient Algorithm

Module 7: Discrete Structures & Efficient Algorithm (also based on TOM education) is attended by second-year bachelor students of mainly two programmes – Technical Computer Science (CS) and Applied Mathematics (AM), in the third academic quartile.

"The module is designed so as to teach the role of discrete structures for modelling and problem solving in mathematics and computer science, both through theoretical study as well as practical implementation of algorithms" (CANVAS, 2020).

The aim of the module is to have a mix of theoretical understanding of important concepts in discrete mathematics and theoretical computer science and acquiring practical ability to effectively using discrete structures (Osiris, 2020). The intended learning goals are summarized as follow:

- understand and use discrete structures for modelling and problem solving,
- work with a basic toolbox of formal techniques (e.g. mathematical induction, analysis of algorithms, asymptotic analysis of computation time, …),
- practically realise and test algorithm designs. (Osiris, 2020)

The content of the module is divided into five overarching topics: (1) Algorithm Design & Analysis (ADS), (2) Algorithmic Discrete Mathematics (DM), (3) Languages & Machines (L&M), (4) Algebra (ALG). All the aforementioned topics are interconnected and prepare students for successful implementation of (5) Project: Graph Isomorphisms (Project GI). In Figure 4, a timeline and a brief overview of the module in the academic year 2019/2020 is pictured. The module combines lectures, theoretical and practical tutorials (CANVAS, 2020).

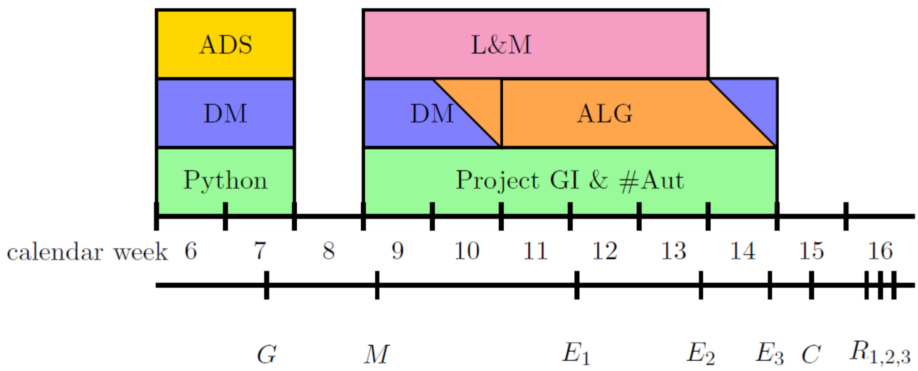

Figure 4: Overview Module 7 (2019/2020). Explanation: G= individual check graph implementations (python), M= matchmaking drinks (formation of project groups), E_i= exam, C=programme delivery and competition, R_i= re-exam. Retrieved from: CANVAS (2020)

Project teams are formed during so-called Matchmaking drink and each team consists preferably of four students, at least from two different bachelor programmes. The goal of the project is to solve the graph isomorphism problem. Within the module, there are four lectures that introduce a set of algorithmic ideas to solve the graph isomorphism problem, and six practical sessions (each lasts four hours) so-called Coaching project (CANVAS, 2020). In the academic year 2019-2020, there were no mentors/tutors provided to project groups. The project has two deliverables: (1) a programme implementation in Python that solves graph iso- and automorphism problems, and (2) brief documentation (CANVAS, 2020). The final grade consists of the project and three individual written exams, namely Algorithmic Discrete Mathematics, Languages & Machines and Algebra. The three exams together account for 80% of the final grade and the project accounts for the remaining 20%. Students can also earn homework or programming bonus points. To successfully accomplish the module, students are required to pass each exam with a grade higher or equal to 5.0 and the project with a grade higher or equal to 5.5.

3.3.1 Participating Bachelor programmes

Two main bachelor programmes participate in Module 7: Discrete Structures & Efficient Algorithm – CS and AM. The module is, however, also available to the students from other bachelor programmes (e.g. Business Information Technology or Advanced Technology). The module is also popular among students of Technology, Liberal Arts, and Science (ATLAS) of the University College Twente.

Technical Computer Science

CS is a three-year, English-taught bachelor programme at the University of Twente. The official name of the programme is Computer Science & Engineering. The programme is coordinated by the faculty of Electrical Engineering Mathematics and Computer Science. The programme is promoted in the brochure as follow:

> *"… a broad Bachelor's programme, in which working together across disciplines is a given and application is key. These unique features will ensure that when you graduate doors will swing open for you on the job market."* (University of Twente, 2020)

CS offers multidisciplinary partnership, in research and project-based education. The students of CS will get acquainted with insights from various fields, such as business administration, biology, or medical science. Also, they will learn about extra topics, including computer security, telematics, that are not offered at other universities. Additionally, challenge-oriented students have an opportunity to study a double degree in CS and AM.

Applied Mathematics

AM is also a three-year, English-taught bachelor programme at the University of Twente and is also coordinated by the faculty of Electrical Engineering Mathematics and Computer Science.

The programme is highly focused on the practical application of mathematics, in comparison to "pure" mathematics offered at other universities. The students learn how to apply mathematical instruments in engineering, medical field or in traffic by making practical problems simpler and planning mathematical models based on them. Students that seek for an extra challenge can study a double degree in AM and Applied Physics.

"... you will often look beyond the boundaries of your own discipline as an Applied Mathematics student, you will acquire an understanding of many areas in which mathematics are applied." (University of Twente, 2020)

3.4 Covid-19 crisis

At the end of 2019, a new type of coronavirus, known as Covid-19, was identified in Wuhan, China. The virus spread globally and lead to a global pandemic. The first case in the Netherlands was confirmed on the 27th of February 2020. From the 9th of March on, a number of measures to prevent spreading the Covid-19 virus in the Netherlands were introduced, including social distancing, a prohibition to travel to certain destinations, closing educational institutions or restaurants, and many others (Government.nl, 2020).

Covid-19 crisis had an impact on the ongoing Module 7 as well as on this research. All physical educational activities at the University of Twente were banned from the 13th of March 2020 and were not resumed at least until the end of the academic year (University of Twente, 2020b). Consequently, entire education at the University of Twente had to be quickly transferred to the online environment. In Module 7, alternative ways of communication and teaching were introduced. Lectures took place online in the forms of videos or pencasts, and the tutorials and project sessions were replaced by online conferences (e.g. using BlueJeans or BigBlueButton). (CANVAS, 2020).

4 Research questions

To address the main goal of this study, the following three research questions (RQ) and their sub-questions need to be answered.

RQ1: What is the value of interdisciplinary education in Module 7: "Discrete Structures & Efficient Algorithms" according to students and involved academic staff?

RQ2: What are the challenges in Module 7: "Discrete Structures & Efficient Algorithms" regarding interdisciplinary education?

RQ2.1: *Which barriers are perceived by students and involved academic staff to hinder interdisciplinary education in Module 7?*

RQ2.2: *How are the learning goals, learning activities and assessment of Module 7 aligned and clear to students and involved academic staff?*

RQ2.3*: How do students experience teamwork-related challenges within their project group?*

RQ2.4: *How are students and involved academic staff prepared and supported in Module 7 regarding interdisciplinarity?*

Due to the Covid-19 crisis, all educational activities at the University of Twente took place online from the 13th of March 2020. The following research question was additionally added to investigate to what extent the project teamwork was affected by such an unexpected situation.

RQ3: How was the project teamwork in Module 7: "Discrete Structures & Efficient Algorithms" affected by Covid-19 crisis?

5 Research design and methods

In this study, a pragmatic mixed-method research design was applied (Cohen, Manion, & Morrison, 2011) in which qualitative and quantitative data collection instruments were combined, specifically surveys and semi-structured interviews. The data were complemented by analysing the documentation of the module and the university. Such research design helps to view the module within its broadest context and to identify its challenges. The nature of the study is descriptive, as it aims to describe and interpret the current situation of the module (Cohen et al., 2011).

5.1 Participants

The population of focus are bachelor students that were enrolled in Module 7: "Discrete Structures & Efficient Algorithms" in the academic year 2019/2020 and all the involved academic staff. The involved academic staff include a module coordinator, lecturers, project coaches and programme directors.

Students

The total number of students enrolled in the module, according to the Student Evaluation Questionnaire (SEQ), is 217. Based on the information from the Centre for Educational Support (CES), 204 students finalized the Implementation Project. This latter number (204) will be used as effectively enrolled in the module. These students belong to the following programmes: Technical Computer Science (165); Applied Mathematics (26); Management, Society and Technology (8); Advanced Technology (3); ATLAS (2); Business Information Technology (1); and Civil Engineering (2). Six students studied a double-degree programme – a combination of Technical Computer Science & Applied Mathematics (5); or Technical Computer Science & Civil Engineering (1).

An online survey was distributed to all students at the end of the module. Responses were received from 128 participants. Forty responses had to be excluded from follow-up analysis, as they did not contain any data. Thus, 88 responses were used. The numbers of respondents based on their gender and attended bachelor programme are illustrated in Table 1. From all the respondents, 55 (62.5%) were members of project teams that were formed by people from different disciplines. Mostly (indicated by 33 respondents) these project teams consisted of 3 CS students and 1 AM student. Four of all respondents were 18 years old or younger, 71 students were between 19-21, 12 between 22-24 and one respondent was 25 or older.

Table 1: Gender and bachelor programmes of the respondents

Bachelor programme	Gender		
	Female	Male	Total (n)
Applied Mathematics	8	7	15
Computer Science	8	60	68
Other*	2	3	5
Total (n)	18	70	88

(*) = Advanced Technology, ATLAS, double degree CS & AM, Electrical Engineering, pre-master of AM

Academic staff

In Module 7, 14 academic staff are involved. The gender ratio is 13 males and 1 female. The academic staff include two programme directors, one module coordinator, nine lecturers and two project coaches. The project coaches, as well as the module coordinator also give one or more lecturers. In addition, teaching assistants are also involved in the module by supporting project teams. All the academic staff were approached, and online semi-structured interviews were conducted with 9 of them. Interviewees data can be seen in Table 2. All interviewees are male.

Table 2: Overview of interviewees data. Explanation: an asterisk (*) = since Module 7 was introduced, two asterisks (**) = until the 31st of December 2019.

Role in Module 7	Educational experience	ID experience	Involved in Module 7
Lecturer	30+ years	Yes	5 years*
Lecturer	15 years	Some	2 years
Lecturer	7 years	Yes	2 years
Lecturer	6 years	Yes	2 years
Lecturer	4 years	Some	4 years
Lecturer	4 years	Some	1 year
Lecturer/project coach	7 years	Some	1 year
Lecturer/programme director**	30+ years	Yes	5 years*
Module coordinator	19 years	Yes	5 years*

5.2 Instruments

A triangulation technique, collection of data by two or more methods, was applied to ensure the validity of the study (Cohen, Manion, & Morrison, 2011; Frey, 2018). Two main instruments were used for the data collection, namely survey and semi-structured interview, and the obtained data were complemented by analysing the module and university documentation to help prevent bias. Table 3 shows the alignment between the research questions and the used instruments. Prior to data collection, the Behavioural, management and social science (BMS) Ethical Committee of the University of Twente approved the ethical request for the research (see Appendix A: BMS Ethical Committee research project approval – 200177).

