Faculty of Science
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SUPPORTING QUALITY OF LEARNING IN UNIVERSITY MATHEMATICS

CONTRASTING STUDENTS' APPROACHES TO LEARNING, SELF-EFFICACY, AND REGULATION OF LEARNING IN TWO STUDENT-CENTRED LEARNING ENVIRONMENTS

Juulia Lahdenperä

DOCTORAL DISSERTATION

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ABSTRACT

During the last decades of higher education research, new student-centred learning environments have emerged with the emphasis on students' own activity, responsibility, and independence for learning. Still, in the context of university mathematics, teacher-led instruction remains the most frequent instructional practice. Although the urgent need for developing more student-centred university mathematics learning environments is acknowledged in the literature, research focusing on this area is scarce. This doctoral dissertation addresses the research gap by creating new knowledge on how student-centred learning environments can support mathematics students' quality of learning at university.

To offer a holistic perspective, quality learning is conceptualised with three theoretical concepts, namely students' approaches to learning, academic self-efficacy, and self-regulation of learning. The students' approaches to learning (SAL) tradition comprehends an approach to learning as a combination of students' aims for learning and the processes used to achieve them. Typically, two distinctive approaches are considered, a deep approach aiming to understand, and a surface approach aiming to reproduce knowledge. The tradition values a deep approach to learning and its development during university studies. The notion of academic self-efficacy refers to a person's belief in their ability to perform a specific task in a specific context. Self-efficacy has been identified as the strongest indicator of study success in higher education. In addition, self-efficacy has a central role in the disciplinary context of mathematics, as it increases especially women's retention in mathematics-related majors. The notion of self-regulation of learning (SRL) characterises how students regulate their cognition, behaviour, motivation, and emotions to enhance their personal learning processes. In this doctoral dissertation, self-regulation of learning is viewed as both an individual and a social practice, and in this vein, the notion of co-regulation refers to a transitional process of acquiring self-regulation skills.

Learning environment refers to "the social, psychological and pedagogical contexts in which learning occurs and which affect student achievement and attitudes" (Fraser, 1998). In this doctoral dissertation, the same students are investigated in two parallel student-centred mathematics learning environments, offering an opportunity to address the role of the context on students' quality of learning. The two learning environments were chosen for their well-established but different student-centred instructional practices; Course A functioned within a typical lecture-tasks-small groups framework with the inclusion of student-centred elements, and Course XA was implemented with Extreme Apprenticeship, a form of inquiry-based mathematics education with a flipped learning approach.

The results of this doctoral dissertation are based on both quantitative and qualitative data. The quantitative data consists of students who answered an electronic questionnaire in both courses (N=91). The questionnaire included items measuring students' approaches to learning, self-efficacy, self-regulation of learning, and experiences of the teaching-learning environment. In addition, data collected during the courses (number of completed tasks, participation, and course exam results) were merged with the questionnaire data. All participants of the prior quantitative data collection point were invited for an interview on a voluntary basis. The qualitative data consists of 16 semi-structured interviews where the students reflected on their experiences in both learning environments.

This doctoral dissertation summarises four studies, each articulating the quality of learning in the university mathematics context from different perspectives. Study I quantitatively contrasts students' approaches to learning, self-efficacy, and perceptions of the learning environments in the two learning environments. In addition, the study identifies three student subgroups: 1) students applying a deep approach to learning, 2) students applying a surface approach to learning, and 3) students applying a context-sensitive surface approach to learning. Study II is a follow-up of Study I and takes a qualitative approach when contrasting the student subgroups and their aims for learning and the actualised learning processes in the two learning environments. Study III quantitatively examines gender-specific differences in self-efficacy, and Study IV takes a mixed-methods approach when contrasting students' self- and co-regulation of learning in the two learning environments.

The results of this doctoral dissertation show that there can be substantial variation in students' quality of learning between different student-centred learning environments. The central elements of the learning environment contributing to the quality of learning were tasks, lectures, scaffolding, and student collaboration. In particular, student collaboration was focal in supporting students to move away from undesired learning practices, such as applying a surface approach to learning or unregulated learning. Moreover, the results demonstrate that disrupting the typical course structure by a flipped learning approach elicited various benefits for the quality of students' learning. In this vein, this doctoral dissertation argues for a holistic approach to design university mathematics learning environments and promotes pedagogical development as a significant factor in supporting students to learn mathematics within higher education. Overall, this doctoral dissertation demonstrates how discipline-based higher education research can advance both the fields of university mathematics education and higher education towards the development of research-based student-centred learning environments.

Keywords: undergraduate mathematics education, discipline-based higher education, learning environment, student-centred, approaches to learning, self-efficacy, regulation of learning

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It all started a bit randomly with the Greek letter ε. Some of you might have met this little creature. If you have, perhaps your experience was a bit different than mine; for me it was mind-blowing. For the first time in a mathematics class, I did something else than manipulate equations or copy procedures. The experience was so empowering that I transferred my study right to the mathematics department from the major subject I was studying at the time. Being a stranger to academia, I had no plans for pursuing a doctoral degree. However, plans can change when a bunch of mathematics education enthusiasts come together; I have had the privilege to participate in establishing the mathematics education research group in Kumpula and to be one of the first in Finland to address university mathematics education in a doctoral dissertation. Numerous people have accompanied me along the way, and I feel honoured to have this opportunity to thank all the people who have supported me during this journey.

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Typically, I come out as a very happy person – the happy pill, some say. Sebastian, you have also seen the other side of it. Besides your support and commitment to my academic endeavours, I am grateful for the endless amounts of food you served me.

At this point you might have noticed that this doctoral research came together under the influence of many people. Similarly, I came together under the influence of many people. First, I am grateful for my parents Mama and Kimble for letting me choose my own path in life. One of the things I have learned from you is that you can do anything, even things that you do not know – yet. In that case, you just need to think a little longer. Finally, I want to thank the most important people in my life, my siblings Johku, Jenni, Nalle, Veke, Kassu, Kikka, Madde, Maiju, Molli, Juke, Miisku, Oha, and Titi. Among other things, you have taught me how to explain why there is fog and where do tears come from – to eight-, six-, four- and three-year olds simultaneously and just hours after learning it myself. I am extremely proud of all of you and so grateful for our amazing community of talented, emotional, and somewhat opinionated people. It is ever so miraculous how far one can reach when loved.

In Hämeenlinna, February 14th, 2022

Juulia Lahdenperä

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This doctoral dissertation is based on the following publications:

I Lahdenperä, J., Postareff, L., & Rämö, J. (2019). Supporting quality of learning in university mathematics: A comparison of two instructional designs. *International Journal of Research in Undergraduate Mathematics Education, 5,* 75–96. https://doi.org/10.1007/s40753-018-0080-y

II Lahdenperä, J., Rämö, J., & Postareff, L. (2021). Contrasting undergraduate mathematics students' approaches to learning and their interactions within two student-centred learning environments. *International Journal of Mathematics Education in Science and Technology*, 1-19. https://doi.org/10.1080/0020739X.2021.1962998

III Lahdenperä, J. (2018). Comparing male and female students' self-efficacy and self-regulation skills in two undergraduate mathematics course contexts. In V. Durand-Guerrier, R. Hochmuth, S. Goodchild, & N. M. Hogstad (Eds.), *Proceedings of INDRUM 2018* (pp. 346–355). University of Agder and INDRUM.

IV Lahdenperä, J., Rämö, J., & Postareff, L. (2022). Student-centred learning environments supporting undergraduate mathematics students to apply regulated learning: A mixed-methods approach. Manuscript submitted for publication.

The publications are referred to in the text by their roman numerals.

Report on the independent contribution of the doctoral candidate to the publications:

Research idea and planning: JL, JR, LP (Studies I-IV); Acquisition and processing of research material: JL (Studies I-IV); Analysis and interpretation of research material: JL (Studies I-IV), JR (Studies II and IV); Reporting of research outcomes: JL (Studies I-IV); Preparation and writing of the manuscript: JL (Studies I-IV); Review and editing of the manuscript: JL (Studies I-IV), JR (Studies I, II, and IV), LP (Studies I, II, and IV); Project administration: JL (Studies I-IV).

1 INTRODUCTION

One could assume educational development in tertiary mathematics was in vogue. In 2016, the Conference Board of the Mathematical Sciences (CBMS), an umbrella organisation for professional societies of the mathematical sciences in the US, released a statement signed by the presidents of AMATYC[1], AMS[2], AMTE[3], ASA[4], MAA[5], NCTM[6], and SIAM[7], to name a few, urging the integration of active learning methods in tertiary-level mathematics education:

> *[W]e call on institutions of higher education, mathematics departments and the mathematics faculty, public policy-makers, and funding agencies to invest time and resources to ensure that effective active learning is incorporated into post-secondary mathematics classrooms. (CBMS, 2016)*

The statement was in part motivated by the 2015 MAA report *A Common Vision for Undergraduate Mathematical Sciences Programs in 2025*, in which, after synthesising the curricular guides of AMATYC, AMS, ASA, MAA, and SIAM, the conclusion was that “the status quo is unacceptable”. These five professional societies agreed that there is an urgent need to improve university mathematics teaching and learning. To do that, they called the community of mathematical sciences to invest in significant further action – besides updating curricula, addressing the secondary-tertiary transition, and establishing connections to other disciplines – to “scale up the use of evidence-based pedagogical methods” (Saxe & Braddy, 2015).

The calls for educational development are global. For example, similar statements have been made in Europe; the European Commission (2016) urged the modernisation of higher education, especially by improving the quality of teaching. Also in the Finnish context, the *Vision for Higher Education and Research in 2030* calls for the adoption of student-oriented approaches aiming to create “the world’s best learning environments” (Ministry of Education and Culture, 2017). But what are the challenges these evidence-based pedagogical methods are expected to address? Saxe and Braddy (2015) points out that the field of mathematics has undergone major changes caused, for example, by rapid technological development and an

1 The American Mathematical Association of Two-Year Colleges

2 The American Mathematical Society

3 The Association of Mathematics Teacher Educators

4 The American Statistical Association

5 The Mathematical Association of America

6 The National Council of Teachers of Mathematics

7 The Society for Industrial and Applied Mathematics

increasing need to collaborate within and outside STEM fields. This creates a strong need for skilled and diverse workforce in technology-related fields, also in Finland (OECD, 2019; Technology Industries of Finland, 2021). Furthermore, university mathematics has been described as a context struggling to invite women and underrepresented student groups to be part of the community (see e.g., Adiredja & Andrews-Larson, 2017; Saxe & Braddy, 2015). Therefore, there is a recognised need to diversify the mathematics community and promote achievement in mathematics, confidence in mathematical competence, and retention especially for women and underrepresented student groups (CBMS, 2016; Saxe & Braddy, 2015). In this vein, the endeavours to develop university mathematics education have societal motivations. However, they can also be regarded as advancing mathematics as a scientific field because researcher diversity enhances creativity and innovations (Nielsen et al., 2017), and increases scientific impact (AlShebli et al., 2018).

The challenge of adopting new teaching practices is not unique to mathematics. However, the challenge can be more extensive in the STEM fields as traditional teaching practices remain in majority (Hora, 2015; Stains et al., 2018) – despite the extensive evidence promoting the new evidence-based pedagogical methods (see the next section). Furthermore, Lindblom-Ylänne and colleagues (2006) show that in higher education especially science instructors need support in developing more student-centred teaching practices. The educational development work is not only for educational scientists; the MAA report (Saxe & Braddy, 2015) promotes joint efforts to ensure that the mathematical sciences community is at the centre of these – in their words inevitable – changes in pedagogical practices. Indeed, the motivation for this doctoral dissertation is to address the intersection of higher education and university mathematics – a territory no doctoral dissertation in Finland had addressed up to the commencement of this research (cf. Muhonen & Vuolanto, 2020). The premises are that in the university mathematics context, there is an urgent need to both further understand the relationship between teaching and learning, and more specifically, transfer and integrate knowledge from research to teaching and learning practices.

1.1 OUTLINE OF THE PRESENT STUDY

This dissertation originates from the intersection of mathematics, mathematics education, and higher education. I refer to this dissertation as discipline-based higher education (DBHE) research. As the National Research Council defines it, DBHE "combines expert knowledge of a science or engineering discipline, of the challenges of learning and teaching in that discipline, and of the science of learning and teaching generally" (Singer et al., 2012, 2; see also Dolan et al., 2018; le Roux et al., 2021). Using this DBHE approach, this dissertation summarises four studies investigating the quality of students' learning in the university mathematics context. The studies are based on both quantitative and qualitative data collected from the same students in two parallel first-year student-centred mathematics learning environments. The learning environments are contrasted with the perspectives of students' approaches to learning (Studies I and II), academic self-efficacy (Studies I and III), and regulation of learning (Study IV). The theoretical concepts of the aforementioned perspectives, as well as their connections to student-centred learning environments are presented in section 2. The general aims and research questions for this doctoral dissertation are elaborated in section 3, and the research context and the learning environments are described in section 4. Section 5 provides methodological reflections, and description of the participants, data collection, and data analysis. The results (section 6) are followed by a discussion of the main findings (section 7). The general discussion (section 8) sums up the relationship between quality of learning and learning environments, and it is accompanied with theoretical, methodological, and practical implications (section 9). Finally, the doctoral dissertation is concluded in section 10.

2 THEORETICAL FRAMEWORK

The theoretical framework of this doctoral dissertation is built around four theoretical concepts. First, the following sections define the concepts of students' approaches to learning (SAL), academic self-efficacy, and self-regulation of learning (SRL). Then, the notion of student-centred learning environment is elaborated on and its connections to approaches to learning, self-efficacy, and regulation of learning are discussed. The SAL tradition is used mostly in Europe and Australia, while the SRL tradition is used in North America. The choice of these theoretical concepts was guided by SAL and SRL traditions being the key distinction in the field of higher education and offering distinctive ways of conceptualising quality of learning (Pintrich, 2004). Self-efficacy was selected for it being the most significant single construct predicting success in higher education (for a meta-analysis, see e.g., Richardson et al., 2012). Furthermore, as discussed in the following subsections, students' approaches to learning, self-efficacy, and self-regulation of learning are constructs that can be promoted through learning environments. These three concepts offer a holistic perspective on university students learning in student-centred learning environments. The adopted theoretical perspective is summarised in the last subsection in which connections between the concepts are further elaborated.

2.1 STUDENTS' APPROACHES TO LEARNING

Teaching and learning in higher education has been long investigated from the perspective of students' approaches to learning. The tradition originated in the Göteborg group; Marton and Säljö (1976) first empirically identified two qualitatively different ways in which students approach learning, namely deep-level and surface-level processing. They later reformulated the names of these categories as deep approach and surface approach to learning to emphasise the involvement of both the student's aims for learning and the processes employed to achieve them (Marton & Säljö, 1984). Of the two approaches to learning, the *deep approach* refers to learning that aims at understanding and creating a holistic view of the studied content; a student who applies a deep approach to learning is looking for patterns and connections, focuses on the underlying meaning, and seeks integration (Biggs, 1991; Coertjens et al., 2016; Entwistle, 2009; Marton & Säljö, 1984). In contrast, the *surface approach* refers to instrumental, memorisation and reproduction -oriented learning that shows in unreflective studying and rote learning resulting in a fragmented knowledge base (Biggs, 1991; Coertjens et al., 2016; Lindblom-Ylänne et al., 2019; Marton & Säljö, 1984). In a recent study, Lindblom-Ylänne and colleagues (2019) frame unreflective processes to the centre of the surface approach and suggest that it should be renamed as an *unreflective approach*. Therefore, the deep and surface approaches describe the quality of students' learning processes and outcomes in a specific context. The quality shows both in academic achievement and study progress; although the relation is not always straightforward (see e.g., Asikainen et al., 2014), there are multiple studies linking the deep approach to higher, and the surface approach to lower academic achievement (see e.g., Marton & Säljö, 1976; Richardson et al., 2012; Trigwell & Prosser, 1991; in the context of mathematics Crawford et al., 1998; Maciejewski & Merchant, 2016; Murphy, 2017). Furthermore, a deep approach to learning has been connected to completing a degree in time and a surface approach to a delayed graduation (see e.g., Haarala-Muhonen et al., 2017). This makes the deep approach the most desirable approach to learning. The role of the deep approach is extensive specifically in the university mathematics contexts; it is linked to students' cohesive conception of mathematics (Crawford et al., 1998) and is characterised as essential for learning proof-based mathematics at university level (Maciejewski & Merchant, 2016).

Later, a third approach to learning, named *strategic approach* by Entwistle and Ramsden (1983) or an *achieving approach* by Biggs (1987), was added. This third approach referred to organising studying or studying according to the assessment criteria. More recently, the third approach has lost the achievement element and is more commonly referred to as organised studying; *organised studying* refers to students organising and managing their everyday study practices rather than the learning itself (Biggs, 1987; Coertjens et al., 2016; Entwistle & Peterson, 2004; Hailikari & Parpala, 2014; Marton & Säljö, 1984). A central element of organised studying is also time and effort management (see e.g., Hailikari & Parpala, 2014). Because of the strong emphasis on organising rather than engaging in learning, the third approach is typically seen as conceptually different from the deep and surface approaches to learning; it is viewed as an approach to studying rather than an approach to learning (Biggs, 1987; Parpala & Lindblom-Ylänne, 2012; Vanthournout et al. 2014).

The approaches to learning are non-exclusive. Literature has reported on various student profiles representing different combinations of the deep, surface, and organised approaches (Asikainen et al., 2020; Parpala & Lindblom-Ylänne, 2012; Parpala et al., 2010; Vanthournout et al., 2013) and in many studies, the combination of a deep and an organised approach coexists with many positive attributes related to learning and studying (see e.g., Asikainen et al., 2020; Hailikari & Parpala, 2014; Vanthournout et al., 2013). The non-exclusiveness of an approach to learning is further supported by the rarity of a pure deep or a pure surface approach to learning. For example, Lindblom-Ylänne and colleagues (2019) identified five surface-approach student profiles, four of which were dissonant profiles implying the inclusion of some elements of a deep approach. They argue that the dissonant profiles might be in a transition phase from a surface approach towards more favourable approaches to learning (Lindblom-Ylänne et al., 2019). This line of thought is supported by Kember (2016) who suggests that deep and surface approaches are not two distinct extremes but a continuum along which it is possible to gradually transition (see also Fryer & Vermunt, 2018).

Before going deeper into the variation in students' approaches to learning, there is a potential conceptual confusion that needs to be addressed. Approaches to learning can be considered on different levels: on a general degree-level or on a context-specific course- or task-level. Originally, Marton and Säljö (1976) theorised approaches to learning on the context-specific level, but their work has later been applied in multiple studies, which consider the approaches to learning on a general level. This generalisation, not being in line with the original theoretical assumptions, has been criticised in literature (see e.g., Asikainen & Gijbels, 2017; Richardson, 2015; Wierstra et al., 2003). For this reason, it is important to note that in this doctoral dissertation, students' approaches to learning are considered on a course-level – in line with the original work by Marton and Säljö (1976). However, the idea of a general-level approach to learning is not discarded; students are viewed as having both a general predisposition towards a certain approach to learning and a contextual, actualised approach to learning (cf. Wierstra et al., 2003). A general approach to learning – the predisposition – consists of student's general aims for learning at university and their general learning processes to achieve them (Wierstra et al., 2003). This implies that students have tendencies towards certain approaches to learning when entering a certain context (Alansari & Rubie-Davies, 2020; Lindblom-Ylänne et al., 2013; Wierstra et al., 2003). The actualised approach to learning is formed when this predisposition is applied as a response to the context (Trigwell et al., 2012). Research shows that the general-level approaches predict the course-level approaches to learning (Coertjens et al., 2016). In this vein, while examining variation in students' approaches to learning, it is important to note that the general approach can be viewed as the source of stability, and the contextual approach as the source of variation in students' approaches to learning (Wierstra et al., 2003). This emphasises the extensive role of the context when seeking change in students' approaches to learning.

The variation in students' approaches to learning can be viewed from both general-level and context-specific perspectives. The first perspective draws on the continuum between deep and surface approaches to learning (cf. Kember, 2016). In this sense, a student can develop their general-level approaches to learning by transitioning along the continuum. The second perspective draws on approaches to learning as contextual responses (cf. Trigwell et al., 2012; Wierstra et al., 2003); students can change their approach to learning as a response to the context. These contextual responses can be extremely sensitive; for example, Öhrsted and Lindfors (2016) conclude that even small changes in the learning environment can induce changes in the students' course-level approaches to learning. Also, a change in students' approaches to learning can originate from the students themselves; a student who typically applies a deep approach to learning can make a strategic decision to apply a surface approach to learning for a particular course (cf. Fryer & Vermunt, 2018; Schneider & Preckel, 2017). All this indicates that it is impossible to draw a comprehensive picture of students' general-level approaches to learning based on their single course-level approaches to learning.

One could hope that a university setting per se supported students to move towards a deep approach to learning. But how do students change their approaches to learning during their university studies? In a literature review of longitudinal studies on approaches to learning, Asikainen and Gijbels (2017) conclude that the evidence is mixed; students can change their approaches to learning, but there is no clear evidence on the direction of the change. This can be due to confusing the general- and context-specific approaches to learning (Asikainen & Gijbels, 2017). Still, this indicates that at least on a group-level, students' mere exposure to a university setting and increase in domain expertise do not automatically generate a shift towards a deep approach to learning. However, some approaches to learning may be more sensitive to the learning environment than others (see e.g., Hailikari & Parpala, 2014; Lindblom-Ylänne et al., 2013; Quinnell et al., 2012; Varunki et al., 2017). For example, some studies suggest that students who apply a deep approach to learning are more stable in their approaches to learning across different learning environments compared to students applying a surface approach (Coertjens et al., 2016; Wilson & Fowler, 2005). Wilson and Fowler (2005) suggest that students who generally apply a surface approach can sometimes move towards a deep approach in a student-centred learning environment. More generally, student-centred learning environments can promote a deep approach to learning (Baeten et al., 2010). The connections between learning environments and students' approaches to learning are elaborated further in section 2.4.1.

2.2 ACADEMIC SELF-EFFICACY

Wealth of literature investigates the relationship between self-efficacy and learning in academic contexts. The notion of *self-efficacy* originates from Bandura's work on Social cognitive theory since the 1970's and is defined as a person's belief in their capability to perform a specific task in a specific context (Bandura, 1994; 2012). Through cognitive, motivational, affective, and selection processes, self-efficacy beliefs influence the choice of activities a person engages with; based on their self-efficacy beliefs, a person determines whether an activity is to be mastered or avoided (Bandura, 1977; 2012; Pajares, 2005). To continue, self-efficacy determines the amount of effort and persistence a person shows when engaging in a task; the greater the self-efficacy, the greater the effort and persistence (Bandura, 1977; 2012; Pajares, 2005). In addition, self-efficacy beliefs play a role in emotion regulation, and influence the extent of options considered, when at an important decision point in life (Bandura, 2012). In contrast to other motivational constructs such as self-concept, self-efficacy concerns context-specific beliefs about perceived competence and capability (Bandura, 1994). Still, self-efficacy is transferable, especially to resembling activities (Bandura, 1977).

According to Bandura's (1977) model, self-efficacy is derived from four principal sources, namely performance accomplishments, vicarious experiences, verbal persuasion, and emotional arousal. *Performance accomplishments* refer to personal mastery experiences; success supports and failing hinders mastery expectations of the future events. The negative effects of failure can be more pivotal at the early stages of a course of events; if a person has already built strong self-efficacy, failures or challenges can – if eventually overcome – further support self-efficacy. It is also notable that mastering unchallenging tasks do not necessarily strengthen a person's beliefs in their own capabilities but instead, lead to discouragement and failure when not living up to the expectation of easy success (see also Bandura, 2012). The mastery experiences are noted to be the most fundamental source of self-efficacy. *Vicarious experiences* refer to social modelling experiences one can have by observing others; seeing others being successful in performing activities can increase the observer's expectations of their own success and result in increased persistence. Although not as fundamental as mastery experiences, the influence of social modelling on self-efficacy can be increased by observing a diverse set of individuals or individuals similar to oneself. Also, individuals with lower self-efficacy can be more sensitive to the effects of social modelling (see also Pajares, 2005). *Verbal persuasion* refers to social interaction through which a person can cultivate their confidence in their abilities resulting in increased persistence when facing challenges. Pajares (2005) points out that with this type of social persuasion, it is easier to lower one's beliefs in their capabilities than to increase them. Compared to mastery experiences, social persuasion is also a less significant source of self-efficacy. Also, social persuasion that strengthens one's expectation outcomes but fails to facilitate the process to achieve them might further weaken the person's self-efficacy. *Emotional arousals* refer to stress reactions such as dysfunctional fear that elicit disbelief in one's capabilities and results in avoidance of the stressful activities. Reducing emotional arousal supports self-efficacy; therefore, supporting students' physical and emotional well-being improves the development of self-efficacy (see also Bandura, 2012; Pajares, 2005).

The voluminous research interest in self-efficacy is grounded in the extensive role it has on academic achievement; in a meta-analysis of 242 datasets, Richardson and colleagues (2012) show that out of fifty measures, self-efficacy is the most significant single correlate of academic achievement (see also literature reviews by Honicke & Broadbent, 2016; van Dinther et al., 2011). The situation is similar in the disciplinary context of university mathematics (see e.g., Pajares, 1996; 2005; Pajares & Miller, 1994; Peters, 2013; Zakariya, 2020). In general, the connection between self-efficacy and assessment is interesting. As described above, self-efficacy shows in academic achievement, but the connection is present not only for typical closed-book exams: research reports on other assessment practices such as self-assessment as promoting students' self-efficacy (for a meta-analysis, see Panadero et al., 2017; in the context of university mathematics, see Nieminen et al., 2021). Promoting self-efficacy in students is multidimensional; empirical research on self-efficacy shows that self-efficacy is supported differently for different students. For example, Duchalet and Donche (2019) report that autonomously motivated and amotivated students need different type of support to enhance their self-efficacy.

The extensive role of self-efficacy in mathematics achievement has elicited research, which investigates the connections between self-efficacy and gender. Many studies show that despite similar mathematics achievement at university (Pajares, 1996; Peters, 2013), men have higher mathematics self-efficacy than women (for a meta-analysis, see Huang, 2013; see also Kogan & Laursen, 2014; Pajares, 1996; 2005; Peters, 2013). In a meta-analysis including participants from all stages of education, Huang (2013) shows that the gender difference in mathematics self-efficacy is not present with younger students, but it emerges only at the early adolescence with students fifteen years or older – and accentuates from there on. It has been shown that in STEM fields, self-efficacy is critical to retention (for mathematics, see Pajares, 1996; for STEM fields, see Raelin et al., 2014) and the role of self-efficacy on retention is more extensive for women (Ellis et al., 2016; Marra et al., 2009; Raelin et al., 2014). This indicates that, especially for women, the higher the self-efficacy, the more likely they are to continue pursuing a degree in mathematics-related majors.

The connections between learning environments and self-efficacy are elaborated in section 2.4.2.

2.3 REGULATION OF LEARNING

Students' regulation of learning is one of the central research areas within educational psychology (Panadero, 2017; Sitzmann & Ely, 2011). Self-regulation of learning is a comprehensive term that describes learning from the cognitive, metacognitive, behavioural, motivational, and emotional perspectives (Panadero, 2017; Pintrich, 2000; Zimmerman, 2000). There are multiple models of self-regulation (Panadero, 2017; Puustinen & Pulkkinen, 2001; Sitzmann & Ely, 2011). In Panadero's (2017) review, six well-established models were identified: Pintrich (2000) and Zimmerman (2000) approach self-regulation from the socio-cognitive perspective, Winne and Hadwin (1998; see also Winne, 2011) and Efklides (2011) emphasise metacognition, Boekarts (1991; 2011) include the aspect of well-being, and Hadwin and colleagues (2011) examine regulation specifically in the social contexts. This doctoral dissertation draws on the socio-cognitive perspective and rely mostly on the Pintrich's (2000) model – for it being often used (Panadero, 2017), comprehensive (cf. Sitzmann & Ely, 2011), and aiming to provide a general framework for self-regulation of learning (Pintrich, 2000).