Table 3: Alignment between the research questions and the instruments used for data collection

Research question	Survey	Interview	Documents
RQ1: What is the value of interdisciplinary education in Module 7: "Discrete Structures & Efficient Algorithms" according to students and involved academic staff?	☑	☑	
RQ2: What are the challenges in Module 7: "Discrete Structures & Efficient Algorithms" regarding interdisciplinary education?			
RQ2.1: Which barriers are perceived by students and involved academic staff to hinder interdisciplinary education in Module 7?	☑	☑	☑
RQ2.2: How are the learning goals, learning activities and assessment of Module 7 aligned and clear to students and involved academic staff?	☑	☑	☑
RQ2.3: How do students experience teamwork-related challenges within their project group?	☑		☑
RQ2.4: How are students and involved academic staff prepared and supported in Module 7 regarding interdisciplinarity	☑	☑	☑
RQ3: How was the project teamwork in Module 7: "Discrete Structures & Efficient Algorithms" affected by Covid-19 crisis?	☑		☑

5.2.1 Survey

A survey was the instrument chosen to gather data from the students of Module 7. The main reason for selecting such an instrument is the ease to obtain information from a large audience (Cohen et al., 2011). An online survey using SurveyMonkey was distributed at the end of the module with the assistance of the module coordinator and the project coach, and later on the student associations. Participation in the survey was requested from the students during an online "Project delivery" session in which the presence of all the students was mandatory. The survey link was shared via a CANVAS announcement and two reminders were sent to the students via personal emails. Under the Covid-19 circumstances, this was selected as the best available approach to promote a relatively high response rate. As an additional motivation, the students that participated in the survey were put in a lottery to win one of four bol.com vouchers, worth 25€ each. Four randomly selected winners were contacted on the 30th of April. The structure of the survey and the questions can be seen in Appendix B: Student online survey (SurveyMonkey).

The survey was available to fill in between the 15th and the 29th of April 2020 and it contained 16 questions in total (average completion time was 6 minutes). It consisted of closed questions, namely multiple choice (6 items) and 5-point Likert Scale questions (5 items), and open questions (5 items). The composition of the closed survey questions according to themes can be found in Appendix C: Composition of the closed survey questions. The questions on ID experience and challenges (questions 8a – 8f of the survey) were retrieved from the work of Johnson-Veldhuis (2020) who performed similar research on another ID module at the University of Twente which was reported to be valid and reliable. The original versions of the retrieved questions can be found in two ID surveys - Interprofessional Attitudes Scale (IPAS) (Norris et al., 2015) and Interdisciplinary Project Management Questionnaire (IPMQ) (Tormey & Laperrouza, 2019). The questions used for this research were adjusted based on the context of Module 7. As we assumed that the students were most likely unfamiliar with the term "interdisciplinary" and not all project groups consisted of students from different disciplines, the term "interdisciplinary" was replaced by "collaboration with other team members".

5.2.2 Interviews

Semi-structured online interviews were conducted with the academic staff that were involved in Module 7 (2019/2020). Interview was selected as the most fitting instrument, as it allows to clarify potential misunderstanding and ask for further elaboration if necessary (Cohen et al., 2011). In regards to the reliability of the interviews, the following aspects were addressed: (1) data collection: by using the same format and sequence of words for every interviewee, avoiding leading questions and ensuring anonymity (promotes openness), (2) representativeness: by approaching all the involved academic staff (Cohen et al., 2011). To minimize the amount of bias and ensure the validity of the interviewees, the analysed data were discussed with supervisors and more experienced colleagues.

All the interviews (9 in total) were conducted after Module 7 was over (after the 20th of April 2020) and, due to Covid-19 crisis, all took place online. Online platforms Blue Jeans and Microsoft Teams were used. It was intended to use both camera and microphone to substitute personal interviews as best as possible and minimize the absence of important social elements (e.g. non-verbal communication). The time of interviews ranged from 19 to 38 minutes. All the interviews were recorded after approval was given by the interviewee. Prior to interviews, each interviewee was informed about the aim of the research, the relative anonymity of the interview and voluntary attendance.

The interview script consisted of 13 questions. The exact number of questions varied based on the previous answers and the interviewee's role in Module 7. The interview items focused on a number of themes:

- Interviewees data; a role in the module, educational and ID experience,
- values of ID education and its perceived challenges and opportunities,
- perceived challenges and opportunities of Module 7,
- support in Module 7 and preparation for providing ID education,
- constructive alignment,
- future steps.

The interview items about challenges and opportunities of ID education were retrieved from the study of Lyall, Meagher, Bandola, & Kettle (2015) that similarly investigated challenges in ID programmes at higher education. The questions were subsequently adjusted to the context of Module 7. The general structure of the interview can be seen in Appendix D: General structure of the semi-structured interview.

5.2.3 Documentation

Document analysis is a type of qualitative research which analyses and interprets documentary evidence (Frey, 2018). In this research, analysis of the module and University of Twente documentation assisted to expand the findings of the two previously mentioned instruments. Analysed documents included internal documents related to Module 7 as well as promotion material of the University of Twente that are publicly available on the university webpage. In Table 4, the summary of the analysed documents, their purposes and web links, if available, can be seen.

Table 4: Summary of the analysed documents

Document	Kind of information	Link
Blockbook Module 7 A PDF document provided to the students	Information about Module 7 (structure, assessment, …)	https://canvas.utwente.nl/ (internal)
CANVAS page of Module 7 Learning management system of the University of Twente	Information about Module 7 (announcements, course content, …)	https://canvas.utwente.nl/courses/5536 (internal)

OSIRIS page of Module 7 Student Information system of the University of Twente	Information about Module 7 (aim, learning goals, content, …)	https://osiris.utwente.nl/ (internal)
Project Guide Module 7 A PDF document provided to the students	Information about the project within Module 7	https://canvas.utwente.nl/courses/5536 (internal)
Project report Deliverable of Module 7, including brief report on student collaboration	Perception of students about their collaboration	https://canvas.utwente.nl/courses/5536 (internal)
SEQ document Results of the student evaluation questionnaire given at the end of Module 7	Information about student perception about Module 7	N/A (internal)
Shaping 2030 Strategic document of the University of Twente	Information about the vision, mission, and strategy of the University of Twente until 2030	https://www.utwente.nl/en/organisation/about/shaping2030/documents/
Student-Driven Learning at the University of Twente brochure	Information about educational approach at the University of Twente	https://www.utwente.nl/en/tom/sdl-brochure-a5-lr-digitaal-def.pdf

5.3 Data analysis

Two types of data were obtained, namely quantitative data from closed survey questions and qualitative data from open survey questions, interviews, and documentation.

Quantitative data

Quantitative data from the survey were processed with the programme SPSS. First of all, data from Likert Scale questions were labelled with a number ranging from 1 to 5. This can be seen in Appendix E: Labelling of the Likert Scale questions for the analysis in SPSS. For the purpose of analysis, a reversed scoring had to be used for question 8.3 "*I have prejudices or make assumptions about students from other disciplines*" (1- Strongly Agree, 5- Strongly Disagree), as the question was phrased reversed.

Demographic data (gender and age) were compared and did not affect the outcomes so that they were excluded from the further analysis. Descriptive statistics, such as means and standard deviation (std), were undertaken in SPSS to give an overview of the obtained data.

A *factor analysis* was performed in SPSS to validate the Likert Scale survey questions and reveal underlying components. Based on the outcomes of the factor analysis, six main components were identified whereas the original survey consisted of five (see Appendix C: Composition of the closed survey questions).

The *reliability* of the survey was measured by Cronbach's Alpha. Cronbach's Alpha estimates internal consistency among the items that are supposed to measure the same aspect (Cohen et al., 2011). Overall, acceptable values of Cronbach's Alpha range between 0.7 and 0.8 (Cohen et al., 2011). According to Field (2013), when psychological aspects are measured, Cronbach's Alpha can be expected to vary between 0.5 and 0.7 due to the diversity of items. As a result of low internal consistency (Cronbach´s Alphas <0.5) and the non-intuitive grouping among the items of two components identified by the factor analysis, we decided to treat them as one component and named this combined component Others. The components are presented in Table 5 in descending order of their reliability values. Additionally, Cortina (1993) as cited in Field (2013) claims that the value of Cronbach's Alpha depends on the number of items in a component – the lower the number of the component items, the lower the Cronbach's Alpha is. In this study, each component consisted of only 2-3 items which may explain their relatively low Cronbach's Alphas. This matter is further discussed in the limitation section.

Table 5: Components of the student survey in descending order of the reliability values

Component *(educational process framework)*	**Cronbach's Alpha**	**Likert Scale question**	**Research question**
One: Value of ID education *(vision)*	0.59	8.1. Benefit of ID	RQ1
		8.2. Future ID opportunities	RQ1
Two: Teamwork challenges I *(education)*	0.57	7. Division of task	RQ2.3
		12.4. Covid19 – collaboration	RQ3
Three: Reflection on Covid-19 *(facilitation)*	0.55	12.2. Covid19 – flexibility	RQ3
		12.3. Covid19 – relax	RQ3
Four: Teamwork challenges II *(education)*	0.53	6. Familiarity with teamwork	RQ2.4
		8.4. Change of my prejudice	RQ2.3
		8.6. Language improvement	RQ2.3
Others	NA	8.3. My prejudice	RQ2.3
		8.5. Use of different language	RQ2.3
		8.7. Sufficient support	RQ2.4
		12.1. Covid – productivity	RQ3
		13. Assessment	RQ.2.2

As shown in Table 5, even though the factor analysis revealed 6 underlying components, this grouping did not always agree with our initial grouping of the closed survey Likert-scale questions that was done based on the research questions (see Appendix C: Composition of closed survey questions). The factor analysis identified two distinct components (one and three) consisting only of research question 1 and 3 related Likert-scale questions. However, all research question 2 and two research question 3 Likert-scale questions were spread over multiple components due to their broad nature (see limitations, section 9). Therefore, to retain the internal coherence of this thesis and present the results with clarity, we decided to group and present the questions based on our initial grouping rather than on the components identified by the factor analysis.

The adequacy of the *sample size* was identified by Kaiser-Meyer-Olkin Measure. Kaiser-Meyer-Olkin Measure is required to be greater than 0.5. The exact coefficient was 0.55 (see also Table 6). Additionally, the percentage of responses was 62% (n=128) of all module participants (n=204), while the usable sample size percentage after excluding the non-usable data was 43% (n=88). The sample size percentage was considered to be sufficient with a confidence level of 95% and a margin of error of 8%. By Bartlett´s Test of sphericity, homogeneity of the sample was tested. Due to the value lower than 0.05 for significance, the factor analysis could be performed.

Table 6: Kaiser-Meyer-Olkin Measure, sample size percentage and Bartlett's Test

Measure	Value
Kaiser-Meyer-Olkin Measure	0.55
Response percentage	62%
Sample size percentage	43%
Bartlett´s Test of sphericity	
Approximate Chi-Square	164.24
Degree of Freedom	91
Significance	<0.0005

All the *statistical tests* for comparing groups based on their answers (i.e. ID vs. non-ID), were performed depending on whether the data from the groups we wanted to compare were normally distributed. All the data were assumed to be independent. To check for normality, the Shapiro-Wilk test was used. The Shapiro-Wilk test compares the group sample scores to a normally distributed set of scores with the same mean and standard deviation (Field, 2013). Because of the p-values being below 0.05, the assumption of normality did not hold for our data. Thus, to identify mean differences between the groups, the non-parametric Mann-Whitney test for independent samples was used (Field, 2013). This was only used for comparing the groups based on the nature of the project team (ID and non-ID). The means of the groups based on bachelor programmes were compared only in a descriptive way without the use of statistics (Mann-Whitney) due to the low number of samples and unequal sample sizes among the compared groups (see Table 1).

Qualitative data

Qualitative data from the interviews were first transcribed by a transcription software AmberScript. The transcription was thoroughly read and re-read to eliminate any errors and to get familiar with the content, and later on, analysed in a programme Atlas.ti. Based on the theoretical framework, the phrases were coded. Then, the codes were colour coded and organized into themes to identify relationships among data (Cohen et al., 2011). For that purpose, Microsoft Excel was used. Similar steps were taken to analyse the data obtained from the four open questions of the student survey as well as data from the documents. Because the data were already received as a written text, transcription was not needed. Apart from the above mentioned, some steps, as proposed by (Kawulich, 2004), were considered to ensure the data quality: (1) repeating coding multiple times using inductive and deductive reasoning, (2) identifying patterns in data, (3) creating summaries of the data, (4) comparing earlier data with later data as they were collected, and (5) eliminating subjective assumptions by discussing with others. Finally, for each research questions, the outcomes were visualized in tables and representative quotes were selected.

6 Results

The results represent the main findings of this study and are organized according to the research (sub)questions. At the beginning of each section, relevant items of the survey (students) and the interviews (academic staff), as well as documentation, are presented. The survey data are further analysed based on two variables, the bachelor programmes of the participating students and the (non-)ID nature of the project teams. In this section, the results of the Likert Scale questions are presented on item level. Detailed information presented on scale level can be found in Appendix F: Detailed results of the Likert Scale questions.

6.1 Value of interdisciplinary education

What is the value of interdisciplinary education in Module 7: "Discrete Structures & Efficient Algorithms" according to students and involved academic staff?

Instrument	Survey question	Interview question	Documentation
Relevant source	8_1, 8_2, 10, 14, 15	4, 9, 10, 13	---

Students

From all the students who filled in the survey, 55 (62.5%) were members of project groups consisting of students from different disciplines (ID). Based on the results, the students from ID groups mainly appreciated the possibility to learn and help one another (n=22). Another point that was valued by them was the possibility to look at the problem from different perspectives (n=7). The below quotes represent each of the aforementioned points.

"Mathematics student was able to help us (CS students) with part of the implementation of a software issue, not due to his programming prowess but due to a better fundamental understanding of the material."

"Working with students of different disciplines provides the opportunity to look at a problem from different viewpoints."

Two Likert Scale question investigated whether students saw their attendance in ID education beneficial for their future as well as whether they welcome future ID opportunities. The responses were also further analysed based on the bachelor programmes (Table 7) and the nature of the project team (Table 8), as it was expected that these variables might reveal some differences. Overall, the rating was relatively high for both questions regardless of bachelor programmes.

Table 7: Analysis of students answers regarding the value of ID education divided per bachelor programmes. The highest scores are highlighted in bold.

Bachelor programme	AM (n=15)	CS (n=68)	Other (n=5)
	Mean (±std)	Mean (±std)	Mean (±std)
8.1. Benefit of ID	3.80 (±0.78)	3.88 (±0.76)	**4.20** (±0.84)
8.2. Future ID opportunities	3.47 (±1.06)	**3.81** (±0.83)	3.60 (±0.89)

1 (Strongly Disagree). 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), 5 (Strongly Agree)

Considering the nature of the project team, both questions were rated higher by respondents from non-ID teams. The non-parametric Mann-Whitney test for independent samples was used to compare the means of ID and non-ID per question. Based on the test, there was a significant difference for future ID opportunities ($p < 0.05$). Meaning, that the students from non-ID groups were more open for future ID opportunities than the students from ID groups.

Table 8: Analysis of students answers regarding the value of ID education divided per nature of the project team and their significance (Mann-Whitney test). The highest scores are highlighted in bold. Explanation: an asterisk (*) = the significant values ($p < 0.05$).

Nature of the project team	ID (n=55)	Non-ID (n=33)	Significance
	Mean (±std)	Mean (±std)	P-value
8.1. Benefit of ID	3.82 (±0.72)	**4.00** (±0.83)	0.198
8.2. Future ID opportunities	3.56 (±0.92)	**4.03** (±0.73)	0.027*

1 (Strongly Disagree). 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), 5 (Strongly Agree)

Moreover, students from both, ID and non-ID project groups, appreciated teamwork over individual work mainly because it was considered to be fun and each member could introduce new insights into the project.

"When you are with different people, each of them with a different way of thinking, you can attack problems much easier and faster. That's the beauty of collaboration."

Academic staff

Regarding the value of ID education in comparison to monodisciplinary education (as described in Table 9), the academic staff mainly perceived it in learning from each other and broadening each other´s view by listening to other insights and cooperating. This was followed by preparation for real life. This is illustrated by a quote from an academic staff member:

"I think one of the main purposes of interdisciplinary education is not actually to educate people or students for academia, but for the rest of the world."

Table 9: Perceived value of interdisciplinary education by academic staff

Value of ID education – academic staff	**Occurrence**
Learning from each other/broadening view	6
Preparation for real life	5
Learning languages of other disciplines	3
Fun/interesting	2
Challenging	1

The academic staff indicated their personal opinion about ID education. The majority (n=7) of the interviewees were in favour of implementing ID education in university curricula. On the other hand, two interviewees were hesitant to give a clear opinion. A lecturer expressed his opinion by the following analogy:

"It has value, but I don't know. Eating chocolate also has value but you should not eat it too much. If you only do interdisciplinary education, then you lack depth. When I was thinking about what I would like to study. One piece of advice I got was "Do whatever you like but try to do something where you at least know something better than others." If you know, from everything a little bit, but nothing specific well, then why to hire you?"

In addition to general values of ID education, several opportunities of Module 7 that support the current implementation of ID education were found. Firstly, the contribution to the practical application of the taught topics (n=4) as well as ID settings in the module were valued. Secondly, the academic staff appreciated the coherence of the module and the integration of AM and CS insights (n=4). This was supported by the following quote from the module coordinator:

"I'm of proud of the coherence of the topics and the fact that all these different themes that are present in the module, languages and machines, formal languages, discrete mathematics and algebra, are all relevant in this one implementation project to get fast solutions."

According to the project coach, students were enthusiastic about the project and enjoyed it, as the delivery of the final outcome was in the form of a competition. Moreover, two academic staff clearly stated that this module was in their opinion the best module they teach in. Overall, thanks to TOM the quality of education in the involved bachelor programmes was considered to be improved.

"(...) it really works well for computer science. We can create meaningful modules where there is an integration. I think the education is much better than it was before TOM. In the past, students finished their bachelors in five or six years and now it is three or four years."

6.2 Barriers of interdisciplinary education

Which barriers are perceived by students and involved academic staff to hinder interdisciplinary education in Module 7?

Instrument	Survey question	Interview question	Documentation
Relevant source	11, 14, 15	11, 12	Project report

Students

According to the answers to open survey questions, which allowed them to elaborate on various topics, the main challenges that hinder ID application in Module 7 were spotted. The answers regarding Covid-19 situation will be further discussed in section 6.6. Statements not related to student's collaboration (e.g. a content of lectures or teaching style) were excluded from this study.

The main challenge in terms of student's collaboration was seen in an uneven workload of each participating programme. This barrier was further emphasized by the insufficient programming skills of AM students. One student mentioned that another challenge was a large number of CS students in comparison to the number of AM students (see Table 10).

Table 10: Perceived challenges in Module 7 according to students

Challenges in Module 7 – students	Occurrence
Uneven workload for CS and AM students	6
Insufficient programming skills of AM students	5
Insufficient support to form project teams	4
Large number of CS students	1

"The project was mostly coding focussed and the CS students were not in need of much extra mathematical insight, leading the CS students to work ahead with the code quicker than I could keep up."

"The whole project is easy for computer science students and somewhat difficult for mathematics students, so the teamwork is immediately very unfairly distributed."

The students also reported dissatisfaction (n=4) with the organization of forming project teams. In the academic year 2019/2020, the project teams were formed during Matchmaking drinks and organized by students' associations. Concerning this, a significant number of students (n=12) expressed the need for an improvement in the way the project teams are formed. This and other suggestions for future improvement can be seen in Table 11.

"It would be advisable to make having interdisciplinary groups compulsory. It's far too easy to take the comfortable route and have a homogenous group with just your friends, and I don't see this happening in my professional life."

Also, the students asked for support regarding their collaboration (n=14). In their answers, two main topics prevailed: (1) support on how to work with people from different disciplines, (2) a person who can be contacted in case an issue with collaboration occurs.

Table 11: Desired future improvement in Module 7 according to students

Future improvement in Module 7 – students	Occurrence
Support on collaboration of project teams	14
Support to form project teams	12
Larger task for AM	4
Support on programming skills of AM students	3

Academic staff

According to the interviewed academic staff, three main barriers hindered ID education in Module 7: (1) large number of students in general (n=5), (2) large number of CS students in comparison to the number of AM students (n=5), (3) unequal tasks for CS students and AM (n=4). For further information see Table 12.

Table 12: Perceived challenges in Module 7 according to academic staff

Challenges in Module 7 – academic staff	Occurrence
Large number of students	5
Large number of CS students	5
Uneven workload for CS and AM students	4
Lack of academic staff	2
Organizational conflicts	2
Insufficient support on collaboration of project teams	1
Working in groups of unknown people	1

The academic staff perceived that the tasks were not equal for each involved bachelor programme. Particularly, the contribution of CS students was considered to be greater than the contribution of AM students. Such an opinion can be showcased by the following quote:

"In the final project, you see that Computer Science students are very proficient in the programming and that they shift aside the mathematics students."

On the other hand, an interviewed lecture (mathematician) thought that the students from AM had a bigger share in the project. Another notable opinion was given by a lecturer who believed that the project did not require the collaboration of different disciplines, but it could be completed by insights from one field only. According to the module coordinator, the project theme was adequately suiting two disciplines and was the best possible.

"Every year we discuss if we should keep the same project and we decide that we should. It fulfils the purpose and it's not so easy to find a good replacement."