In his attempt to synthesise the self-regulation of learning models, Pintrich (2000) identified four assumptions shared by all the models. These shared assumptions state that 1) regulation of learning is an active and constructive process, 2) a person has potential for controlling different aspects of regulation, 3) regulation of learning is goal-oriented, and 4) regulatory activities mediate individual and contextual characteristics and performance (Pintrich, 2000). Typically, the SRL models identify three phases of self-regulated learning, namely a preparatory phase, a performance phase, and an appraisal phase (Panadero, 2017; Puustinen & Pulkkinen, 2001). The Pintrich's (2000) model of self-regulation divides the performance phase further into monitoring and controlling phases. However, when learners report on their regulation experiences, they often do not distinguish between the activities within these two phases (Pintrich, 2000; 2004). Pintrich (2000) posits the regulation phases as sequential but does not discard the idea of dynamic and simultaneous nature of the phases. Each of these phases address the four areas of self-regulated learning, namely cognition, behaviour, motivation, and emotion. Regulation of cognition involves, for example, goal setting, activation of prior content knowledge and metacognitive knowledge, judgements of learning, monitoring comprehension, selecting cognitive strategies, and evaluations of performance. Regulation of behaviour is shown in time and effort management, persistence, self-handicapping, or help-seeking, to name a few. Compared to the other SRL models, Pintrich's (2000) model puts a special emphasis on the motivational aspect of regulated learning (cf. Panadero, 2017). Regulation of motivation and emotions refer, among others, to goal orientations, motivational beliefs about self in relations to the tasks, personal interest, and affective reactions to self or the tasks. In this vein, *self-regulation of learning* can be defined as students planning, monitoring, and reflecting on their cognition, behaviour, motivation, and emotions to reach their learning goals (Pintrich, 2000; Zimmerman, 2000). In other words, a student who self-regulates can set goals for their learning, monitor, and reflect their progress, and if needed, adjust the learning processes accordingly (Pintrich, 2000; Zimmerman, 2000).

Self-regulation skills are essential in many ways. In higher education, students need regulation skills and are expected to develop them during their university studies (Coertjens et al., 2013; Coertjens et al., 2017; Jansen et al., 2019). Regulation of learning is central also in the disciplinary context of mathematics; it is viewed essential in proof-based mathematics (Talbert, 2015), problem solving, and building up mathematical competence (de Corte et al., 2000; 2011). To continue, self-regulation of learning is related to learning outcomes; in their meta-analysis, Sitzmann and Ely (2011) argue that most of the SRL processes have positive effects on learning – goal level, persistence, effort, and self-efficacy having the strongest effects. They conclude that students who engage in self-regulated learning learn more (Sitzman & Ely, 2011). Similarly in the Finnish higher education context, self-regulation skills have been found to be positively linked to academic achievement (Rytkönen et al., 2012). Although the link between self-regulation skills and academic achievement is evident, Pintrich (2000) points out that self-regulation activities can be considered learning outcomes also in their own right.

As mentioned, the SRL models share the assumption that all students have the potential to regulate their learning (Pintrich, 2000). However, self-regulated learning is not self-evident; the quality and quantity of self-regulation skills, as well as the motivational and emotional factors orchestrating the application of these skills vary between individuals and learning contexts (Pintrich, 2004; Zimmerman, 2000). This implies that students are not always able to regulate their learning optimally – or at all (Pintrich, 2000; Winne, 2005). This type of non-optimal or unregulated learning is disadvantageous for student's learning in higher education; it has been identified as a part of the undirected learning pattern indicating challenges in approaching studies and developing secondary education study habits up to the level required in tertiary education (Vermunt, 2003; 2005). To continue, unregulated learning is negatively related to academic achievement (Vanthournout et al., 2012; Vermunt, 2005), and positively related to dropping-out (Vanthournout et al., 2012) and study-related exhaustion (Räisänen et al., 2020).

In this vein, self-regulation is the desired way for students to go about learning. But how can students develop self-regulation skills? In the higher education context, students are adults and have years of experience of learning in formal educational settings. This indicates that the students may no longer need support in developing regulation strategies per se. Instead, they need opportunities and support to apply these skills in higher education learning situations (Jansen et al., 2019; Vrieling et al., 2017; see also Wigfield et al., 2011, 33). Opportunities for applying and developing regulated learning arise from for example challenge episodes – instances in which students have difficulties in achieving their learning goals (Hadwin et al., 2011). However, it is notable that students might not be able to resolve these challenge episodes by themselves. Vermunt (2005) uses the notion of lack of regulation to refer to instances in which learning remains unregulated, as the student has difficulties in regulating their learning in one or multiple phases and/or areas of regulation. Furthermore, the regulation can be (partly) taken over, for example, by a teacher; this is referred to as external regulation (Vermunt, 2003; 2005; Vermunt and Verloop, 1999). Vermunt and Verloop (1999) describe these instances of external regulation in terms of the balance between the degree of teacher-regulation (strong, shared, loose) and student-regulation (low, intermediate, high) of learning (see also Vrieling et al., 2017). If the balance is congruent – for example, when the degree of teacher-regulation is strong, and student-regulation is low – learning is likely to take place. In non-congruent cases, Vermunt and Verloop (1999) distinguish between constructive and destructive friction. Constructive friction refers to situations in which students are challenged to increase their degree of self-regulated learning. This is the case, for instance, when the degree of teacher-regulation is shared but student-regulation is low. This type of constructive friction stimulates the development of self-regulation skills (Vermunt & Verloop, 1999). Destructive friction refers to situations in which the balance is too off – for example, when the degree of teacher-regulation is loose and student regulation is low. In these types of settings, it is unlikely that regulation skills develop – on the contrary, they can even regress (Vermunt & Verloop, 1999).

As discussed above, developing regulation skills can be seen as a joint activity. This leads us to discuss the role of the *social* in self-regulated learning. From the socio-cognitive perspective, self-regulation of learning occurs not only in self-study but also in collaboration; self-regulation of learning is both an individual and a social practice (Hadwin et al., 2011; Järvelä & Hadwin, 2012; Pintrich, 2004; Volet, Vauras, et al. 2009; Zimmerman, 2002). Research on regulation of learning in collaborative settings is a relatively new endeavour (Schoor et al., 2015). Perhaps for the novelty, many terms such as co-regulation, other-regulation, social regulation, or socially shared regulation are used, often ambiguously, to refer to regulated learning in these collaborative settings (Schoor et al., 2015). In this doctoral dissertation, the term co-regulation of learning is used in line with Järvelä and Hadwin (2013) to refer to the dynamic process of co-constructing knowledge in between self-regulation and socially shared regulation (see also Schoor et al., 2015). This type of co-regulation of learning is viewed from the perspective of two types of social interaction, intersubjectivity and scaffolding (Hadwin et al., 2011; Järvelä and Järvenoja, 2011; Volet, Vauras, et al., 2009). Intersubjectivity refers to peer learning and use of social resources, namely the psychological relation between individuals, and can be captured with notions such as 'mediating peers' and 'capable others' (Hadwin et al., 2011; Volet, Vauras, et al., 2009; Zimmerman, 2000). Scaffolding refers to the gradually decreasing support of helping students to accomplish tasks that would otherwise be beyond their reach. It is notable that in the context of this doctoral dissertation, co-regulation of learning occurs between students in the same courses, students and the lecturers, and also between students and tutors – the more advanced mathematics students who are a part of the courses' teaching teams. For this reason, perhaps contrary to Vermunt and Verloop (1999), scaffolding is seen as a form of co-regulation and not as an external regulation of learning. Overall, it is notable that from the socio-cognitive perspective, the role of the social is to influence self-regulation. In this vein, co-regulation of learning is not viewed as separate from self-regulation of learning but as supporting the development of self-regulation skills (Hadwin et al., 2011; Schoor et al., 2015; Volet, Vauras, et al., 2009). To sum up, although these types of social interaction are not necessary for regulated learning, they support students in regulating their learning more efficiently (Winne, 2005).

Self-regulation of learning is cyclical in nature; in this closed feedback system, the set goals serve as the reference value with which the regulation takes place (Pintrich, 2000; Schoor., 2015). This cyclical nature indicates that motivational beliefs related to learning experiences are used to adjust future learning processes (Pintrich, 2004; Zimmerman, 2000). From the socio-cognitive perspective, the contextual motivational beliefs can be viewed as a part of regulated learning or as a predisposition for regulated learning (see Pintrich and Zusho, 2007); either way, the role of the context is substantial. Indeed, Pintrich (2000) included – among cognition, behaviour, motivation, and emotion – the context as one of the areas of regulation. Regulation of context refers to students' perceptions of the context and the tasks; regulation of context is applied when for example monitoring and making judgements about classroom norms, equity, and teacher warmth, or when shaping the learning environment by task negotiation and seeking suitable places for studying outside of the lectures (Pintrich, 2000). The connections between learning environments and regulation of learning are elaborated further in section 2.4.3.

2.4 STUDENT-CENTRED LEARNING ENVIRONMENTS

This doctoral dissertation investigates university mathematics learning that occurs in student-centred learning environments. In the first editor's introduction of the newly established *Learning Environments Research: An International Journal*, Fraser (1998) defines *learning environment* as "the social, psychological and pedagogical contexts in which learning occurs and which affect student achievement and attitudes". There are also many other ways of conceptualising the notion of a learning environment. For example, Entwistle and colleagues (2002) use the concept of *teaching-learning environment* to emphasise that teaching and learning are inherently intertwined. In this doctoral dissertation, the notion of teaching practices is used to address teachers' employed teaching practices with certain intentions, and Fraser's deliberately broad definition of a learning environment (1998) to address the students' actualised experiences of those teaching practices.

Research on learning environments has relied heavily on the comparisons between teacher-centred and student-centred contexts (in the context of university mathematics, cf. Fredriksen & Hadjerrouit, 2020; Freeman et al., 2014; Rasmussen et al., 2021). As comparisons between two or more student-centred contexts are scarce, at present it is not possible to offer distinctive theoretical and empirical descriptions for the various student-centred learning environments. For this reason, the term *student-centred* is used as an umbrella term throughout this doctoral dissertation. It should be noted that the term student-centred refers to a spectrum of contexts – it does not exclude any learning practices per se but describes the quality of such practices (cf. CMBS, 2016; Hora, 2015). For example, Loyens and Gijbels (2008) describe constructivist learning environment as featuring students' active knowledge construction, social interaction, engagement of metacognitive skills, and authentic tasks that challenge problem solving skills. Dochy and Segers (2018, 12-18) promote the High Impact Learning that Lasts model (HILL), in which they address learning from seven dimensions, namely hiatus, learner agency, collaboration and coaching, hybrid learning, action and knowledge sharing, flexibility (formal and informal learning), and assessment as learning. Vermunt (2003, 115) describes powerful learning environments from the perspective of the degree of students' self-regulation and own initiative and responsibility. In the CMBS (2016) statement, mathematical sciences associations promote active learning as supporting students' higher-order thinking skills through active engagement in mathematical investigation, communication, and problem-solving in a collaborative and feedback-rich environment. In addition, other terms are used to describe university mathematics teaching and learning, such as inquiry-based mathematics education emphasising engagement in meaningful mathematics, student collaboration, teacher's inquiry into students' thinking, and fostering equity (IBME; Artigue & Blomhøj, 2013; Laursen & Rasmussen, 2019), and flipped learning inverting the purpose of the class time (Lesseig & Krouss, 2017; Talbert, 2017), both included here under the term student-centred learning environment. To sum up, student-centred learning environments aim to promote conceptual understanding and thinking skills via students' active engagement in learning processes, problem solving, and collaboration. As a side note, this is not far from European higher education students' idea of a good learning environment (cf. Wierstra et al., 2003).

The literature on student-centred learning environments is unanimous – it seems to be effective. In a large meta-analysis of 225 studies on traditional and student-centred learning environments in undergraduate STEM education, Freeman and colleagues (2014) conclude that active learning increases performance on average by half a standard deviation, that in traditional context, the failure rate is 55 percent higher, and that these results are stable across disciplines and robust to methodological variation. Similar results have been obtained from other meta-analyses on inquiry-based learning (Lazonder & Harmsen, 2016), flipped classroom (Lo et al., 2017; Wright & Park, 2021), and learner-centred education (Li et al., 2021). To continue, student-centred learning environments can promote students' sense of belonging, for example in mathematics (Lahdenperä & Nieminen, 2020), and higher attendance and engagement, for example in physics (Deslauriers et al., 2011).

Student-centred learning environments can also promote the learning of underrepresented student groups in STEM fields. Besides improving general academic achievement, research conducted in student-centred learning environments report that the achievement gap is flattened and the differences in failure rates between underrepresented and overrepresented student groups reduced (Kogan & Laursen, 2014; for a literature review, see Theobald et al., 2020). Also, student-centred learning environments can have a positive effect on retention; students who have been exposed to student-centred learning environments are more likely to continue to pursue a degree in a STEM major – a connection present for women in particular (Ellis et al., 2016; Kogan & Laursen, 2014; Laursen et al., 2014; Raelin et al., 2014). Kogan and Laursen (2014) followed over 3200 university mathematics students for two years and suggest that traditional teacher-led instruction does selective disservice to underrepresented students, such as women. However, they demonstrate how exposure to student-centred learning environments can promote learning that benefits equally both men and women (Kogan & Laursen, 2014; see also Laursen et al., 2014). To support the underrepresented students, exposure to student-centred learning environments can be even more beneficial at the beginning of university studies (Kogan & Laursen, 2014).

But what are the instructional elements that make student-centred learning environments so effective? In a literature review on student-centred teaching practices in higher education, Baeten and colleagues (2010) acknowledge that although there are multiple ways of applying student-centred teaching in practice, they all emphasise students' active role in the learning processes and students taking responsibility over their learning, and aim to foster deep learning and holistic understanding. Furthermore, in a review of 38 meta-analyses on higher education, Schneider and Preckel (2017) conclude that the strongest correlate of achievement is social interaction; it can be demonstrated, for example, by teacher's encouragement of questions and discussion, small-group learning, and teacher's availability, helpfulness, friendliness, and respect for students. There are also other meta-analyses supporting the importance of social interaction; for example, students who collaborate with other students have higher achievement rates and more positive attitudes compared to students who study alone (Kyndt et al., 2013). However, it is notable that "teachers with high-achieving students invest time and effort in designing the microstructure of their courses, establish clear learning goals, and employ feedback practices" (Schneider & Preckel, 2017). This indicates that even when the students are placed in the centre, the teacher still has a significant role in guiding the student's learning processes (cf. Schneider & Preckel, 2017). Indeed, many studies support appropriate guidance to accompany student-centred teaching practices (see e.g., Lazonder & Harmsen, 2016; Mayer, 2004; Pepin & Kock, 2021).