In the past, the deliverables of Module 7 also included a research project (a report on a scientific paper). According to the interviewed staff, the tasks were more balanced, as the AM students were more involved in the research project whereas the CS students were mainly engaged with programming. The main reason for excluding the research project was the large number of students attending the module as well as the lack of academic staff. The following quotation represents the opinion of three lecturers.

"There is not a research project anymore because we simply cannot manage that anymore. (...) We don't have enough staff to grade all that."

The interviewees were also asked what, according to their opinions, could be improved in the next years. The interviewees also got a chance to think out of the box ("If you could wave a magic wand, (…)"). The interpretation of the obtained (less or more realistic) answers is summarized in Table 13. The answers not directly related to improving student's collaboration in the next years were excluded.

Table 13: Desired future improvement in Module 7 according to academic staff

Future improvement in Module 7 – academic staff	Occurrence
Support to form project teams	5
Balanced number of CS and AM students	2
Larger task for AM	1
Support on collaboration of project teams	1
Involvement of AM teacher assistants	1

To improve the way the project teams were formed was the main wish mentioned by the academic staff.

"… it seemed to not have worked out because afterwards there were still, I know about probably 20 to 30 students, who didn't find a group. They didn't even understand how they could find the group. So, I think that can be organized better."

Teaching assistants were largely involved in Module 7. However, all of them study CS and none is from AM. Additionally, concerns about the future of the module were also expressed.

"I'm afraid it may be possible that this whole interdisciplinary thing in the future will go away because the computer science students have a lot of difficulties with math. We can't simplify the math because then it becomes too easy for the math students, and the other way around (...)."

Documentation

In the *project report*, six groups indicated that the AM students had limited knowledge or skills, whereas CS students were proficient in most of the tasks. The positive side of this setting, an opportunity for the AM students to learn, was also mentioned (n=4). Keep in mind that the project report was one of the module deliverables and its content influenced the final grade.

"The math student had limited applicability due to the focus of the project being on the coding aspect, whereas mathematical theory did not need extra explanation."

"(...) on the positive side, their programming skills gave also plenty of opportunities to learn from that."

Overall, 21 groups appreciated the ID nature of their project teams. Thank to which they could learn from each other and broaden their views. On the other side, five groups, that consisted only of CS students, felt the lack of mathematical insight. According to two non-ID groups, insights from students from other disciplines were not needed. Thus, they did not feel disadvantaged.

"Due to the group consisting of only computer science students there might have been a better view from a mathematical standpoint sometimes if a math student were to be in our group."

6.3 Constructive alignment

How are the learning goals, learning activities and assessment of Module 7 aligned and clear to students and involved academic staff?

Instrument	Survey question	Interview question	Documentation
Relevant source	13	8	Module documentation Osiris SEQ document

Students

On the Likert Scale, the students indicated their opinion about the assessment percentage of the project. The project accounted for 20% of the final grade whereas three individual written exams accounted together for 80%. According to a majority of the students (see Table 14), the assessment percentage of the project should remain the same in the next years. The student's answers were similar regardless of their bachelor programmes or the nature of their project team. One student who would have appreciated the project percentage to be higher indicated the following reason.

"I would like the percentage of the project to be somewhat higher because that would trigger to spend more time on the project. And I would like to spend more time on the project, because I feel I learned very much by doing the project (I may have learned even more useful stuff in the project than in some of the other subjects)."

Table 14: Analysis of students answers on the assessment percentage of the project

Scale	Significantly lower	Lower	Remain the same	Higher	Significantly higher
N (%)	4 (4.55%)	11 (12.5%)	53 (60.23%)	17 (19.32%)	3 (3.41%)

Mean (±std) = 3.05 (±0.80)

N = 88

Academic staff

The first four interviewed academic staff were asked to reflect on the assessment percentage in the module. One academic staff claimed that the 20% contribution on the final grade for the project work was adequate. However, three interviewees were not able to answer due to their lack of knowledge about the assessment percentage or the structure of the whole module. Thus, the question was found redundant and excluded from the next interviews.

Documentation

In *OSIRIS,* the learning goals, learning activities and the assessment were clearly described. The information was further elaborated in the *module documentation*, particularly in the Blockbook Module 7 document which was available on the Canvas page of the module. The timeline of the module was described in details and the requirements for successful completion seemed to be clear. The timeline corresponded also with the information at Rooster (rooster.utwente.nl). Moreover, information regarding the project was described in the Project Guide document that was also available to the students on the module Canvas page. Although team collaboration was not an explicit learning goal in this module (see section 3.3), a reflection on it was required in the project report. However, it was not clear from the document whether this part of the project report affected the final grade, and at the same time what the purpose of this reflection was. Both, the Blockbook and the Project Guide documents, were up to date.

According to the results of the *SEQ document,* the students reported that they agree or strongly agree with the clarity of the learning goals and the purpose of the module (n=42). The average was 3.8 (±0.7) when 1 meant Strongly Disagree and 5 Strongly Agree. On the same scale, the module internal coherence scored, on average, 4.0 (±0.8).

6.4 Teamwork challenges

How do students experience teamwork-related challenges within their project group?

Instrument	Survey question	Interview question	Documentation
Relevant source	7, 8_3, 8_4, 8_5, 8_6	Not applicable	Project report

Students

The way students collaborated during the project was identified by question 7. Overall, the students described their collaboration as a balance between individual and group work. The average for this question was 3.02 (±1.11). When we had a closer look at answers based on the nature of the project team (ID or non-ID), we could see only a slight, non-significant difference, as shown in Table 15.

It is important to keep in mind that Covid-19 crisis had a large impact on the students' collaboration in Module 7, and, consequently, on the results of this study. We will pay more attention to these impacts in section 6.6. Below, a student quote from the survey can be found:

"Working from home reduced collaborative capability and rewarded individual work more as it was more efficient than trying to share ideas over Discord."

Table 15: Analysis of students answers on their team collaboration divided per the nature of the project team and their significance (Man-Whitney test). The highest scores are highlighted in bold. Explanation: an asterisk (*) = the significant values ($p < 0.05$).

Nature of the project team	**ID (n=55)**	**Non-ID (n=33)**	**Significance**
	Mean (±std)	Mean (±std)	P-value
7. Division of task	**3.15** (±1.18)	2.82 (±0.99)	0.184
			Mean (±std) = 3.02 (±1.11)
1 (Fully individual work on a specific task), 2 (Moderately individual work on a specific task), 3 (Balance between individual and groupwork), 4 (Moderately groupwork and shared expertise), 5 (Fully groupwork and shared expertise)			

Four Likert Scale questions were directly linked to this research sub-question. The responses were further analysed based on the bachelor programmes (Table 16) and then on the nature of the project team (Table 17) to identify any significant differences. According to the results, slight differences between different bachelor programmes as well as between (non-)ID teams were revealed.

Table 16: Analysis of students answers regarding teamwork challenges divided per bachelor programmes. The highest scores are highlighted in bold.

Bachelor programme	**AM (n=15)**	**CS (n=68)**	**Other (n=5)**
	Mean (±std)	Mean (±std)	Mean (±std)
8.3. My prejudice	2.93 (±1.10)	3.07 (±1.08)	**3.40** (±0.89)
8.4. Change of my prejudice	2.20 (±0.86)	**2.32** (±1.03)	2.20 (±0.45)
8.5. Use of different language	**4.00** (±0.76)	3.65 (±0.93)	3.40 (±0.55)
8.6. Language improvement	3.07 (±1.03)	3.06 (±1.04)	**3.40** (±0.55)

1 (Strongly Disagree). 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), 5 (Strongly Agree)

All students, regardless of their bachelor programmes and the nature of their project teams, claimed relatively no prejudice towards other disciplines, and thus, their prejudice did not change after the module. Next, AM students scored higher on being aware that different fields use different language. However, at the same time, AM students (as well as CS students) did not improve nor worsen their ability to explain ideas to people from other disciplines. Additionally, the non-parametric Mann-Whitney test for independent samples was used to compare the means of ID (which scored higher in all 4 questions) and non-ID groups, but no significant differences were identified.

Table 17: Analysis of students answers regarding teamwork challenges divided per nature of the project team and their significance (Man-Whitney test). The highest scores are highlighted in bold. Explanation: an asterisk (*) = the significant values ($p < 0.05$).

Nature of the project team	ID (n=55)	Non-ID (n=33)	Significance
	Mean (±std)	Mean (±std)	P-value
8.3. My prejudice	**3.13** (±1.12)	2.97 (±0.98)	0.536
8.4. Change of my prejudice	**2.44** (±0.94)	2.06 (±0.99)	0.089
8.5. Use of different language	**3.73** (±0.78)	3.64 (±1.06)	0.969
8.6. Language improvement	**3.18** (±0.98)	2.91 (±1.04)	0.242

1 (Strongly Disagree). 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), 5 (Strongly Agree)

Documentation

In the *project report*, only ten groups indicated their division of tasks. Only two groups worked as a team and shared all the tasks. Individual work, as well as work in pairs, were indicated by four groups. The following quote not only showcases working in pairs but also (most probably) already indicates the lack of programming skills of AM students which was reported by six groups (see more in section 6.2).

"Since we were working in pairs of two students, the Applied Mathematics student was always working together with a Computer Science student. This way the Applied Mathematics students learned since the Technical Computer Science students were eager to explain what they were doing."

6.5 Preparation and support

How are students and involved academic staff prepared and supported in Module 7 regarding interdisciplinarity

Instrument	Survey question	Interview question	Documentation
Relevant source	6, 8[7], 9	5, 6, 7	SEQ document Student-Driven Learning brochure

Students

Based on the student's answers, they were somewhat familiar with how to work with people from other disciplines prior to the module. The average score for this question is 3.17 (±0.72). When the averages of different bachelor programmes were compared, only slightly differences were seen – the average of AM students, as well as the students from other bachelor programmes, equals to 3.20, while the average of CS students is 3.16.

Regarding the sufficiency of the provided support on how to develop skills needed for collaboration within their project team, the students had a neutral opinion (with the slight inclination to negative). Overall, the average score for this question was 2.76 (±0.97). When data were compared for different bachelor programmes (Table 18), it was evident that the AM students felt slightly less supported in comparison to the feeling of the CS students and other bachelor programmes.

Table 18: Analysis of students answers on sufficiency of the provided support divided per bachelor programmes. The highest scores are highlighted in bold.

Bachelor programme	**AM (n=15)**	**CS (n=68)**	**Other (n=5)**
	Mean (±std)	Mean (±std)	Mean (±std)
8.7. Sufficient support	2.53 (±0.99)	**2.81** (±0.95)	2.80 (±1.30)
			Mean (±std) = 2.76 (±0.97)
1 (Strongly Disagree). 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), 5 (Strongly Agree)			

Also, when the answers were analysed based on the nature of the project team (Table 19), it was found that that the students from ID teams felt significantly more unsatisfied with the provided support, in comparison with the non-ID groups. This was tested by the non-parametric Mann-Whitney test for independent samples.

Table 19: Analysis of students answers on sufficiency of the provided support divided per nature of the project team and their significance (Man-Whitney test). The highest scores are highlighted in bold. Explanation: an asterisk (*) = the significant values ($p < 0.05$).

Nature of the project team	**ID (n=55)**	**Non-ID (n=33)**	**Significance**
	Mean (±std)	Mean (±std)	P-value
8.7. Sufficient support	2.51 (±0.94)	**3.18** (±0.88)	0.001*
			Mean (±std) = 2.76 (±0.97)
1 (Strongly Disagree). 2 (Disagree), 3 (Neither agree nor disagree), 4 (Agree), 5 (Strongly Agree)			

As already indicated in section 6.2, students (n=14) would have appreciated more support on the way they collaborated, respectively on how to work with people from other disciplines. As well as having explicit information about who was the contact person who could help if there were any problems with their collaboration.

The students found support regarding their team collaboration mostly on the internet (n=42), followed by help from other students/groups (n=41). Five students indicated that they did not require any help. Note that the students could select multiple answers from a defined list of choices and specify when the choice “other” was chosen. The incidence of the selected answers is shown in Table 20. On average, the students selected 2.2 answers (maximum 7 answers).

“Personally, I didn't make use of any such support, apart from the internet and discussing with other students.”

Table 20: Different sources of support used by students

Different sources of support	Occurrence
Internet	42
Other students/groups	41
CANVAS	33
Lectures	29
Lecturers	24
Literature	9
Other academic staff not directly involved in the module	7
Other*	4
(*) = Friends & family (n=2), Teaching assistants (n=2)	

Academic staff

To gain more information on how the academic staff were prepared and supported in the module, we first analysed information regarding the general preparation of the module and the interaction of the academic staff involved. According to the module coordinator, there was no central meeting for all the involved academic staff before the module started. They used to organize such meetings only in the past.

“In the beginning when we were running the module for the first and also the second time, we even had weekly or at least biweekly meetings. Now that we have gained experience, we don't do that anymore.”

Some of the interviewees were not sure if there was any meeting organized. Additionally, four of them claimed that even if a module meeting was organized, their role in the module was minor and, thus, their attendance would not have been required. In the academic year 2019/2020, there was one meeting organized. This was organized for preparing and informing teaching assistants involved in the coaching sessions.

The communication among the academic staff was perceived as non-problematic and usually based on one to one interaction. If necessary, the academic staff could find support from other academic staff or the module coordinator. This mainly applied to support on the content of their lecturers, etc. However, none of the interviewees received any support on how to facilitate student´s collaboration.

The module is reasonably decentral. If everybody sticks to the schedule, which is anyhow given, it works out."

Regarding support provided to the students, academic staff perceived that there was enough support provided to the students. Two lecturers believed that there was no more need to support team collaboration.

"This is the second year course; I generally think that people are mature enough to cope in different working and group environments and with different group dynamics."

Documentation

One item of the *SEQ document* aimed to investigate whether the communication throughout the module was clear. Overall, the students were somewhat satisfied with the communication in the module. On five-point scale (1 = Strongly Disagree, 5 = Strongly Agree), the answers on average were 3.8 (±0.9).

Student-Driven Learning (SDL) at the University of Twente is an overarching concept that expects the students to take initiative and be responsible for their own learning. This also applies to Module 7. According to the *brochure*, in SDL, students are still carefully supervised and monitored and step by step guided towards self-regulation. The safety net in terms of guidance is in any stage available to the students (Visscher-Voerman, 2017).

6.6 Reflection on Covid-19 crisis

How was the project teamwork in Module 7: "Discrete Structures & Efficient Algorithms" affected by COVID-19 crisis?

Instrument	Survey question	Interview question	Documentation
Relevant source	10, 11, 12_1, 12_2, 12_3, 12_4, 15	Not applicable	CANVAS Project report SEQ document

Students

Due to the Covid-19 crisis, all physical education activities at the University of Twente were banned from the 13th of March 2020 and had to take place online. This unusual and unexpected situation affected Module 7 and the project teamwork in particular. In Table 21, the results of four Likert Scale questions related to this situation are shown. In general, the students perceived their collaboration slightly more flexible and relaxed when working from home whereas their productivity and the extent to which their collaborated dropped.

Table 21: Analysis of students answers on the effect of Covid-19 crisis on their teamwork

	Mean (±std)
12.1. Covid - productivity	2.61 (±1.04)
12.2. Covid19 - flexibility	3.69 (±0.91)
12.3. Covid19 - relax	3.38 (±0.98)
12.4. Covid19 - collaboration	2.51 (±1.06)
	N = 88
	1 (Much less). 2 (Less), 3 (Equally), 4 (More), 5 (Much more)

The students could further elaborate on the aforementioned results in the open questions. The students mainly appreciated the flexibility and efficiency of working remotely. They could work from any place and at any time it suited them the best. The meetings were found more effective, as no time was wasted on chit-chatting.

"Working from home increased efficiency of some people because they can work when it best suits them and in a more comfortable environment."

Apart from communication barriers, team collaboration issue was indicated as the main challenge of working remotely. The communication barriers were mentioned by 21 students and team collaboration issue by 14.

"There was a lack of contact with some group members, which made it unclear what was and what was not already done. Multiple people were doing the same thing separately because of insufficient contact."

From 14 students that reported team collaboration issue 12 of them indicated that working remotely limited their collaboration, as it made it more difficult to explain and show ideas to each other. Nevertheless, two students welcomed the option of sharing a screen because, in physical meetings, it is difficult to have a good view on a single laptop screen with four people.

"Working separately on the same program whilst not in the same room as others turned out to be difficult. We mostly ended up with one person modifying our algorithm and sharing his screen and the others watching and contributing as well."

Besides, the students indicated that working from home increased the occurrence of freeriding behaviour (e.g. by not attending the online meetings) (n=5). Another challenge stated by the students (n=5) was related to the poor internet connection which raised the occurrence of misunderstandings and decreased effectiveness. Also, problems with time management (n=1) and different time zones were reported (n=2).

Documentation

Canvas announcements were used as the main information channel from the academic staff to the student. The students were regularly informed about the changes regarding lectures, tutorials, and exams dates (some had to be rescheduled) and their forms. The first announcement was posted on the 13th of March.

Challenges caused by Covid-19 crisis were also reflected in the *project report*. The project groups (n=7) noted that team productivity decreased while working remotely and the communication became more challenging. On top of that, some members of 3 project groups became more focussed on their personal needs (such as exams or leisure time activities) which consequently also affected their motivation to continue with the project. Overall, none of the project groups mentioned their appreciation of the remote collaboration. The below quotes are retrieved from the project report and illustrate the students' experience.

"Due to the sudden COVID-19 crisis, there was not much room for collaboration or discussion on the implementation of certain features, which made it difficult to learn from each other's work."

"When working from home, more work was done individually and so communication in implementation was limited and discussion was mainly held after each member finished a particular implementation."

"Before the university closed because of the coronavirus, we worked together every tutorial session, but once the university closed, we all started focusing a bit more on the exams."

Based on the data obtained from the *SEQ document*, the students (n=43) perceived that they could continue working in the module during the Covid19 crisis. On the scale from 1 (very bad) to 10 (excellent), on average, the score was 6.3 (±2.2). Thinking of the relatively high standard deviation value it can be concluded that there was clearly a wide variety of student perception on how the Covid-19 situation affected their teamwork. Another question regarding Covid-19 crisis focused on their learning. The students were asked if they learned as well as in the normal situation. The option "yes" was selected by 46.5% students, "no" was chosen by 48.8%. No opinion was selected by 4.7%. Additionally, a quotation from the SEQ document showcases one of the challenges experienced by the students during Covid-19 crisis.

"(...) as for students who are already back to their home countries, there is a different time zone. So, when we checked the results online, it was in the midnight for me."

7 Discussion

The results from the previous section will be further discussed below in order to answer the research questions and sub/questions and address the main goal of this study.

Research question
What is the value of interdisciplinary education in Module 7: "Discrete Structures & Efficient Algorithms" according to students and involved academic staff?

Both, students and academic staff, perceived ID education as valuable. Positive perception of academic staff on ID education is essential for their motivation to establish and run such a complex educational set-up. Also, when it comes to the students, their positive attitude towards ID education increases their learning experience (Borrego & Newswander, 2010). The key values of ID education were perceived by both students (Table 8) and academic staff (Table 9) in the possibility to learn from other disciplines, to look at problems from different disciplinary perspectives and in broadening personal perspectives. Next to that, the academic staff (n=5) claimed that ID education prepares students for real life.

On average, the students of every bachelor programme regardless of the nature of their project team (ID or non-ID) believed that they will benefit in their future career from participating in ID modules. The students from non-ID groups valued the future career benefits of ID education even more. Besides, the CS students are more open to work on more ID projects in the future, in comparison to the other bachelor programmes. This also applies to the students from non-ID groups (consisted of only CS students) that are significantly more willing to participate in future ID projects. This result indicates that the students were willing to engage in ID education, meaning that once challenges of its application are addressed, students will be motivated to participate in it. More details can be seen in Table 16 and Table 17.

Research question
What are the challenges in Module 7: "Discrete Structures & Efficient Algorithms" regarding interdisciplinary education?

Research question 2 consists of four sub research questions that will be discussed separately.

2.1 Which barriers are perceived by students and involved academic staff to hinder interdisciplinary education in Module 7?

Overall, the students and the academic staff mostly agreed on their perception of the barriers of ID education in Module 7. Although it is stated in the module documentation that *"the project is carefully crafted in such a way that not only programming skills are needed, (...)"*, the students and the academic staff saw programming as the core theme. In general, it was perceived by both, the students and the academic staff, that the AM students contributed less, in comparison to the CS students. This was mainly caused by the knowledge gap - on one side, CS students had relatively high programming proficiency, and on the other side, the AM students had insufficient programming skills. The CS students were already familiar with the relevant programming language (Python) from the prior courses, whereas the AM students needed two weeks to be able to learn it. This seemed to create a delay, and, in practice, it often led to CS students taking over the main programming tasks of the project rather than collaborating. As there was only little integration, such collaboration can be rather seen as multidisciplinary than ID. In this module, there was quite a lot to learn for the AM students. However, the module was rather easy for the CS students (Table 10). For the successful completion of an ID project, the contribution of all participating programmes should be required (MacLeod & van der Veen, 2019), however, this was not always the case in module 7. In line with this, the students indicated that they would appreciate providing a larger task for AM students within the project (n=4) and support on programming skills of AM students (n=3). When the programming skills of AM students are enhanced, their contribution might grow. By doing so, unequal students' contribution (particularly, taking over by CS students) may be eliminated.