How to then promote the application of student-centred teaching practices in university mathematics? Apkarian and colleagues (2021) investigated factors that are commonly believed to promote or hinder the usage of student-centred teaching practices. They noticed that mathematics instructors in all kinds of situations can and do implement student-centred teaching practices in their courses. However, large class sizes, traditional fixed-seat classrooms, and emphasising student evaluations of teaching can hinder the use of student-centred teaching practices; on the other hand, instructors' own experiences on student-centred learning, and participation in educational research or curriculum development activities can encourage mathematics instructors to use student-centred teaching practices (Apkarian et al., 2021). Also, among multiple other researchers, they emphasise the importance of professional development opportunities for mathematics instructors (Apkarian et al., 2021; Benabentos et al., 2021; Hayward et al., 2015). For example, in a one-year follow-up, Hayward and colleagues (2015) noticed that mathematics instructors who had attended a series of professional development workshops decreased the time used in instructor lecturing and solving problems, but increased the time used for student-led discussions, small-group discussions, and students presenting problems and proofs. Laursen and colleagues (2014) state that mathematics instructors take on student-centred teaching practices slowly and this limits the advancement of university mathematics education. However, as demonstrated above, pedagogical changes can also happen in the university mathematics context.

The next chapter elaborates on the relationships between student-centred learning environments and the other theoretical constructs utilised in this doctoral dissertation, namely students' approaches to learning, academic self-efficacy, and regulation of learning.

2.4.1 STUDENTS' APPROACHES TO LEARNING AND LEARNING ENVIRONMENTS

Researchers agree that students' approaches to learning are related to their perceptions of the learning environment. This relationship is multidimensional; students with different approaches to learning can respond to the same learning environment differently (Asikainen & Gijbels, 2017; Postareff et al., 2015; Wierstra et al., 2003). For example, students applying a deep approach perceive the learning environment more positively than students applying a surface approach (Baeten et al., 2010; Parpala et al., 2010; in the context of mathematics Crawford et al., 1998; Mji, 2003). On a more general level, researchers acknowledge the challenges of enhancing a deep approach to learning through traditional teaching practices (Baeten et al., 2013; Marton & Säljö, 1984). In contrast, student-centred learning environments can support students to develop towards a deep approach to learning (see e.g., Baeten et al., 2010; Hailikari et al., 2021; Uiboleht et al., 2018; Wierstra et al., 2003).

Although the overall findings favour student-centred learning environments in relation to students' approaches to learning, the relationship is not self-evident (Asikainen & Gijbels, 2017; Baeten et al., 2010; Gijbels et al., 2008); in some cases, student-centred learning environments can push students towards a surface approach to learning. For example, Baeten and colleagues (2013) investigate approaches to learning and various student-centred teaching methods. They conclude that student-centred teaching practices, especially if new to the students, can be high in workload and therefore promote the application of a surface approach to learning (Baeten et al., 2013). Because of this ambiguity of the relationship between approaches to learning and learning environments, it is important to look at the specific elements of the learning environments that can support students to shift towards a deep approach to learning. Previous studies have found that a deep approach is positively correlated, and surface approach negatively correlated with students' perceptions of the course feedback, course alignment, and peer support (Baeten et al., 2010; Coertjens et al., 2016; Entwistle & Tait, 1990; Parpala et al., 2010). Also, Uiboleht and colleagues (2019) conclude that social interaction promotes a deep approach to learning – but only when students are prepared for it. Moreover, literature reports on the significant role of the perceived challenge of the learning environment. Various studies show that the learning environment must be challenging enough, as lack of challenges provokes the application of a surface approach to learning; however, also learning environment that is perceived too challenging is linked to a surface approach (Coertjens et al., 2016; Postareff et al., 2015; Postareff et al., 2014). The balancing of the challenge level can be considered from two perspectives, workload and task complexity. In terms of the workload, the perception of an overly heavy workload has been related to a surface approach to learning (Baeten et al., 2010; Entwistle & Tait, 1990). In contrast, in Kyndt and colleagues' (2011) study, no relationships between perceived workload and approaches to learning was found. They explain the result by reflecting on the quantity and quality aspects of the workload. It might be that too much work in terms of quantity is the aspect related to a surface approach; instead, challenging tasks in terms of quality can, if the student is successful in completing them, provide experiences of success and promote a deep approach to learning (Kyndt et al., 2011). Task complexity describes this qualitative aspect of the workload and in this vein, workload increased through increased task complexity has the potential to promote a deep approach to learning. It is notable that the perceived task complexity per se is not that relevant; what matters is whether the student has enough knowledge – or access to it – to complete them (Kyndt et al., 2011). This aspect emphasises the importance of guidance, as lack of guidance has been linked to a surface approach to learning (Hailikari & Parpala, 2014). In this vein, for a learning environment to be successful in promoting a deep approach to learning, it needs to offer enough challenges for the students but also means to overcome them (see also Uiboleht et al., 2019).

As a final remark, it should be noted that it is not clear to what extent teaching practices can support the more favourable approaches to learning; according to Wierstra and colleagues (2003), the role of the context is not determining but facilitating or inhibiting. This makes sense if we consider the general approach to learning as a synthesis of all the contextual approaches to learning. This indicates that when a student is exposed to a learning environment that supports the development of a deep approach to learning, the contextual experience is then integrated into the general approach to learning with which the student enters the next learning environment. Therefore, the development of a deep approach is not a single change but a process that takes time (cf. Kember, 2016). From this perspective, single courses or interventions may not be long enough for the process to take place (Baeten et al., 2010; Entwistle & Peterson, 2004; Wilson & Fowler, 2005). This indicates that it is easier to induce chances on the course-level than the general-level approaches to learning; in essence, the students' general-level shifts towards a deep approach require deliberate degree-level pedagogical development (cf. Dolmans et al., 2016; Koster & Vermunt, 2020).

2.4.2 ACADEMIC SELF-EFFICACY AND LEARNING ENVIRONMENTS

Despite the high contextuality of self-efficacy, there is a limited number of studies investigating the relationships between learning environments and self-efficacy, especially in the higher education context (Alt, 2015). Van Dinter and colleagues (2011) review literature on self-efficacy interventions in higher education and conclude that it is possible to support students' self-efficacy through teaching practices. This is similar to the results of Alt (2015), who found that certain learning environment characteristics, such as promoting reflection and learning as a constructive activity, were the most dominant predictors of academic self-efficacy. Despite these results, the evidence on the relationship between learning environment characteristics and self-efficacy is still somewhat mixed; Alt (2015) reports that social science students' self-efficacy is higher in student-centred learning environments, but in the case of mathematics students, Peters (2013) shows that the students' self-efficacy is higher in teacher-centred learning environment. As Peters (2013) notes, this result is contradictory to what has been found in the context of upper secondary school mathematics (cf. Fast et al., 2010). Also, there is some evidence that women and other underrepresented student groups in mathematics are more confident in their mathematical abilities in student-centred learning environments (see e.g., Ellis et al., 2016; Kogan & Laursen, 2014). So, teaching practices can be used to support students' self-efficacy – but how? In line with Bandura's (1977) model, van Dinther and colleagues (2011) found that from the four sources of self-efficacy, the mastery experiences were the most significant. They conclude that to support students to develop academic self-efficacy, it is crucial to provide them with practical experiences of applying knowledge and skills in diverse and demanding situations (van Dinther et al., 2011). In the context of mathematics, mathematical problem solving can be seen as a central source of mastery experiences. Van Dinther and colleagues' (2011) conclusion indicates that special attention is required in diversifying the task designs to further support students' self-efficacy in mathematics context.

2.4.3 REGULATION OF LEARNING AND LEARNING ENVIRONMENTS

The socio-cognitive perspective on regulation of learning conceptualises the social and physical environments as mediators for developing regulatory skills (Pintrich, 2004; Zimmerman, 2000). The process of regulation of learning is guided by the learning context, and some learning environment characteristics, such as the social system, can hinder or support students' use of regulated learning (Pintrich, 2000; 2004). It can be assumed that learning environments that support students' participation in self-regulatory processes promote self-regulated learning. However, as de Bruijn-Smolders and colleagues (2016) conclude in their review study, higher education research focusing on the relationship between regulation of learning and learning environments is scarce (see also Jansen et al., 2019 for a meta-analysis). In the disciplinary context of mathematics, Talbert (2015) touches upon self-regulation of learning in their description of classroom activities; however, the connection between regulation of learning and learning environments remains unresearched territory also in the disciplinary context of university mathematics (de Corte et al., 2011).

How could we address this need for research investigating the relationship between regulation of learning and learning environments (cf. de Bruijn-Smolders et al., 2016)? It is suggested that regulation of learning should be investigated in a specific context, preferably on a course-level (Pintrich, 2004; Pintrich & Zusho, 2007). As mentioned in section 2.3., there are certain elements of learning environments that can support students to apply and develop their regulatory skills. First, the learning environment should provide enough challenge episodes for stimulating students to apply and develop their regulation skills (cf. Hadwin et al., 2011; Vermunt & Verloop, 1999). Second, the learning environment should promote social interaction in the form of intersubjectivity and scaffolding; this type of co-regulation of learning supports students to develop their self-regulation skills (Hadwin et al., 2011; Schoor et al., 2015; Vermunt & Verloop, 1999; Volet, Vauras, et al., 2009; Vrieling et al., 2017; Winne, 2005). This is further supported by Zimmerman's (2000) notion that one of the origins of unregulated learning is the lack of social experiences.

Prior research acknowledges that regulation of learning can be a challenge especially in the beginning of university studies (Pintrich, 2000; Lindblom-Ylänne et al., 2015; Koivuniemi et al., 2017). This challenge may be further accentuated in the disciplinary context of university mathematics; students in primary and secondary mathematics classrooms are often denied opportunities to develop their regulation skills as external regulation – teacher regulating students' learning – prevails over students' self-regulation (de Corte et al., 2011). In this vein, unregulated learning can be viewed as an outcome of the learning environment failing to offer the learner enough opportunities to apply and develop self-regulated learning (see Lindblom-Ylänne and Lonka, 1998). In general, student-centred learning environments have the potential to offer possibilities for the development of regulation skills;

for example, students in student-centred learning environments have more autonomy and responsibility over the learning context (Pintrich, 2000). However, it is not evident how student-centred learning environments contribute to students' regulated learning; different student-centred learning environments might support different dimensions of regulation (Stefanou et al., 2013). To sum up, although there is a limited number of studies investigating the relationship between student-centred learning environments and regulation of learning, it can be concluded that learning environments need to be challenging enough and promote social interaction to offer possibilities and support for the development of regulation skills.

2.5 SYNTHESIS OF THE ADOPTED PERSPECTIVE

This doctoral dissertation draws on the theoretical notions of students' approaches to learning, academic self-efficacy, and self-regulation of learning and discusses their interplay with student-centred learning environments. Students' approaches to learning originate from empirical phenomenographic research on how students in practice go about learning in higher education (cf. Marton & Säljö, 1976). The theoretical notion and an approach to learning combines students' aims for learning as well as the cognitive processes used to achieve those aims (Marton & Säljö, 1984). Typically, two distinctive approaches are considered, a deep approach aiming to understand and a surface approach aiming to reproduce knowledge (Biggs, 1991; Marton & Säljö, 1984). Self-regulation of learning is based on theoretical research on metacognition and includes four areas of regulation, namely cognition and metacognition, behaviour, motivation, and emotion (Panadero, 2017; Pintrich, 2000; Zimmerman, 2000). There are different models of SRL, but they share three distinctive phases of self-regulation: a preparatory phase, a performance phase, and an appraisal phase (Panadero, 2017; Puustinen & Pulkkinen, 2001).

The SAL and SRL traditions offer a key distinction in higher education, as much of the SAL research is conducted in Europe and Australia, whereas SRL research is more dominant in North America (Pintrich, 2004). Besides geographical differences, the SAL and SRL traditions differ in their ways of conceptualising motivation. In SAL, the motivational aspect of learning is integrated into the approaches but in SRL, motivation is a separate area of regulation. This indicates that students' motivation is central to both traditions; however, the SRL perspective is more flexible as it allows multiple ways in which the goals and strategies are linked (Pintrich, 2004). To continue, the SAL tradition is sometimes viewed as a bottom-up approach for its larger units of analysis and qualitative and empirical origins, whereas the SRL tradition is viewed as a top-down approach for its smaller units of analysis and quantitative and theoretical origins (Pintrich, 2004). There is substantial empirical overlap between the SAL and SRL constructs (for the Finnish higher education context, see e.g., Hailikari & Parpala, 2014; Heikkilä & Lonka, 2006). Also, these two traditions have been theoretically combined in previous research (e.g., the *learning patterns*, see Vermunt, 2003; Vermunt & Donche, 2017). However, for the differences described above, Pintrich (2004) states that the SAL and SRL traditions are incommensurable. In this doctoral dissertation, SAL and SRL are first investigated separately, but later combined to provide multiple perspectives on students' learning in the context of university mathematics.

Because the SAL tradition does not include a separate motivational dimension, it is often investigated in tandem with motivational constructs such as self-efficacy. This doctoral dissertation follows the same course. The notion of self-efficacy refers to a person's belief in their ability to perform a specific task in a specific context (Bandura, 1994; 2012). Self-efficacy has earned its place in its own right as the strongest single construct related to study success in higher education (Richardson et al., 2012). In addition, higher self-efficacy is positively related to a deep approach to learning and lower self-efficacy to a surface approach to learning (in the context of higher education, see Diseth (2011); in STEM, Rozgonjunk et al., 2020; in mathematics, Zakariya et al., 2020). Self-efficacy is also positively related to self-regulation of learning (in the context of higher education, see Honicke & Broadbent, 2016; in mathematics, Roick & Ringeisen, 2018). Overall, it seems that many favourable and many unfavourable factors related to learning go empirically hand in hand (Hailikari & Parpala, 2014).