Another attention point mentioned by the academic staff was a large number of the students, and particularly the unequal proportion of the CS and AM students. In the academic year 2019/2020, about 204 students (165 CS, 26 AM) were enrolled in the module. This is, indeed, a significant increase in comparison to the situation five years ago when the module was established. Back then, there were approximately 60 CS and 30 AM students. According to the previous programme director, due to the relatively low number of the students, the module had to become multidisciplinary to ensure an economically healthy module. Moreover, as the courses taken by both bachelor programmes are similar, combining students of these two programmes in one module was a logical step. Thus, it can be concluded that the motivation (referred as *vision* in our theoretical framework) for establishing this module was mostly based on practical rather educational reasons. Increasing student numbers at the universities is a current trend. This can be expected to cause practical challenges in the future years in terms of, for instance, the lack of academic staff (a current barrier reported by the academic staff in Module 7) which may decrease educational quality. As a result of the high number of students in Module 7 and the insufficient number of academic staff to support them, a report on a scientific paper (a research project) was cancelled. According to the statements of three of the academic staff, that was unfortunate, since the research project was essential, as it brought more balance to the contribution of the participating bachelor programmes. As stated by one of the interviewees and having the aforementioned in mind, there is a possibility that the ID nature of the module might diminish. Also, one of the participating bachelor programmes might join or establish another (non-)ID module (more relevant or with fewer students).

Both, students and academic staff, would have welcomed improvement on the process of how the project teams were formed (see Table 11 and Table 13). In the Project Guide document, it was indicated that *"it is desirable that these teams are mixed.",* however, this might be hard to achieve in practice, as limited attention at the Matchmaking drinks session was paid to this aspect and due to the unequal proportion in numbers of CS and AM students. The current form of organizing Matchmaking drinks was perceived as chaotic. The session in the academic year 2019/2020 was organized in a room of insufficient size, so not all the students could fit in. Also, the project coach claimed that the students had a hard time to find available team members and some did not belong to any team even after the session.

2.2 How are the learning goals, learning activities and assessment of Module 7 aligned and clear to students and involved academic staff?

The learning goals, learning activities and the assessment were clear and satisfactory for the majority of the students. What is noteworthy is the lack of knowledge of the academic staff about the module structure, respectively the assessment, due to which they could not indicate their opinion about the assessment percentage. This might, to some extent, reflect poor organization and communication within the module. This matter will be discussed in detail in the later section (sub research question 2.4).

In ID settings, according to McNair et al. (2011), at least one of the learning goals should motivate the students to collaborate with people from other disciplines. In Module 7, the learning goals only explicitly focused on understanding discrete structures and the application of algorithms for discrete structures and no attention was paid to learning goals related to the students' collaboration. We can assume that this is because the motivation for establishing the module was practical (creating economically healthy module) rather than educational. In the academic year 2019/2020, there seemed to be an attempt to "assess" student's collaboration, as they were required to write a reflection on their group collaboration in the project report.

2.3 How do students experience teamwork-related challenges within their project group?

Although some teamwork challenges were present in the module, it is important to keep in mind that the team collaboration was heavily impacted by the Covid-19 crisis, and thus, the outcomes of this study might not represent the module situation in normal circumstances.

Misunderstanding and freeriding behaviour were reported when working remotely (more details in research question 3). This could have been due to not sufficiently developed trust (no face-to-face interactions) and shared understanding among the members which is required for successful team collaboration (Borrego et al., 2013). Another reported source of misunderstanding was technical problems (e.g. poor internet connection). As a result of the circumstances, the teams tended to work more individually than they would in a normal situation.

Misunderstanding situations may arise from using a different language (e.g. with different semantic meaning). Hence, being aware of different languages used within a group is a key factor to avoid misunderstanding. From all the attending bachelor programmes, AM students were aware of this difference at most, followed by CS students. Such results might reflect their ID experience from previous modules of their study. However, the way they explain their ideas to other disciplines neither improved nor got worse. Whereas some language improvement was reported for the members of ID groups and the students from other bachelor programmes (see Table 16 and Table 17).

It is crucial to acknowledge self-prejudice towards other disciplines in order to ensure effective ID collaboration and value insights of others (Lattuca et al., 2004). Relatively no prejudice or assumption about students from other disciplines was indicated (more details can be seen in Table 16). Therefore, prejudice or assumption about students from other disciplines did not change after the module completion.

2.4 How are students and involved academic staff prepared and supported in Module 7 regarding interdisciplinarity?

Open communication, teamwork and willingness to integrate disciplinary insight (crossing disciplinary boundaries) are prerequisites for the academic staff to successfully apply ID education (Borrego & Newswander, 2010; de Greef et al., 2017; Menken & Keestra, 2016). It seems that staff teamwork and communication in the module was not sufficiently developed. This opinion was supported by the following findings. First, some academic staff were not aware of the overall structure of the module (e.g. assessment percentage, as discussed in the sub research question 2.2.), as well as whether a module meeting was organized. Second, some of the academic staff did not feel important enough to participate in any meeting. Keep in mind that no central meeting was organized (used to be in the past). The academic staff cooperated within small subgroups based on their expertise or based on one to one discussion. Such an organization might have its practical reasons (e.g. time management), however, based on the aforementioned examples, it seems that this structure might have negatively affected the effectiveness of ID education in this module. Even when having these negative examples in mind, the communication in the module was perceived by the academic staff as sufficient.

Overall, the academic staff felt well-supported in terms of content-related questions, nevertheless, no support on how to provide ID education was offered. In ID education, teacher support and their training, for instance, on how to deliver ID education, is perceived to be crucial (Gardner et al., 2014; van den Beemt et al., 2020). Some of the academic staff in the module had only a few years of educational experience and lacked an extensive ID experience (see Table 2), which is an important factor for providing effective ID education.

According to the result, the support in terms of student's collaboration was perceived as lacking according to the students. Contradictory, some academic staff believed that more support was not desired, as it would hinder student's development towards self-directed learning, as promoted by the University of Twente. From our understanding of Student Driven Learning brochure (Visscher-Voerman, 2017), even though students are required to be initiative and responsible for their learning, they should not be left on their own without any guidance and monitoring. On top of that, the students from the ID teams, in comparison to non-ID groups, felt significantly more unsatisfied with the support provided on their collaboration (see Table 19). This result may reflect the fact that support in ID education is important. Regular supervision supports students through their learning process and ensures that the ID nature of their collaboration remains (MacLeod & van der Veen, 2019; Stentoft, 2017). The students in Module 7 preferred to seek for help from "external" sources, such as internet (n=42) and other students (n=41), rather than from the academic staff or the provided module materials. This indicates that the students were not fully aware of who to contact in case of any collaboration issues. This is also supported by their wish to have information on who is a responsible person who can help in such situations. In 2019/2020, this was mainly handled by the module coordinator. On top of that, the student would also appreciate being more supported on how to work with people from other disciplines. On average, students were somewhat familiar with ID collaboration prior to the module (average = 3.17). It is important to keep in mind that interdisciplinarity, respectively students' collaboration, was not a module learning goal and little support regarding this matter was provided (no mentors/tutors available to the project groups, six practical Coaching projects session). Alongside the findings, it is concluded that the current approach of "coaching session for all" was not optimal.

Research question
How was the project teamwork in Module 7: "Discrete Structures & Efficient Algorithms" affected by Covid-19 crisis?

Based on the results of the SEQ document, about half of the students (46.5%) reported that they have learned as well as they would have in a normal situation. The second half (48.8%) indicated the opposite. However, we cannot conclude from this study whether they would have learned more otherwise.

According to the information obtained from the students' survey (Table 21) and the project report, collaboration in an online environment due to Covid-19 had its positives and negatives. The group collaboration felt slightly more flexible and relaxed, as the students could work from any place and at any time. On the other hand, their productivity slightly decreased. The main reported barriers in their collaboration were: (1) misunderstanding (e.g. multiple people working on the same task, poor internet connection, different time zones), (2) freeriding behaviour, and (3) preference of completing individual activities (e.g. parallel exams). As a result of communication and collaboration constraints, team collaboration in some cases gradually shifted from teamwork to individual work.

8 Recommendations

This study aimed to identify the main challenges of IEE in Module 7: Discrete Structures & Efficient Algorithms. Based on the detected challenges present in the module, several recommendations for the future improvement of the module from an ID perspective are proposed. The presented recommendations, their relevance to the module challenges and underlying module characteristics can be seen in Figure 5.

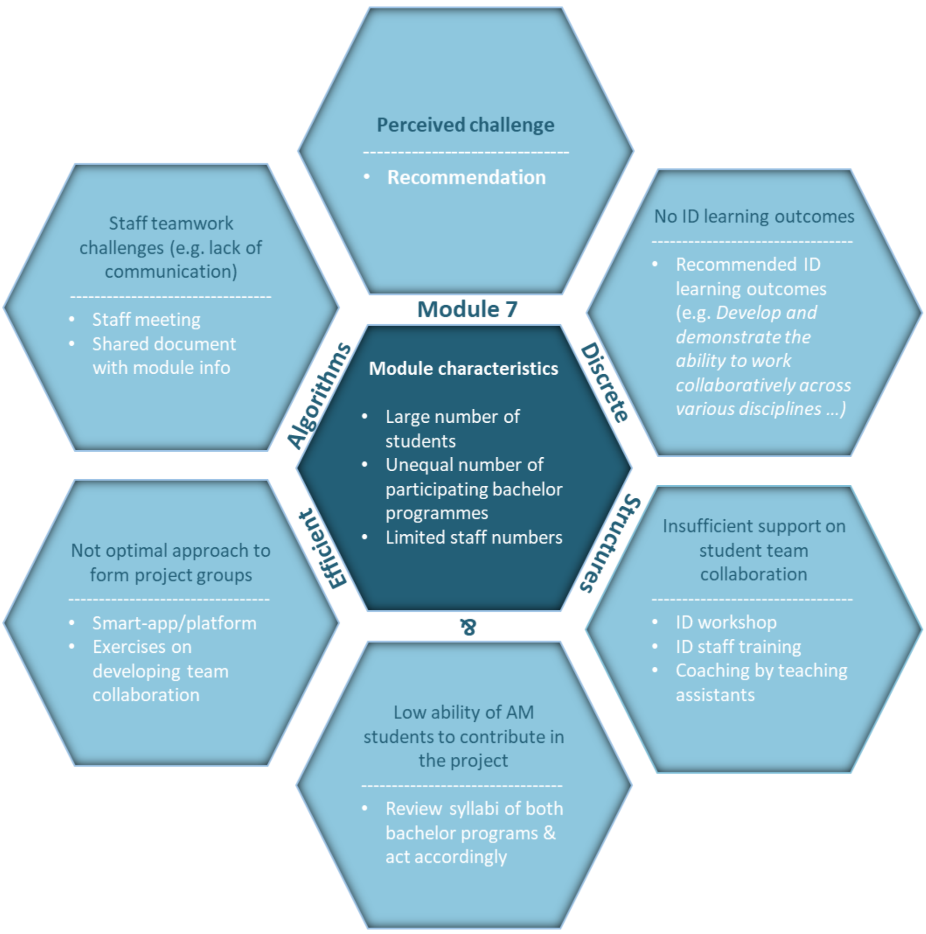

Figure 5: Recommendations (in white at the bottom) and their relevance with the perceived challenges (in blue at the top)

Interdisciplinary learning outcomes

Intended learning outcomes regarding the student's collaboration were absent in Module 7. Having learning outcome(s) that aim to facilitate students collaboration are desired for their motivation to collaborate (McNair et al., 2011). ID learning outcomes should be achievable, measurable and specific in order to assess student's achievement as well as aligned with other (content-related) learning outcomes of the module (Repko, 2008). Such learning outcomes, based on Bloom´s taxonomy, could be formulated as follows: *Upon completion of the module, students should be able to:*

1) Develop and demonstrate the ability to work collaboratively across various disciplines (...)
2) Integrate knowledge from two disciplines (...)

Scaffolding and support

Alongside implementing ID learning outcomes, extra attention needs to be paid to students and staff support in terms of ID collaboration by providing them with the proper tools and education. Below, some recommendations are proposed to achieve this support.

Before the project, *a short workshop* (approximately 1-2 hours) on ID collaboration/learning can be offered to the students to help increase their ID experience and learning. The workshop can cover topics, such as, what ID collaboration is and its practical application, and how to work in teams. This workshop could be provided by the Centre of Expertise in Learning and Teaching (CELT) or any researcher whose research domain is ID collaboration.

Similarly, short *staff training* (teaching in ID education, student´s skills development, supporting students in ID projects, etc.) can help academic staff to deliver effective ID education and can be beneficial for the module. Ideally, the training would be mandatory for all the involved academic staff in their first year. Later, only new incoming staff would be required to attend (optional for the others unless there is new material). This training could also be provided with the help of the CELT or any researcher whose research domain is ID education.

As a result of the large students' numbers and the lack of academic staff, group supervision was replaced by "coaching for all". Based on the results and findings of MacLeod and van der Veen (2019), such an approach does not seem to be optimal for ID education. Based on the fact that the module has great experience with *teaching assistants*, we propose to involve them in *coaching/supervising teams*. Teaching assistants first need to attend coaching training (provided by CELT) to become competent. Besides, academic staff only need to regularly (e.g. biweekly) meet with the teaching assistants for discussion. This solution can, overall, provide the student teams with the necessary (and also according to the results requested by students) support without involving many academic staff.

Balanced contribution

Imbalance in the ability of each bachelor programme to contribute to the project was apparent in the module. While the project was relatively easy for the CS students, it was challenging for AM students, mainly due to lack of programming skills. We suggest reviewing the syllabi of both bachelor programmes to identify what proficiency students obtained prior to the module and compare them with the required skills to meaningfully complete the projects as well as skills learned in the module courses. This comparison can reveal necessary information to help either adjust syllabi of one of the bachelor programmes or to modify the project – in a way that it is challenging for all and that integration of different disciplines and views is crucial to complete the project (McNair et al., 2011). This may also be done by redefining mathematics oriented project subtasks.

Forming project groups

In this module, a Matchmaking drinks session was used for forming project groups but was not optimal (small room, students not being able to find any group). Considering the large number of students and current Covid-19 crisis (which may also affect the future years), we propose to develop *a smart-app/platform*, on the basis of a "dating-app", to form the groups. The students would create groups based on the information from their profile (e.g. bachelor programme). This non-traditional solution promotes creating mixed groups, eliminates space concerns and may also be appealing to the students.

Moreover, with the intention to create a team environment where everybody feels safe to express ideas as an important factor for successful ID collaboration (Borrego et al., 2013; de Greef et al., 2017), we suggest investing time during the first coaching/supervising sessions on developing such a safe environment but also ID collaborative skills. With the same purpose in mind, an educational consultant involved in the module created a document and proposed *exercises on developing team collaboration.* This document is available to the staff; however, it was not used in the academic year 2019/2020 and therefore, we recommend using it. Additionally, several interaction exercises can be also found in a handbook "Experts in Teamwork" (NTNU, 2020). Based on NTNU experience, these exercises are recommended to be performed in three phases: (1) Start-up phase: to get information about each other (e.g. Getting to know you, Map of the people), (2) Work phase: to practice the team interaction (e.g. Reflection on diversity in teams, Approaching an idea from different angles), (3) Completion phase: a reflection on issues related to teamwork.

Academic staff teamwork

There was a clear lack of communication between staff members (unawareness of general module aspects or organization of meetings) and some members did not even feel that their contribution would be valuable. Thus, more attention needs to be paid to staff teamwork. According to a teamwork theory of van den Bossche, Gijselaers, Segers & Kirschner (2006) to further develop team effectiveness, *mutually shared cognition*; having the same understanding on what the situation is about, should be established. This can be done by ensuring the presence of four interpersonal beliefs (interdependence, task cohesion, group potency and psychological safety). Given all the available information, it seems that two aspects were not fully present in Module 7 staff team: (1) task cohesion; shared commitment, and (2) psychological safety; a shared belief that the team is safe for interpersonal risk-taking (Edmondson, 1999). Accordingly, we recommend improving the internal module cohesion by:

- strengthening team communication: organizing a general meeting for all staff at least at the beginning of the module
- sharing the main goal and other module aspects: creating a shared document/platform with all the module relevant information

Psychological safety in the module can be increased by encouraging and accepting feedback, involving the staff in the decision-making process, and providing learning opportunities (teacher training as proposed earlier). Applying these general steps could set a fruitful base for team learning and consequently, improve team and module effectiveness.

9 Limitations

The results of this study have to be interpreted with some limitations in mind. The limitations are acknowledged below.

The first limitation of this study concerns the *instruments* used. Firstly, no personal interviews with the students were held. Short interviews with several students would have helped to expand and further justify the survey data. Secondly, due to the unexpected Covid-19 outbreak, face-to-face interviews with the academic staff were not possible. Although there was an effort to conduct online interviews as best as possible (e.g. by using a web-camera), having personal interviews might have given more complex information on their perception about the module and ID education. Next, only the Matchmaking drinks session and the first Coaching session were observed. We initially intended to attend and observe several Coaching sessions (and chat with the students). This would have provided additional information about the students' support, as well as it would have helped to get even more familiar with the module.

The impact of Covid-19 crisis on the results is the second limitation of this study. Because this study was conducted during the Covid-19 outbreak, some results (e.g. teamwork challenges or provided support) might not represent the module situation under normal circumstances.

The third limitation is related to the closed survey questions. Firstly, the *relatively low Cronbach´s Alpha* of the survey Likert Scale questions (between 0.53 and 0.59). This value might indicate relatively low internal consistency among the closed questions used in the survey and, thus, the derived results must be interpreted with this limitation in mind. To reduce the impact of this limitation, a triangulation technique was applied – the data from Likert Scale questions were complemented by open survey questions, interviews, and documentation (see section 5.2). Secondly, the factor analysis for the closed survey Likert Scale questions revealed *six underlying components in disagreement with the original five components* proposed (directly linked to the research questions). Despite two components being linked to distinct research questions (research questions 1 and 3), we speculate that the broad nature of the questions related to research question 2 led them being spread over multiple components. Because of the project time constraints and the Covid-19 outbreak we did not have the opportunity to first test a pilot version of the survey, which would have helped to overcome the survey limitations.

Last, due to comparing the means of *unequal sample sizes* (ID=55, non-ID=33), the outcomes of the statistical analysis (Mann-Whitney test) need to be considered with caution, as their statistical power might be reduced.

10 Future research

Based on the results of this study, we drew several recommendations for Module 7: Discrete Structures and Efficient Algorithms concerning the challenges of applying ID education. Alongside the study, several possible topics for further research were detected.

First, as a clear constructive alignment plays a crucial role in ID education (van den Beemt et al., 2020), it is striking that little attention has been paid to *assessment in ID education* in the current literature. The central topics for future research could focus on what skills and knowledge should be assessed and how to effectively assess them. Investigating assessment techniques which can evaluate overall ID learning by also assessing disciplinary integration (as a requirement for ID education) is vital.

Second, PjBL is a commonly used educational format in ID education and has played a central role in education at the University of Twente. Having in mind the new strategical document of the University of Twente "Shaping2030", this might be the right time to study the implementation of *challenge-based learning* to ID context. Overall, CBL is a relatively new educational format and there are numbers of practical concerns as well as gains that can be investigated. For instance, research on how to apply CBL in already existing modules (e.g. Module 7 of this study) can be one of them.

Last, educational institutions all over the world have dealt with the unexpected Covid-19 crisis which led to restricting all physical education activities. It is too early to predict whether the same or similar situation will repeat in the future, but it can be agreed that it is better to be prepared. As we can also see from the results of this study, about half of the students felt that they could not learn as well as in a normal situation. The Covid-19 crisis can be then considered as a great opportunity to invest in *developing online ID education* (e.g. developing remote assessment or IT tools for effective remote collaboration, etc.)

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Appendices

Appendix A: BMS Ethical Committee research project approval – 200177

3/22/2020 University of Twente Mail - Approved BMS EC research project request

UNIVERSITY OF TWENTE.

Nikola Petrová <n.petrova@student.utwente.nl>

Approved BMS EC research project request

ethicscommittee-bms@utwente.nl <ethicscommittee-bms@utwente.nl> Thu, Mar 5, 2020 at 4:00 PM
To: n.petrova@student.utwente.nl
Cc: j.h.walmavandermolen@utwente.nl, ethicscommittee-bms@utwente.nl, j.t.vanderveen@utwente.nl

UNIVERSITY OF TWENTE.

APPROVED BMS EC RESEARCH PROJECT REQUEST

Dear researcher,

This is a notification from the BMS Ethics Committee concerning the web application form for the ethical review of research projects.

Requestnr. :	200177
Title :	Module "Discrete Structures and Efficient Algorithms": An evaluation of interdisciplinarity
Date of application :	2020-02-25
Researcher :	Petrová, N.
Supervisor :	Veen, J.T. van der
Commission :	Walma van der Molen, J.H.
Usage of SONA :	N

Your research has been approved by the Ethics Committee.

The ethical committee has assessed the ethical aspects of your research project. On the basis of the information you provided, the committee does not have any ethical concerns regarding this research project.

It is your responsibility to ensure that the research is carried out in line with the information provided in the application you submitted for ethical review. If you

https://mail.google.com/mail/u/1?ik=ef30a160f7&view=pt&search=all&permmsgid=msg-f%3A1660336678237991744&simpl=msg-f%3A166033667823… 1/2

Appendix B: Student online survey (SurveyMonkey)

Module "Discrete Structures and Efficient Algorithms": An evaluation of collaboration

* 2. What is your gender?

- ◯ Female
- ◯ Male
- ◯ Other
- ◯ I would rather not specify

* 3. What is your age?

- ◯ 18 or below
- ◯ 19-21
- ◯ 22-24
- ◯ 25 and above
- ◯ I would rather not specify

* 4. Which bachelor program do you belong to?

- ◯ Applied Mathematics
- ◯ Computer Science
- ◯ ATLAS
- ◯ Other (please specify)

[ ]

* 5. How many students from your group do belong to the following bachelor programs?