These three theoretically distinctive but often empirically overlapping notions offer a holistic perspective on university students learning in student-centred learning environments. It is preferred to investigate all of them in a domain-specific context and on a course- or task-level (for SAL, see e.g., Marton & Säljö, 1976; Asikainen & Gijbels, 2017; for self-efficacy, see Bandura, 1994; 2012; for SRL, see Pintrich, 2000; 2004). For this reason, the three theoretical notions are investigated within the learning environments of individual courses. Learning environment refers to "the social, psychological and pedagogical contexts in which learning occurs and which affect student achievement and attitudes" (Fraser, 1998). The term student-centred is used as an umbrella term to describe learning environments that aim to promote conceptual understanding and thinking skills via students' active engagement in learning processes, problem solving, and collaboration. There is extensive prior research reporting on how students can benefit from these type of student-centred learning environments.

3 THE AIMS OF THE DOCTORAL DISSERTATION

The aim of this doctoral dissertation is to advance our understanding of the relationships between student-centred learning environments and students' quality of learning in the context of university mathematics. Freeman and colleagues (2014) distinguish between first- and second-generation research on university STEM education teaching practices. The *first-generation research* refers to studies that compare a variety of student-centred teaching practices to traditional teacher-led lecturing. As described in the previous section, the results of this type of research in favour of the student-centred teaching practices are largely reported in literature. Therefore, it is time to conduct *second-generation research* (cf. Freeman et al., 2014) – to look beyond the teacher-centred vs. student-centred comparisons and acquire more nuanced understanding on how different student-centred teaching practices facilitate the quality of mathematics learning at university (see also Fredriksen & Hadjerrouit, 2020; Rasmussen et al., 2021). With a mixed-methods approach, this doctoral dissertation contrasts the same students' quality of learning in two parallel student-centred learning environments. As the same group of students is investigated in both learning environments, this doctoral dissertation creates an opportunity to address the role and the effect of the context on students' learning. Overall, this doctoral dissertation promotes discipline-based higher education; the aim is to offer essential knowledge on the practical orchestration of university mathematics learning environments and facilitate the further developments and orchestrations of effective instructional practices. The general research question is:

How can different student-centred learning environments support university mathematics students' quality of learning?

The Studies I-IV articulate this general research question from different theoretical and methodological perspectives. Studies I and II utilise the students' approaches to learning theory and address quantitatively and qualitatively the following two research questions:

- How do the student-centred learning environments relate to the students' approaches to learning and experiences of the teaching-learning environment? (Study I)
- How do the student subgroups with different approaches to learning interact with the two student-centred learning environments? (Study II)

The notion of academic self-efficacy is addressed quantitatively in Studies I and III via the following research questions:

- How do the student-centred learning environments relate to the students' self-efficacy? (Study I and III)
- How is this relation related to the students' gender? (Study III)

Furthermore, Study IV utilises the notion of self-regulation of learning, and the quantitative approach is accompanied with a qualitative approach and the notion of co-regulation of learning. The research questions are:

- How do student-centred learning environments relate to students' self-regulation of learning? (Study IV)
- Which elements of student-centred learning environments support and hinder mathematics students regulated learning? (Study IV)

4 RESEARCH CONTEXT

This section provides a description of the context in which this doctoral dissertation was conducted. First, an outline the Finnish higher education context is presented and then the two learning environments investigated in this doctoral dissertation described. The doctoral dissertation was conducted as an individual project and it was inspired by the pedagogical development that had taken place in the mathematics department serving as the context of this research.

4.1 MATHEMATICS IN THE CONTEXT OF FINNISH HIGHER EDUCATION

The research was conducted in the mathematics department of a research-intensive university in Finland. Following the Bologna Process framework (Bologna Process Committee, 1999), university studies typically last for five years consisting of a three-year bachelor's degree and a two-year master's degree. Students are accepted into a specific degree programme to pursue both bachelor's and master's degrees. From the beginning, the studies focus heavily on their chosen major subject. The Finnish welfare state provides tuition-free tertiary education for European Union students, and Finnish students receive a grant from the state to assist in paying for their living costs.

The first university mathematics courses are already proof-based courses beyond calculus. In upper secondary school, the students have studied mathematics up to the concept of an integral, and the university mathematics courses start with topics such as set notation and proofs, linear algebra in finite-dimensional spaces, and real analysis with epsilon-delta -definitions. In addition to mathematics majors, the courses are taken by many students studying mathematics as their minor subject; these students are usually majoring in other STEM fields (e.g., computer science, physics, or chemistry), economics, or education. The mathematics student population of the researched university is relatively balanced in terms of gender.

The Universities Act (2009) provides academic freedom for teachers to design and develop their own teaching at university. A typical method of teaching of a university mathematics course can be described as assignment-based teaching (cf. Vermunt, 2003) and it typically includes six weeks of lectures (approximately five hours a week) and small group sessions (approximately two hours a week, in a group of twenty students). The students are set weekly tasks of proving mathematical statements and theorems, and the small group sessions consist of going through the aforementioned tasks, which students have solved prior to the session. Students often take turns to present the tasks on the blackboard. The tasks form the backbone of mathematics teaching and learning, and they usually contribute to the final grade in the form of bonus points. The mathematics departments in Finland usually hire undergraduate and graduate students as teaching assistants or tutors to lead the small group sessions.

4.2 THE LEARNING ENVIRONMENTS UNDER INVESTIGATION

The mathematics department serving as the context for this doctoral dissertation has been a platform for individual educational change efforts; these efforts have led to a systemic department-level changes in teaching culture (see Oikkonen, 2009; Rämö et al., 2019). In this vein, the department offered fruitful contexts for investigating university mathematics education as it was possible to look further from the traditional vs. student-centred research designs and investigate the refinements of various student-centred teaching practices. For the purpose of this doctoral dissertation, two mathematics courses were chosen for a closer inspection. The interest in these two courses in particular arose from their well-established different student-centred pedagogical practices (at the time of data collection, both had been implemented more than five years previously) but also from the large number of students taking the courses at the same time enabling also quantitative and comparative approaches.

The courses named Course A and Course XA are described in Table 1. The courses run parallel, were usually taken by students during their first semester of university mathematics, and were six-week, five-credit (ECTS) courses with approximately 200 students. In addition to mathematics majors, these courses were taken by many students studying mathematics as their minor subject. Common major subjects for these students were computer science, education, physics, chemistry, or economics. Course A functioned within the traditional lecture-tasks-small group setting but included student-centred elements, such as activating lectures and small group sessions that supported student collaboration and participation in mathematical discussions. Course XA used the Extreme Apprenticeship approach; derived from the Cognitive Apprenticeship (Collins et al., 1991), the method combines inquiry-based mathematics education (IBME; cf. Artigue & Blomhøj, 2013) with a flipped learning approach (cf. Talbert, 2017) to support students' own activity, student collaboration, and active participation. The Extreme Apprenticeship method is described in detail by Rämö and colleagues (2021).

From a student's perspective, the inquiry-based and flipped learning approaches were focal because they changed the weekly structure of the learning process. To elaborate on this change, the weekly structures of Course A and Course XA were as follows. In Course A, the entry point to mathematics was the lectures, where the lecturer supported students' active participation and explained the mathematical reasoning behind formal proofs. After that, the students solved weekly tasks consisting of proving mathematical arguments in two ways. First, some of the tasks were solved by the students themselves prior to a small group session. In the beginning of that session, students discussed their solutions in smaller groups and then took turns in writing and explaining them on the blackboard. The small group session was led by a tutor. Second, there was another set of weekly tasks that were solved during another small group session together with peers and guided by a tutor. The small groups were fixed, meaning that a student had a specific group to attend to. This traditional lecture-tasks-small group structure was changed in Course XA learning cycle (see Figure 1). Here, the entry point to mathematics was the weekly tasks. The students solved introductory tasks by themselves and/or together with peers, while the tutors offered inquiry-oriented guidance. The introductory tasks consisted of the first steps needed in proof construction, such as recognising definitions from the course material and utilising them to form arguments. Guidance was offered several hours a day on a drop-in basis in an open learning space located in the middle of the department. The tutors in Course XA attended pedagogical meetings every week. The students then submitted the tasks for feedback, after which the lectures followed. As the students had already solved and submitted tasks, they were prepared for the lectures that discussed the same topics to the tasks. Also, the lecturer was aware of the students' misunderstandings and challenges, so the lectures could focus on addressing these issues and creating links between the topics through students' active participation and small group activities. The cycle continued when the students went on to proving more challenging arguments on the same topic and a new set of introductory tasks on the next topic. It is notable that as some of the tasks in Course XA were smaller, they were more in numbers.

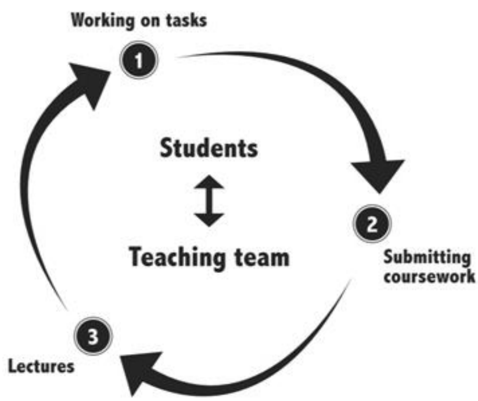

Figure 1 The Extreme Apprenticeship method is built around a learning cycle where students work on tasks, submit their coursework, and attend lectures. The students interact with each other and with the teaching team in every step of the process. (Rämö et al., 2021).

To summarise, the main practical differences between the courses centred 1) on the design of the weekly tasks. All the tasks were of similar challenge level in Course A, but in Course XA there was a sequence of tasks with gradually increasing difficulty for each topic; 2) in the form of support given to the students by the tutors. In Course A, the guidance was offered in scheduled small group sessions, but in Course XA, continuously in an open learning space. Also, the tutors' weekly meetings in Course XA included pedagogical training with the lecturer; and 3) on the role of the lectures. In Course A, the lectures came first but in Course XA, only after the students had solved tasks. Course XA required more responsibility and independence from the student, as solving the tasks was not scheduled, and one needed to start solving the tasks and reading the course material independently before any formal introductions to the topic. However, it is notable that in both learning environments, student participation and collaboration were encouraged, and plenty of support for solving the weekly tasks was offered.

Table 1. *Summary of the two learning environments.*

	Course A	Course XA
Stage	1st year	1st year
No. of students enrolled	approx. 200	approx. 200
Content	Analysis (limit of a function, continuity, the derivative, and its applications) emphasising exact definitions and proof construction	Linear algebra and matrices (general vector spaces, subspaces, linear mappings, and scalar products) emphasising skills such as reading mathematical text, oral and written communication, and proof construction
Pedagogical approach	Traditional lecture-tasks-small groups framework with the inclusion of student-centred elements	Extreme Apprenticeship, a combination of IBME and a flipped learning approach
Lecturer	Mathematician and mathematics educator acknowledged for their excellent teaching by both students and the university	Mathematician and mathematics educator acknowledged for their excellent teaching by both students and the university

Lectures	4 hours a week; lectures focus on how to approach the main content of the course	3 hours a week; lectures come after students have solved problems; the lectures are based on students' discussions and focus on the main content of the course
Course material	A general Analysis book	Course book written by the lecturer
Task design	Students solve problems every week prior to and during small group sessions; tasks are designed by the lecturer	Students start a new topic with approachable problems that teach content and study skills; more challenging problems follow the lecture; tasks are designed by the lecturer
Form of support	Two-hour small group sessions (approx. 20 students) twice a week; Presemo (anonymous online chat platform)	Open learning space on a drop-in basis with tutors; Presemo (anonymous online chat platform)
Tutors	More advanced mathematics students	More advanced mathematics students who attend weekly pedagogical meetings with the lecturer
Assessment	Final grade based on a written course exam; bonus points from completed course tasks. The most difficult course exam question (as defined by the lecturer) was: *Consider the function* $f: \mathbb{R} \to \mathbb{R}, defined\ via$ $f(x) = \frac{x^2 \sin(e^{x^2})}{(x^4+1)e^{\sin x}}.$ $Show\ that\ there\ exists\ a\ real\ number\ a \in \mathbb{R}, such\ that\ f(x) \leq f(a) holds\ for\ all\ x \in \mathbb{R}.$ NB: $It\ is\ not\ useful\ to\ consider\ the\ derivative\ here$!	Final grade based on a written course exam; bonus points from completed course tasks. The most difficult course exam question (as defined by the lecturer) was: $Let\ V\ be\ a\ vector\ space\ with\ a\ basis\ (\bar{v}_1, \ldots, \bar{v}_n).\ Assume\ that\ L: V \to W\ is\ a\ linear\ mapping.\ Show\ that\ if\ \left(L(\bar{v}_1), \ldots, L(\bar{v}_n)\right)\ is\ a\ basis, then\ L\ is\ an\ isomorphism.$

5 METHODOLOGY

This doctoral dissertation is positioned in the centre of mathematics, mathematics education, and higher education – fields typically associated with different epistemological stances. Therefore, it is vital to take the space for some methodological reflections. As Guba and Lincoln state, questions of method are secondary to questions of paradigm (1994, 105). This section begins with methodological reflections and then continue to reporting on the data collection, participants, and data analysis as fit for this summary. See the original studies for detailed descriptions of the methods used.

5.1 METHODOLOGICAL REFLECTIONS

To rethink the dualism of the Qualitative and Quantitative Approaches, sometimes also framed as a paradigm war between the (post)positivist and the constructivists, a third methodological paradigm has been introduced (cf. Johnson & Onwuegbuzie, 2004; Johnson et al., 2007; Morgan, 2007). Despite its many names (see Johnson et al., 2007), current methodological research suggests that the third paradigm should rely on Peirce's, James', and Dewey's work on classical pragmatism (see e.g., Johnson & Onwuegbuzie, 2004; Johnson et al., 2007). In Morgan's (2007) categorization (see Table 2), the Pragmatic Approach integrates both induction and deduction into abduction, accepts that both a single real world and its individual interpretations can exist simultaneously – and the relevance lies in the transaction between the two, and that in between the context-specific and generalisable results there is an important question of to what extent can research results in one setting be transferred to another settings. By orienting towards practical implications and offering a middle position both philosophically and methodologically (Creswell & Plano Clark, 2007, 27; Johnson & Onwuegbuzie, 2004), the Pragmatic approach offers more versatile possibilities for conducting research on what usually are complex phenomena. (Johnson & Onwuegbuzie, 2004; Onwuegbuzie & Leech, 2005).

Table 2. *The Pragmatic alternative to the Qualitative and the Quantitative approaches (Morgan, 2007).*

	Qualitative Approach	Quantitative Approach	Pragmatic Approach
Connection to theory and data	Induction	Deduction	Abduction

Relationship to research process	Subjectivity	Objectivity	Intersubjectivity
Inference from data	Context	Generality	Transferability

In this doctoral dissertation, triangulation is used as the theoretical framework for the Pragmatic Approach (cf. Flick et al., 2012). The notion of triangulation was first described by Denzin as "the combination of methodologies in the study of the same phenomenon" (1978, 291). Denzin (1978) identified four different triangulation categories which Miles and Huberman (1994) supplemented with a fifth category; these categories are 1) triangulation by data source, 2) triangulation by method, 3) triangulation by researcher, 4) triangulation by theory, and 5) triangulation by data type. Other researchers have provided similar definitions and promote triangulation as a way of obtaining corroborating evidence and developing a comprehensive understanding of a phenomenon (see e.g., Jick, 1979; Onwuegbuzie & Leech, 2007; Patton, 1999; Van Drie & Dekker, 2013). Therefore, triangulation is seen as especially beneficial when investigating multifaceted complex phenomena (Meijer et al., 2002; Van Drie & Dekker, 2013). In triangulation, different aspects offer different perspectives of the phenomenon under investigation; also, as the different triangulation aspects have unique strengths and weaknesses, the complementary perspectives increase the validity of the findings (Jick, 1979; Johnson & Onwuegbuzie, 2004; Meijer et al., 2002; Miles & Huberman, 1994, 267; Patton, 1999).

The notion of a learning environment as a multidimensional concept, for which the implementation of triangulation is a fit choice. To address the complexity of learning environments, this doctoral dissertation utilises triangulation in multiple ways (see Table 3). Triangulation by method and by data type are present in using both surveys and interviews that produce both quantitative and qualitative data, and in applying both exploratory and confirmatory quantitative and qualitative analysis methods. This serves the purpose of identifying differences between the learning environments in terms of size and power, but also to seek explanations for these differences. Triangulation by researcher is present throughout this doctoral dissertation; first, the supervisors represent different areas of expertise, namely mathematics, mathematics education, and higher education, and throughout the doctoral dissertation the author has operated in close interaction with all three of these fields. Furthermore, another researcher participated in the qualitative data analyses by acting as a second coder and engaging in discussions on the relevance and practical implications of the fidings. Triangulation by theory is also extremely relevant to this doctoral dissertation. The theoretical notions of students' approaches to learning, self-efficacy, and self- and co-regulation of learning are used to investigate the same data. This offers a possibility to bring theory typically used in a higher education context to the disciplinary context of university mathematics. Finally, the detectives' and medical doctors' modus operandi (cf. Miles & Huberman, 1994, 267) is followed as multiple sources of information are pieced together to offer a synthesis on how university mathematics learning environments can support or hinder the quality of students' learning.

Table 3. *Overview of the studies.*

Study	Methodological approach	Key concepts	Data	Analysis methods
I	Quantitative	Approaches to learning, self-efficacy, experiences of the teaching-learning environment	Student survey (N=91)	Confirmatory factor analysis, Cronbach's alpha, hierarchical and K-means clustering, ANOVA, paired samples t-test, Cohen's d
II	Qualitative	Approaches to learning	Student interviews (N=16)	Qualitative framework analysis
III	Quantitative	Self-efficacy, self-regulation of learning	Student survey (N=91)	Exploratory and confirmatory factor analysis, Cronbach's alpha, paired samples t-test, Cohen's d
IV	Quantitative and qualitative	Self-regulation of learning, co-regulation of learning	Student survey (N=91) and student interviews (N=16)	Exploratory factor analysis, Cronbach's alpha, paired samples t-test, Cohen's d, theory-driven qualitative content analysis

5.2 DATA COLLECTION

This doctoral dissertation draws on both quantitative and qualitative data. **The quantitative data** was collected at the end of the courses in December 2016. The students on both courses voluntarily answered an electronic questionnaire including scales from HowULearn (previously LEARN; Parpala & Lindblom-Ylänne, 2012) and Inventory of the Learning Styles (ILS; Vermunt, 1994).

This doctoral dissertation utilised three scales from the HowULearn, namely students' approaches to learning, experiences of the teaching-learning environment, and self-efficacy. These scales have been validated in the Finnish higher education context by Parpala and colleagues (2013). The scale measuring students' approaches to learning has been modified from the Approaches to Learning and Studying Inventory (ALSI, Entwistle et al., 2003) and the revised Learning Processe Questionnaire (R-LPQ-2F; Kember et al., 2004). The 12-item scale consists of three factors, namely deep approach to learning, surface approach to learning, and organised studying. Deep approach to learning was measured, for example, with an item "I tried to relate what I had learned in this course to what I had learned in other courses.", surface approach with an item "I often had trouble making sense of the things I had to learn in the course.", and organised studying with and item "I organised the study time I had allocated for this course carefully to make the best use of it." The scale measuring experiences of the teaching-learning environment has been modified for HowULearn from the Experiences of Teaching and Learning Questionnaire (ETLQ; Entwistle et al., 2003). It consists of 14 items measuring five factors, namely constructive feedback, alignment, requirements, interest and relevance, and peer support. Constructive feedback refers to receiving feedback that helps developing study skills, making connections to existing knowledge, and clarifying potential misunderstandings. Alignment refers to the clarity of the course objectives and the way these objectives are associated with the teaching practices. Requirements refer to the clarity of the course work objectives and the way the course work is related to the learning objectives of the course. Interest and relevance refer to enjoyment and sense of purpose of studying the course content, and peer support refers to students interacting and supporting each other in learning the course material. The five-item scale measuring self-efficacy has been slightly modified for HowULearn from the (MSLQ; Pintrich et al., 1991) and it was measured, for instance, with an item "I'm certain I could understand the most difficult material in the course."

The ILS includes multiple scales measuring different strategies, conceptions, and orientations related to learning (Vermunt 1994; 2005). The data collection for this doctoral dissertation included the scale measuring regulation strategies. Originally, this part of the ILS included 28 items measuring four dimensions of regulated learning: self-regulation of process, self-regulation of content, external regulation, and lack of regulation. The self-regulation scale has later been shortened to 15 items, still including the four factors, and modified and validated in the Finnish higher education context (Heikkilä & Lonka, 2006; Räisänen et al., 2020). Self-regulation of process was measured, among others, with an item "To test my learning progress, I tried to formulate the main points in my own words", self-regulation of content with an item "In addition to the course requirements, I studied other literature related to the content of the course", external regulation with an item "I studied the course according to instructions given in the course material or provided by the lecturer.", and lack of regulation with an item "I noticed that it was difficult for me the determine whether I had mastered the content of the course sufficiently."

The questionnaire was open at different time intervals for the two courses to increase the validity of the students' self-reported results; still, there were only two weeks in between to be cautious of systematic change in the students (cf. Metsämuuronen, 2006, 68; Nunnally & Bernstein, 1994, 252-255). The items were asked on a course-level, meaning that the students were asked to evaluate how well each statement describes their own studying during the course. The data was collected on a five-point Likert scale (1 = completely disagree, 5 = completely agree). The origin of the scales and the factors are presented in Table 5. The response rate was 83 percent for students in Course A, 66 percent for students in Course XA, and 80 percent for students attending both courses. After deleting the answers of students who declined to give permission to use their data for research purposes or who disengaged in responding to the items (15 students), the final sample consisted of 91 students. In addition, data collected during the courses (number of completed tasks, participation, and course exam results) were merged with the questionnaire data.

All students who answered the questionnaire in either of the courses in the quantitative data collection point were invited for an interview on a voluntary basis. The student interviews were conducted in the spring of 2017, three to four months after the quantitative data collection. **The qualitative data** consists of interviews of 16 students who attended both of the courses and had also participated in the quantitative data collection. The interviews were semi-structured interviews with an average length of 1h 13 min (min. 49 min, max. 1h 51 min). In the interviews, the students were asked about their aims for and processes of learning by for example asking them to describe how they studied in the courses, what kind of aims they had for the courses, and what supported and/or hindered their learning in the courses; depending on the answers, the students were prompted with more detailed follow-up questions. The semi-structured approach made room for students' own experiences, while keeping the interviews similar enough for meaningful comparisons. The aim of the interviews was to capture students' experiences on the courses and their interactions with the learning environments. The interviews were audio recorded and then transcribed verbatim.

5.3 PARTICIPANTS

It can be assumed that most of the students took the courses with similar pedagogical approaches in the first period of the semester, indicating that the pedagogical approaches utilised in Course A and Course XA were not completely new to the participants. The participants' background information is presented in Table 4. The students' major subject is reported using three categories: 'mathematics' refers to students majoring in mathematics, 'science' refers to students majoring in physics, chemistry or computer science, and 'other' refers to students majoring in other subjects. Students in the 'other subjects' category were predominantly majoring in education. Students with more than a year of university studies were often studying mathematics as their minor subject, implying that they had completed courses on their major subject prior to their mathematics studies. Gender is not reported to protect the students' anonymity. However, both data sets are balanced in terms of gender. Also, in Study II which qualitatively investigates the quantitative student subgroups identified in Study I, the interviewed students represent all the three student subgroups, and all the subgroups include both men and women.

Table 4. *The participants of the studies.*

	N	Major subject			Study year		
		Mathematics	Science	Other	1st	2nd - 3rd	≥4th
Quantitative data	91	57	20	14	59	9	23
Qualitative data	16	8	4	4	7	3	2

5.4 DATA ANALYSIS

The quantitative data for Study I, III, and IV were analysed using IBM SPSS Statistics 24 and Amos 24. The model validity was investigated both with exploratory and confirmatory approaches. Typically, confirmatory factor analysis is seen as superior to exploratory factor analysis. This doctoral dissertation utilises validated instruments which allows the theory-testing approach implemented in confirmatory factor analysis. Therefore, all the scales were analysed with a confirmatory approach. However, with the present sample size the self-regulation scale failed to produce an adequate model fit. As (overly) revisiting the modification indices and respecifying the model on empirical basis is considered exploratory in nature, presenting it as confirmatory can be regarded as undesirable research practice. Therefore, instead of confirmatory factor analysis, an exploratory factor analysis is reported for the self-regulation scale.

In Study I, the scales measuring students' approaches to learning, experiences of the teaching-learning environment, and self-efficacy were subjected to confirmatory factor analysis using the maximum likelihood estimation. Different fit indices were used to assess the model fit. The chi-squared test (χ^2) assessing the overall model fit returned a significant result for all scales implying a poor fit for the model. The root mean square error of approximation (RMSEA; 'badness-of-fit') and the comparative fit index (CFI; 'goodness-of-fit') values for the approaches to learning (RMSEA = .087, CFI = .924), experiences of the teaching-learning environment (RMSEA = .075, CFI .935), and self- efficacy (RMSEA = .050, CFI = .996) scales were within an acceptable range (cf. Hu & Bentler, 1999). Overall, the model fit can be considered acceptable.

In Study III and IV, the factor structure of the self-regulation scale was analysed with exploratory factor analysis (principal axis factoring with direct oblimin rotation; KMO=.722; $\chi 2$=641.463, df=105, $p<.001$). A principal axis factoring was chosen as the extraction method as it is more robust with small sample sizes compared to the maximum likelihood estimation (Fabrigar et al., 1999). The principal axis factoring was accompanied with direct oblimin rotation; an oblique rotation was chosen over orthogonal rotation as there was no reason to assume the latent factors to be linearly independent. The four factors identified in previous research (Heikkilä and Lonka, 2006; Räisänen et al., 2020; Vermunt, 1994; 2005) emerged as explaining 41.5 percent of the total variance.

In all studies using quantitative data (Study I, III, and IV), the factors in all scales were computed as a mean of its items. The factors' internal consistency was measured with Cronbach's Alpha and the reliability levels can be considered acceptable. The scales and the factors with Cronbach's alphas are presented in Table 5.

To compare the students' responses in the two learning environments, further analyses were employed. Study I aimed to identify student subgroups with different approaches to learning, so the students were clustered based on their deep and surface approaches; hierarchical clustering was used to identify the number of clusters (between-groups linkage, squared Euclidean distance), and K-means clustering to identify the cluster membership. These clusters were also utilised in Study II, in which the student subgroups were subjected to qualitative inquiry. To investigate the students' and the student subgroups' mean differences between the learning environments, a two-tailed paired samples t-test was used in Study I, III, and IV; also, Cohen's effect size d is reported (.2, .5, and .8 for small, medium and large effect size respectively; Cohen, 1992). In addition, variance analyses were used to analyse the difference between the subgroups (Study I) or men and women (Study III) within one learning environment, accompanied with η^2 for effect size (.01, .06, and .14 for small, medium, and large effect sizes respectively; Cohen, 1988).

Table 5. A description of the scales and factors used to collect the quantitative data.

Scale	Origin	Factor	# of items	Cronbach alpha
Approaches to learning	HowULearn (Parpala & Lindblom-Ylänne, 2012); modified from ALSI (Entwistle & McCune, 2004), ETLQ (Entwistle et al., 2003), and R-LPQ-2F (Kember et al., 2004); validated in the Finnish context (Parpala et al., 2013)	Deep approach	4	.786
		Surface approach	4	.776
		Organised studying	4	.748
Experiences of the teaching-learning environment	HowULearn (Parpala & Lindblom-Ylänne, 2012), modified from ETLQ (Entwistle et al., 2003)	Constructive feedback	3	.745
		Alignment	2	.690
		Requirements	2	.659
		Interest and relevance	3	.837
		Peer support	3	.802
Self-efficacy	HowULearn (Parpala & Lindblom-Ylänne, 2012), modified from MSLQ (Pintrich et al., 1991)	Self-efficacy	5	.901
Self-regulation of learning	ILS (Vermunt, 1994; 2005), modified to the Finnish higher education context (Heikkilä and Lonka, 2006; Räisänen et al., 2020)	Self-regulation of process	4	.658
		Self-regulation of content	3	.657
		External regulation	4	.710
		Lack of regulation	4	.642

The qualitative data in Study II and IV were analysed with Microsoft Excel and AtlasTI softwares. The aim of the qualitative analyses was to provide explanations for and to deepen our understanding of the students' different approaches to learning and different accounts of self-regulation of learning. In Study II, the aim was to create a comprehensive understanding of the students' learning experiences in the two learning environments and more specifically, investigate how the students' course-level approaches to learning were revealed in their interactions with the learning environments. In Study IV, the aim was to explicitly address the quantitative results revealing that the most substantial difference between the learning environments lay in the factor measuring lack of regulation. These two purposes were addressed in different ways. In Study II, the analysis was based on qualitative framework analysis (Ritchie & Spencer, 1994) as it is developed for applied qualitative research and it addresses the need for a comprehensive between- and within-subject comparison. The framework analysis process consists of five stages: 1) familiarisation, 2) identifying a thematic framework, 3) indexing, 4) charting, and 5) mapping and interpretation. A framework was developed based on a priori themes – the course elements (lectures, course material, working on tasks, guidance, and assessment, see Table 1) and the students' aims for learning. These themes were piloted with the data to ensure that they cover all data; in this process, the category of mathematical content was excluded as it had a miniature role in students' experiences. A data-driven approach was chosen to create a comprehensive picture of students' experiences, and the analysis process sought for students' concrete actions in the two learning environments and their perceptions of, and explanations for, the actions.