	0	1	2	3	4
Applied Mathematics	◯	◯	◯	◯	◯
Computer Science	◯	◯	◯	◯	◯
ATLAS	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

* 6. To what extent were you familiar with how to work together with other disciplines (e.g. from previous experience, Matchmaking drinks)?

Not at all familiar	Not so familiar	Somewhat familiar	Very familiar	Extremely familiar
◯	◯	◯	◯	◯

* 7. Select the most suitable option to describe your group collaboration.

Fully individual work on a specific task	Moderately individual work on a specific task	Balance between individual and groupwork	Moderately groupwork and shared expertise	Fully groupwork and shared expertise
◯	◯	◯	◯	◯

2

* 8. Based on your recent experience, select the most suitable option for the following statements.

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
I will benefit in my future career by participating in educational modules in which people from different disciplines are involved.	◯	◯	◯	◯	◯
I would welcome the opportunity to work on more group projects with other disciplines.	◯	◯	◯	◯	◯
I have prejudices or make assumptions about students from other disciplines.	◯	◯	◯	◯	◯
After this module and project, my prejudices about other disciplines were changed.	◯	◯	◯	◯	◯
I am aware that other disciplines may use the same words differently than how my discipline uses them.	◯	◯	◯	◯	◯
I have improved the manner in which I explain my ideas, so that students of other disciplines can understand me.	◯	◯	◯	◯	◯
There was enough support during the module, to develop my skills needed for collaboration with other group members.	◯	◯	◯	◯	◯

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* 9. Where did you find support regarding the collaboration in your group when you had questions or doubts? You may select multiple options.

- [ ] Lecturers
- [ ] Other academic staff not directly involved in the module
- [ ] Other students/groups
- [ ] Lectures
- [ ] CANVAS
- [ ] Literature
- [ ] Internet
- [ ] Other (please specify)

* 10. Give examples of positive situations that occurred in your group due to the collaboration with other group members and/or working from home.

* 11. Give examples of negative situations (misunderstandings) that occurred in your group due to the collaboration with other group members and/or working from home.

* 12. Due to the current circumstances, your project group had to work from distance. Select the most appropriate option for filling in the blank in the following statements.

	Much less	Less	Equally	More	Much more
I feel that we were ____ productive when working from home.	◯	◯	◯	◯	◯
I feel that we were ____ flexible when working from home.	◯	◯	◯	◯	◯
I feel that we were ____ relaxed when working from home.	◯	◯	◯	◯	◯
I feel that we worked ____ collaboratively from home	◯	◯	◯	◯	◯

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* 13. The assessment percentage of the project is 20%. Based on your recent experience, would you prefer this to be higher or lower?

Significantly Lower	Lower	Remain the same	Higher	Significantly Higher
○	○	○	○	○

* 14. What, based on your personal experience, could be improved in this module in the next years regarding the support of group collaboration?

15. Feel free to add any additional comments or remarks regarding the module or the survey.

16. If you would like to be placed in a lottery to win one of four €25 bol.com vouchers, please fill in your email address (winners will be contacted on the 30th of April 2020).

Thank you for your time!

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Appendix C: Composition of the closed survey questions

Table 22: Original grouping of the closed survey questions directly linked to the research questions

	Survey item *(type of question)*
Informed consent	1. Do you agree to participate in this study? *(multiple choice question)*
Demographic data	2. What is your gender? *(multiple choice question)* 3. What is your age? *(multiple choice question)* 4. Which bachelor programme do you belong to? *(multiple choice question)* 5. How many students from your group do belong to the following bachelor programmes? *(multiple choice question)*

Component *(educational process framework)*	**Research question**	**Survey item *(type of question)***
One: Value of ID education *(vision)*	RQ1: What is the value of interdisciplinary education in Module 7: "Discrete Structures & Efficient Algorithms" according to students and involved academic staff?	8.1. I will benefit in my future career by participating in educational modules in which people from different disciplines are involved. *(Likert Scale question)* 8.2. I would welcome the opportunity to work on more group projects with other disciplines. *(Likert Scale question)*
Two: Constructive alignment *(education)*	RQ2.2: How are the learning goals, learning activities and assessment of Module 7 aligned and clear to students and involved academic staff?	13. The assessment percentage of the project is 20%. Based on your recent experience, would you prefer this to be higher or lower? *(Likert Scale question)*
Three: Teamwork challenges *(education)*	RQ2.3: How do students experience teamwork-related challenges within their project group?	7. Select the most suitable option to describe your group collaboration. *(Likert Scale question)* 8.3. I have prejudices or make assumptions about students from other disciplines. *(Likert Scale question)* 8.4. After this module and project, my prejudices about other disciplines were changed. *(Likert Scale question)* 8.5. I am aware that other disciplines may use the same words differently than how my discipline uses them. *(Likert Scale question)* 8.6. I have improved the manner in which I explain my ideas, so that students of other disciplines can understand me. *(Likert Scale question)*

Four: Preparation and support *(facilitation)*	RQ2.4: How are students and involved academic staff prepared and supported in Module 7 regarding interdisciplinarity?	6. To what extent were you familiar with how to work together with other disciplines (e.g. from previous experience, Matchmaking drinks)? *(Likert Scale question)* 8.7. There was enough support during the module, to develop my skills needed for collaboration with other group members. *(Likert Scale question)* 9. Where did you find support regarding the collaboration in your group when you had questions or doubts? *(multiple choice question)*
Five: Reflection on Covid-19 crisis *(facilitation)*	RQ3: How was the project teamwork in Module 7: “Discrete Structures & Efficient Algorithms” affected by Covid-19 crisis?	12.1. I feel that we were ____ productive when working from home. *(Likert Scale question)* 12.2. I feel that we were ____ flexible when working from home. *(Likert Scale question)* 12.3. I feel that we were ____ relaxed when working from home. *(Likert Scale question)* 12.4. I feel that we worked ____ collaboratively from home *(Likert Scale question)*

Appendix D: General structure of the semi-structured interview

1. How many years of educational experience do you have?
2. What is your role in Module 7? How long have you been involved in Module 7?
3. Do you have any personal experience with interdisciplinary education or collaboration with people from other disciplines? How did you enjoy it?
4. *What, in your own words, is the purpose of Module 7? What makes this module unique?
5. How would you describe the planning of Module 7? Why is done this way?
6. What is your opinion about the support given to the academic staff?
7. What is your opinion about the support given to the students?
8. What do you think about the percentage contribution of the project to the final grade? What do you think about the deliverables (a programme implementation and a report)?
9. *What value does/would interdisciplinarity add to this module, in comparison to monodisciplinary education?
10. *What, according to your opinion, are the main opportunities in Module 7 (regarding interdisciplinary education)?
11. What, according to your opinion, are the main challenges in Module 7 (regarding interdisciplinary education)?
12. What, according to your opinion, could be improved in the next years in Module 7 (regarding interdisciplinary education)? If you could wave a magic wand and change anything in Module 7, what would it be?
13. What is your personal opinion about interdisciplinary education? Do you find it meaningful?

(* items retrieved from Lyall et al. (2015))

Appendix E: Labelling of the Likert Scale questions for the analysis in SPSS

Table 23: Labelling of the Likert Scale questions for the purpose of the analysis in SPSS. Explanation: an asterisk (*) = Excluding question 8.3

Label for analysis	Survey question and scale statement
1	6. Not at all familiar
	7. Fully individual work on a specific task
	8.* Strongly Disagree
	12. Much less
	13. Significantly lower
2	6. Not so familiar
	7. Moderately individual work on a specific task
	8.* Disagree
	12. Less
	13. Lower
3	6. Somewhat familiar
	7. Balance between individual and groupwork
	8.* Neither agree nor disagree
	12. Equally
	13. Remain the same
4	6. Very familiar
	7. Moderately groupwork and shared expertise
	8.* Agree
	12. More
	13. Higher
5	6. Extremely familiar
	7. Fully groupwork and shared expertise
	8.* Strongly Agree
	12. Much more
	13. Significantly higher

Appendix F: Detailed results of the Likert Scale questions

Table 24: The results of the Likert Scale questions including scale level details

Likert Scale Question	Scale level – n (%)					Mean (±std)
	1	2	3	4	5	
6. To what extent were you familiar with how to work together with other disciplines (e.g. from previous experience, Matchmaking drinks)?	3 (3.41%)	5 (5.68%)	56 (63.64%)	22 (25.00%)	2 (2.27%)	3.17 (±0.72)
7. Select the most suitable option to describe your group collaboration.	6 (6.82%)	25 (28.41%)	28 (31.82%)	19 (21.59%)	10 (11.36%)	3.02 (±1.11)
8.1. I will benefit in my future career by participating in educational modules in which people from different disciplines are involved.	1 (1.14%)	4 (4.55%)	13 (14.77%)	56 (63.64%)	14 (15.91%)	3.89 (±0.77)
8.2. I would welcome the opportunity to work on more group projects with other disciplines.	0 (0.00%)	9 (10.23%)	21 (23.86%)	42 (47.73%)	16 (18.18%)	3.74 (±0.88)
8.3. I have prejudices or make assumptions about students from other disciplines.	7 (7.95%)	21 (23.86%)	24 (27.27%)	31 (35.23%)	5 (5.68%)	3.07 (±1.07)
8.4. After this module and project, my prejudices about other disciplines were changed.	23 (26.14%)	25 (28.41%)	31 (35.23%)	9 (10.23%)	0 (0.00%)	2.30 (±0.97)
8.5. I am aware that other disciplines may use the same words differently than how my discipline uses them.	3 (3.41%)	6 (6.82%)	16 (18.18%)	53 (60.23%)	10 (11.36%)	3.69 (±0.89)
8.6. I have improved the manner in which I explain my ideas, so that students of other disciplines can understand me.	7 (7.95%)	16 (18.18%)	32 (36.36%)	29 (32.95%)	4 (4.55%)	3.08 (±1.01)
8.7. There was enough support during the module, to develop my skills needed for collaboration with other group members.	12 (13.64%)	17 (19.32%)	40 (45.45%)	18 (20.45%)	1 (1.14%)	2.76 (±0.97)
12.1. I feel that we were ____ productive when working from home.	13 (14.77%)	28 (31.82%)	31 (35.23%)	12 (13.64%)	4 (4.55%)	2.61 (±1.04)

12.2. I feel that we were ____ flexible when working from home.	2 (2.30%)	7 (8.05%)	20 (22.99%)	45 (51.72%)	13 (14.94%)	3.69 (±0.91)
12.3. I feel that we were ____ relaxed when working from home.	3 (3.41%)	12 (13.64%)	32 (36.36%)	31 (35.23%)	10 (11.36%)	3.38 (±0.98)
12.4. I feel that we worked ____ collaboratively from home.	16 (18.18%)	28 (31.82%)	32 (36.36%)	7 (7.95%)	5 (5.68%)	2.51 (±1.06)
13. The assessment percentage of the project is 20%. Based on your recent experience, would you prefer this to be higher or lower?	4 (4.55%)	11 (12.50%)	53 (60.23%)	17 (19.32%)	3 (3.41%)	3.05 (±0.80)