In Study IV, the qualitative data were analysed through a theory-driven qualitative content analysis (Miles and Huberman, 1994). The results of the quantitative analysis showed a substantial difference in the lack of regulation factor between the two learning environments. This guided the choice of the qualitative unit of analysis; it was defined as a student's description of a challenge episode and the consequent (non)action taken to overcome it. For example, a student could identify a challenge episode by saying *it was challenging* or *I didn't understand*, after which they described the following (non)action. This approach was chosen both to capture students' accounts of regulated learning, because challenge episodes are the way learning environments provide students with an opportunity to apply regulated learning (Hadwin et al., 2011), and to capture students' accounts of unregulated learning, because this was the factor with the most significant difference between the learning environments. A total of 504 analysis units were identified, and an average student reported 32 analysis units (Min. 16, Max. 57). The analysis units were coded exclusively into six predetermined categories presented in Table 6.

Table 6. *The qualitative analysis categories, their definitions, and an example analysis unit.*

Category	Definition	Example analysis unit
Self-regulation of process	Regulating one's own learning processes through regulation activities like planning learning activities, monitoring progress, diagnosing problems, testing one's results, adjusting, and reflecting (Vermunt, 2005).	*At first, I didn't understand [...] when we generalised the vector space, like how does it work and how come functions can be vectors, [...] but when you just read the course material and work on the tasks, [...] it gradually started to unfold.*
Self-regulation of content	Consulting literature and sources outside the syllabus (Vermunt, 2005).	*The textbook was very concise and difficult to read [...] so [...] you had to google and search for the material by yourself.*
External regulation	Letting one's own learning processes be regulated by external sources, such as introductions, learning objectives, directions, questions or assignments of teachers or textbook authors; testing one's learning results by external means, such as the tests, assignments, and questions provided (Vermunt, 2005).	*It's good that we have lectures after all, because somehow you want that [...] someone in the lecture explains the things thoroughly.*
Lack of regulation	Monitoring difficulties with the regulation of one's own learning processes (Vermunt, 2005).	*In the lectures, I had many questions that I, after all, usually didn't ask, which annoys me a little.*

Low-level co-regulation	Simple exchange of ideas and sharing facts (Volet, Summers, et al., 2009); scaffolding (Hadwin et al., 2011).	*Every time you needed, and you didn't know what to do, you just asked the tutor.*
High-level co-regulation	Shared regulation aiming to achieve a shared outcome (Hadwin et al., 2011; Volet, Summers, et al., 2009).	*Once I was studying in [the open learning space] with one of my friends, and then they explained a task that I hadn't understood and they drew a picture, and then suddenly we both realised from the picture what it was all about, and then we were really excited about it, like now, here it is, like this picture now explains what is going on. [...] It was such a good feeling, like this, this we understand.*

6 RESULTS

This chapter presents the main results of this doctoral dissertation. The results are presented in six sections. The first section presents a course-level comparison of students' approaches to learning, self-efficacy, and experiences of the teaching-learning environment. The second section identifies three student subgroups applying different approaches to learning, and the third section reports on the qualitative characteristics of these subgroups. In the fourth section, a course-level comparison of students' self-regulation of learning is provided. The fifth section reports on gender differences in self-efficacy and regulation of learning, and the sixth section provides a qualitative analysis on self-regulation and co-regulation of learning in the two learning environments. The last section provides a summary of the main results categorised under the theoretical concepts of approaches to learning, self-efficacy, and regulation of learning.

For a detailed description of the results, see the original studies. Note that throughout the results section, asterisks are used to denote the *p*-values (* for $p < .05$, ** for $p < .01$, and *** for $p < .001$ significance levels), and the mean differences between the two learning environments are reported as score in Course XA-score in Course A (XA-A). All text in italics is a student quote. The student quotes in Study II are signed as ([subgroup], [student ID], [course context]).

6.1 A QUANTITATIVE COURSE-LEVEL COMPARISON OF STUDENTS' APPROACHES TO LEARNING, SELF-EFFICACY, AND EXPERIENCES OF THE TEACHING-LEARNING ENVIRONMENT (STUDY I)

With a quantitative approach, Study I compares the two learning environments from the perspective of students' approaches to learning, self-efficacy, and experiences of the teaching-learning environment (N=91). Students' approaches to learning are measured with three factors, namely deep approach to learning, surface approach to learning, and organised studying. In addition, students' self-efficacy was measured with a one-factor scale. Students' experiences of the teaching-learning environment were measured with five factors: constructive feedback, alignment, requirements, interest and relevance, and peer support. The results of the course-level comparisons are presented in Table 7. The students reported statistically significantly higher scores in all factors in Course XA compared to Course A; as an exception, the difference is in the opposite direction in the factor measuring surface approach to learning, and not statistically significant in the factor measuring peer support. The most substantial difference between the two learning environments, both in terms of mean difference and effect size, was in the factor measuring surface approach to learning (MD = -.79***, Cohen's d = -.89). Also, the factors measuring self-efficacy (MD = .58***, Cohen's d = .64) and requirements (MD = .57***, Cohen's d = .68) showed substantial differences.

Table 7. *The students' scores on the approaches to learning, self-efficacy, and teaching-learning environment scales in the two learning environments.*

Scale	Factor	Course A		Course XA		Mean difference (XA-A)	T-test	Cohen's d
		Mean	SD	Mean	SD			
Approaches to learning	Deep approach	3.34	0.78	3.48	0.80	0.15*	t=2.337, df=90, p=0.022	0.18
	Surface approach	3.27	0.93	2.48	0.84	-0.79***	t=-7.505, df=90, p<0.001	-0.89
	Organised studying	3.17	0.83	3.34	0.86	0.18*	t=2.493, df=90, p=0.015	0.20
Self-efficacy	Self-efficacy	3.09	0.96	3.67	0.86	0.58***	t=6.226, df=90, p<0.001	0.64
Teaching-learning environment	Constructive feedback	2.75	0.84	3.08	0.81	0.33***	t=4.018, df=90, p<0.001	0.40
	Alignment	3.48	0.86	3.91	0.76	0.42***	t=4.679, df=90, p<0.001	0.53
	Requirements	3.30	0.90	3.87	0.76	0.57***	t=5.758, df=90, p<0.001	0.68
	Interest and relevance	3.35	0.89	3.73	0.75	0.38***	t=3.879, df=90, p<0.001	0.46
	Peer support	4.00	0.75	4.09	0.80	0.088	t=1.252, df=90, p=0.214	0.12

6.2 A QUANTITATIVE IDENTIFICATION OF STUDENT SUBGROUPS APPLYING DIFFERENT APPROACHES TO LEARNING (STUDY I)

The initial course-level comparisons reported in the previous section are followed by an identification of student subgroups applying different approaches to learning. Then, the student subgroups are subjected to both within- and between-context comparisons in the two learning environments. The students were clustered based on their scores on the factors measuring deep and surface approach to learning. The clustering resulted in three student subgroups:

1. students applying a deep approach (N=39)
2. students applying a surface approach (N=24)
3. students applying a context-sensitive surface approach (N=28).

The deep approach subgroup (Cluster 1) consisted of students who scored the highest on the deep approach factor and the lowest on the surface approach factor, and the surface approach subgroup (Cluster 2) of students who scored lower in the deep approach factor and the highest in the surface approach factor in both learning environments. The context-sensitive surface approach subgroup (Cluster 3) changed their approach to learning according to the learning environment; their dominant approach to learning was a surface approach in Course A learning environment but a deep approach in Course XA learning environment. The student subgroups are presented in Figure 2.

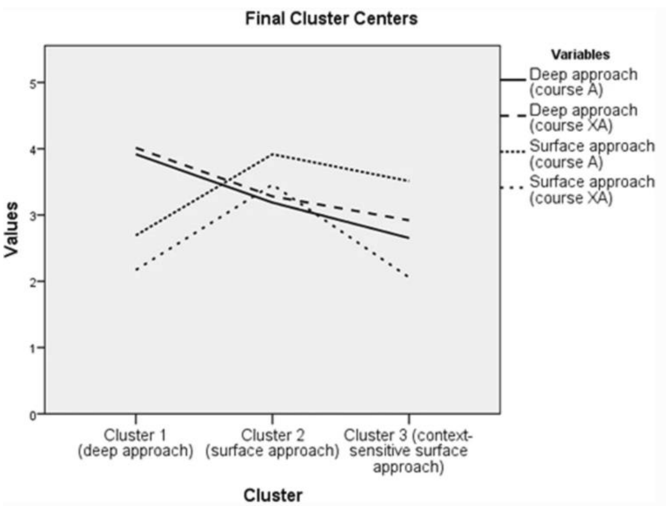

Figure 2 The three student subgroups and their scores on the factors measuring deep and surface approach to learning in both learning environments.

Next, we consider the student subgroups together in one learning environment at a time. Then, we compare one student subgroup's responses in the two learning environments. When considering the student subgroups in the context of one learning environment at a time, the results show that there were no statistically significant differences between the subgroups in terms of the background variables (major subject, gender, participation, number of completed course tasks, course exam results). As an exception, the surface approach subgroup scored statistically significantly lower in the Course XA exam compared to the other two subgroups. In terms of students' self-efficacy and experiences of the teaching-learning environment in Course A, the deep approach subgroup scored statistically significantly higher in the factors measuring self-efficacy, alignment, and interest and relevance in Course A compared to the other two subgroups. In Course XA learning environment, the deep approach subgroup scored statistically significantly higher in factors measuring self-efficacy, and interest and relevance compared to the surface approach subgroup. In addition, the context-sensitive surface approach subgroup reported statistically significantly higher values in the factor measuring self-efficacy in Course XA learning environment compared to the surface approach subgroup. To sum up, the deep approach subgroup reported higher values in both learning environments and in multiple factors compared to the other two subgroups, and the surface approach and context-sensitive surface approach subgroups differed only – favourable to the context-sensitive subgroup – in the course exam results in Course XA learning environment (MD = 15.25*; $F(2,88) = 10.750$, $\eta^2 = 0.202$; max(exam points) = 100) and in the factor measuring self-efficacy (MD = 0.92***; $F(2,88) = 15.651$***, $\eta^2 = 0.262$).

When comparing the subgroups' responses in the two learning environments, the results show that all three subgroups scored statistically significantly higher in many factors in Course XA than in Course A learning environment. The mean differences and effect sizes were largest for the context-sensitive surface approach subgroup. The most substantial difference, both in terms of mean difference and effect size, was for the context-sensitive surface approach subgroup in the factor measuring self-efficacy (MD = 1.01***, Cohen's d = .69) and requirements (MD = .89***, Cohen's d = 1.03). It is also notable that there were no statistically significant differences in the factor measuring peer support – except for the context-sensitive surface approach subgroup that scored higher in Course XA than in Course A learning environment (MD = .35*, Cohen's d = .52).

6.3 A QUALITATIVE INQUIRY INTO THE STUDENT SUBGROUPS APPLYING DIFFERENT APPROACHES TO LEARNING (STUDY II)

Study II is a follow-up study of Study I as it draws on interview data (N=16) and connects the quantitatively defined subgroups reported in the previous section with qualitative reports on the students' aims for learning and the actualised learning processes within the two learning environments. With this approach, the study explores and identifies elements of the learning environments that positively contribute to students' approaches to learning.

In the interviews, the students reported on three distinctive aims for learning; students could aim to understand the course content, *to survive* the course, or see the course in a larger context, e.g., as aiming to fulfil degree requirements. All students reported having similar aims for both courses, so the students' aims remained the same although the learning environment changed. The aims were specific to a certain student subgroup; the students in the deep approach subgroup aimed at understanding in both learning environments, while the students in the surface approach subgroup aimed at *surviving* in both learning environments. The students in the context-sensitive surface approach subgroup reported all of the three identified aims and always more than one aim; a student in this subgroup could aim at both understanding and surviving, understanding and fulfilling degree requirements, or understanding, surviving, and fulfilling degree requirements. Similarly, the aims remained the same in both learning environments. For example, a student in this subgroup stated:

> *I wanted to pass the course, [...] and then [...] it was very important for me [...] to complete lots of study credits. [...] But it was not all about achievement, because I also wanted to understand, it was also my aim. (CSSA, 21, A)*

In addition to their aims for learning, the study identified students' various ways of interacting with the elements of the learning environments, namely ways of taking part in lectures, course material clarity and usage, ways of working on the tasks and task difficulty, relevance of the guidance and helpfulness of the tutors, bonus points received from completed tasks, and experiences of the course exams. The students in **the deep approach subgroup** showed stability and persistence in their interactions with the learning environments. For example, the students utilised the course book in both learning environments, although they – as the students in the other two subgroups – found the Course A course book unclear and challenging to read. Also, the students in the deep approach subgroup were independent and acted based on perceived relevance to their learning. For example, a student stated regarding the Course XA lectures:

> *[The lectures] were not always so relevant. [...] [A]s I had already done [...] the weekly tasks, and in the lectures the same tasks are discussed in detail, [the lectures] were a little boring. [...] So I thought I'll read the course material, it's very good, and I get everything from there. (DA, 19, XA)*

However, the results revealed a major difference in the students' experiences between the two courses. For the deep approach subgroup, the most positively experienced element of the learning environments was the scheduled small group sessions in Course A learning environment, which provided possibilities for discussions and student collaboration. The students reported not having similar access to discussion and collaboration in the more unstructured open learning space in Course XA learning environment. To describe the positive experiences in the Course A small group sessions, a student quote is provided:

> *You eventually had certain people with whom you went to sit at the same table [...] to work on the tasks. [...] [I]t of course made the atmosphere better [...], you knew the people [...]. Probably I was not so actively [...] trying to approach anybody, it was more like a coincidence [...]. Probably the small group sessions are arranged well as you can get to know random people.*

Later, the same student continues:

> *Some people [...] did not know how to get started with the problems, so then I could guide them to the right path. [...] [S]o I gained quite good insight when I had to break it down to simpler terms. [...] [I]n the sessions, [...] I noticed that [solving the problems] is not super easy for anybody [...], instead, the [problems] do require some thinking. (DA, 7, A)*

The surface approach subgroup was distinctive in their unreflective interactions within both of the learning environments. For example, the students did not get much out of the lectures, as demonstrated by the following student quote:

> *I attended the lectures whenever I could, about half of them. [...] I took some kind of notes but [...] they turned out to be such that I didn't read [...] them afterwards [...]. I don't know whether I got so much out of the lectures. I tried to listen and stay on track. There were some tasks like 'think about these problems together' but [...] usually it was someone else who came up with the answer, so I was not able to participate so much in those [activities] either. (SA, 9, A)*

Also, the students had a narrow repertoire of actions to be taken to overcome challenges, for example when solving the weekly tasks; in both courses, the students reported the tasks being *high in workload* and such that one *could barely make it*. The unreflective interactions showed in their inability to overcome these challenges, for example by seeking help from the tutors or peers. This is demonstrated by the following student quote:

> *I would always try to do [the tasks] based on my intuition and if I didn't have any, then I didn't get anywhere from there. (SA, 9, A)*

Many of these challenges derived from challenges in engaging in social interaction within the learning environments. As the two student quotes above demonstrate, the students were not able to participate in lecture discussions or seek help even when in need. It is also notable that in contrast to the deep approach subgroup's accounts of collaborative knowledge construction within the scheduled small groups, the surface approach students, who engaged in social interaction within the learning environments, reported that tutors *truly [...] cater for you* and on feelings of *support and safety* as *you don't need to be alone*. The students' positive accounts of this type of direct individualised teaching and safety from peers were more prevailing in Course XA learning environment, as they associated them with the open learning space.

Overall, the students did not report many learning successes in either of the learning environments; as a student put it, *I can't say that I had any aha moments*. Indeed, this demonstrates a more general challenge for the surface approach students. During the courses, they studied in a way that they thought was the most efficient, but they questioned their ways retrospectively in the interviews; for example, a student asked that *could it be [...] that I used torpedoes against my own learning?* To conclude, the reflection on the productivity of their learning processes came afterwards but it was not present in their accounts of what happened during their studying in the courses.

A central aspect of **the context-sensitive surface approach subgroup** was active engagement in social interaction and student collaboration. This is where the differences in this subgroup's experiences between the two learning environments derive from. For example, the students reported contradictory experiences on the small group sessions in Course A learning environment, but in the Course XA open learning space, they reported exclusively on *a culture of collaboration* and *a sense of community*. This is further demonstrated by the following student quote:

> *In the [open learning space] we worked together [on the tasks], but [...] here too it was the discussions that were the basis of everything. [...] [L]ike how the other person had understood it and have you [...] understood it – you also get to explain [...]. And if no one [...] has understood, support was offered. [...] [I]t is much easier to ask for help in the [open learning space]. [...] [A]nd when you've been sitting there a lot, the tutors started to recognise you. Sometimes I felt that oh no, the tutor remembers me and I'm asking this again, I still can't do this, but despite that the tutor was like 'hey, you remember, just like last time, like this', it created cosiness. (CSSA, 2, XA)*

Also, the students' experiences on the lectures were different in the two learning environments. They attended lectures actively in both courses but in Course A, their participation was passive, and they did not always find the lectures relevant. In contrast to the other subgroups, the students were more active in the Course XA lectures compared to the Course A lectures, and they explicitly reflected on lectures, and especially the successful social interaction, as supporting their learning. For example, a student stated:

> *I attended all the lectures because I found them very useful, you got much out of them [...]. [T]here were so many different perspectives and you deepened your learning. [...] I was very active as a speaker; we discussed a lot there. [...] [T]he questions were easier to approach, [...] because in [Course A], already the questions were such that you didn't get a grasp on them so how could you discuss about it, but here [in Course XA] they were so well formulated that you were able to take a stand and reflect, so I was a very active learner [...] in the lectures. You always left the [lecture hall] with a feeling that something had just opened up in a completely new way. (CSSA, 5, XA)*

But why did the students in the context-sensitive surface approach subgroup change their dominant approach to learning? This question can be addressed by contrasting the deep approach and context-sensitive surface approach subgroups. It seems that these two subgroups preferred different learning environments. The deep approach students enjoyed the Course A small group sessions in particular, as demonstrated by the following statement:

> *It made me feel that now I do mathematics, [...] I fill the blackboard with some real proof, and it is a big experience of success, [...] it is somehow so stereotypical mathematics thing and then it is just so fun to get to do it yourself. (DA, 6, A)*

In contrast, the context-sensitive surface approach students enjoyed especially the Course XA open learning space. As a student in this subgroup described,

> *I was supported by the experiences of success, [...] the tutor gave me a small hint which I was missing but I got to do it by myself so that the joy of discovery was not wasted, [...] that made me feel very mathematical. (CSSA, 5, XA)*

It seems that the students in the deep and context-sensitive subgroups had access to learning successes that supported their positive perceptions of themselves as mathematicians in different kinds of environments. It is notable that the small group sessions and the open learning space were settings that offered access to student collaboration – the small group sessions particularly for the deep approach subgroup, and the open learning space particularly for the context-sensitive subgroup.

6.4 GENDER DIFFERENCES IN SELF-EFFICACY (STUDY III)

In Study III, the students' academic self-efficacy is analysed from the perspective of gender differences. The results presented in Table 9 show that in Course A learning environment, men reported higher self-efficacy than women (MD = -.54**, $F(1, 89) = 6.602$, $\eta^2 = .079$) but this difference was not present in Course XA learning environment (MD = .04, $F(1, 89) = .038$, $\eta^2 = .001$).

Table 8. *The men's and women's scores on the factors measuring self-efficacy.*

Factor	Course	Men		Women		Mean difference (Women – Men)
		Mean	SD	Mean	SD	
Self-efficacy	A	3.36	.96	2.82	.89	-.54**
	XA	3.65	.96	3.69	.72	.04

6.5 A QUANTITATIVE COURSE-LEVEL COMPARISON OF STUDENTS' SELF-REGULATION OF LEARNING (STUDY IV)

In Study IV, the two learning environments were compared from the perspective of students' regulation learning (N=91). The students' self-regulation of learning was measured with four factors, namely self-regulation of process, self-regulation of content, external regulation, and lack of regulation. The results of the course-level comparisons are presented in Table 8. There were statistically significant differences between the learning environments in the factors measuring self-regulation of process and lack of regulation; an average student applied more self-regulation of process (MD = .15*) and seldomly lacked regulation of learning (MD = -48***) in Course XA learning environment compared to Course A learning environment. The effect size for the self-regulation of process factor was small (Cohen's d = .19), suggesting an insignificant role of the learning environment. However, the effect size for the lack of regulation factor (Cohen's d = .63) implies a moderate impact of the learning environment.

Table 9. *The students' scores on the factors measuring self-regulation of learning in the two learning environments.*

Factor	Course A		Course XA		Mean difference (XA-A)	T-test	Cohen's d
	Mean	SD	Mean	SD			
Self-regulation of process	2.83	0.82	2.97	0.80	0.15*	t=2.189, df=90, p=0.031	0.17
Self-regulation of content	2.19	0.88	2.08	0.87	-0.11	t=-1.711, df=90, p=0.091	0.13
External regulation	3.59	0.78	3.65	0.72	0.063	t=0.941, df=90, p=0.349	0.08
Lack of regulation	3.28	0.78	2.80	0.75	-0.48***	t=-6.987, df=90, p<0.001	0.63

6.6 CHALLENGE EPISODES AS GATEKEEPERS FOR DEVELOPING AND APPLYING REGULATED LEARNING (STUDY IV)

As reported in section 6.5., the most substantial difference between the learning environments in students' self-regulated learning appeared in the factor measuring lack of regulation. Guided by this result, the qualitative analysis aimed at identifying challenge episodes and students' ways of resolving or not resolving them. The frequencies of the analysis units (N=504) are presented in Table 10. Approximately 90 percent of the students' challenge episodes were coded into the self-regulation of process, lack of regulation, and low-level co-regulation categories. The biggest proportional differences between the learning environments were in the lack of regulation and low-level co-regulation categories; the lack of regulation category had the highest frequency in Course A learning environment but in Course XA learning environment, the most frequent category was the low-level co-regulation. The following qualitative analysis focused on these three most frequent categories.

Table 10. *The frequency and percentage of analysis units by category and learning environment.*

Category	Course A (n=305)	Course XA (n=199)	Total (N=504)
Self-regulation of process	59 (19%)	44 (22%)	103 (20%)
Self-regulation of content	7 (2%)	3 (2%)	10 (2%)
External regulation	10 (3%)	5 (3%)	15 (3%)
Lack of regulation	129 (42%)	39 (20%)	168 (33%)
Low-level co-regulation	85 (28%)	97 (49%)	182 (36%)
High-level co-regulation	15 (5%)	11 (6%)	26 (5%)

The qualitative analysis identified four learning environment characteristics that according to students created challenge episodes and prevented or supported resolving them. These characteristics were the weekly tasks, teaching, peer support, and scaffolding. All of these showed throughout the challenge episodes in the self-regulation of process and lack of regulation categories. Additionally, peer support and scaffolding showed in the low-level co-regulation category.

For **the self-regulation of process** category, the weekly tasks were very central; they created many challenge episodes that provided opportunities to apply self-regulated learning. The students reported that the tasks guided them to monitor their own learning progress and understanding, to identify learning outcomes, and to reflect on their aims for learning. For example, a student stated:

> *When you work on the tasks, it is very easy to see whether you have understood some new thing, [...] you notice that well, I did know how to do this, [...] I did understand this difficult piece of theory. (Course A)*

Besides regulating the aims for learning, the learning process, and the learning outcomes, the tasks provided students with opportunities to also regulate their emotions. Students received bonus points for the exam by completing the weekly tasks and many students reported having done so – to reduce stress and relieve *exam panic*. Also, the weekly tasks provided students with opportunities to manage their time and effort; when the tasks were challenging, the students largely reported on *just spending more time* to resolve them. Besides individual studying, spending more time and effort meant also attending the lectures more frequently and seeking help from the tutors and their peers.

The lack of regulation category consisted of instances where the challenge episodes remained unsolved. Again, the weekly tasks were central to this category as the students were not always able to solve the tasks. For example, a student reported the following:

> *Somehow, I felt with the tasks that I didn't get a grasp on it, [...] so then it was like I didn't understand what you were supposed to do here, I tried something, but I couldn't really get a grasp on it. (Course XA)*

When the students found the weekly tasks too challenging, it created frustration and motivational challenges. This was more prevailing in Course A learning environment, as there were fewer tasks to choose from every week. Besides the weekly tasks, lack of regulation was also created by the teaching itself; the students reported that the teaching was out of their reach and as they were not able to follow it, they could not understand the bigger picture. This hindered for example the students' possibilities to participate in discussions during the lectures. This was more prevalent in Course A learning environment. This is demonstrated by the following statement:

> *You were completely worn-out just because someone just throws everything on you, and you have no time like, where does this concept fit here, and so on. (Course A)*

In both learning environments, the students reported on challenges in time and effort management. Different from the accounts of self-regulation of process, the students reporting on lack of regulation were, even if they had recognised their way of studying as unproductive, unable to change it accordingly. For example, a student stated:

> *The course, [...] it went somehow wrong, all the time I tried to do something, but it wasn't that successful. (Course A)*

To continue, when being successful in regulating their learning processes, the students often reported seeking help from the tutors and their peers. This was not the case when the challenge episodes remained unsolved. More prevailing to Course A learning environment, the students reported on not being able to seek help as scaffolding was provided only in the scheduled small group sessions. Also, the social environment created negative feelings such as anxiety and helplessness, which hindered the students' ability to seek help from and discuss with their peers. For example, a student described their experience as follows:

> *I felt that I'm not able to and I'm stupid, and [...] in the group when the others worked on the tasks, I was like oh no, everyone else can and I can't, how can I talk to these people and ask for help with the tasks. (Course A)*

The low-level co-regulation category consisted of challenge episodes that were resolved by relying on scaffolding or peer support. As mentioned previously regarding the lack of regulation category, the difference between the learning environments was in the availability of scaffolding; the students reported not receiving enough scaffolding or not knowing how to seek help from the Course A tutors because the scaffolding was offered only in scheduled sessions. This was not the case in Course XA learning environment, in which the scaffolding was offered continuously in the open learning space. For example, a student stated:

> *It was easy because if I was tottering even just a little, I would be like does it go like that and did I understand this right and then [the tutors] were always very good at explaining the tasks. (Course XA)*

Low-level co-regulation in the form of peer support was present when solving the weekly tasks and in lectures. It consisted of students asking for advice and sharing ideas when facing challenge episodes. The following statement further demonstrates this matter:

> *Another student had completed the task and then I asked if they could tell me how they thought about it, because somehow it felt so difficult that I didn't even know where to start, so then they explained exactly that, how it was and why they thought it that way, so it helped. (Course A)*

6.7 SUMMARY OF THE FINDINGS

This section summarises the results one theoretical concept at a time. The concepts are students' approaches to learning (Study I and II), self-efficacy (Study I and III), and regulation of learning (Study IV).

In the quantitative investigation, the students reported more favourable group-level approaches to learning in Course XA learning environment. The most substantial difference was in the factor measuring surface approach to learning. Three student subgroups were identified: 1) students applying a deep approach in both learning environments, 2) students applying a surface approach in both learning environments, and 3) students applying a context-sensitive surface approach, meaning that the students applied a surface approach in Course A learning environment and a deep approach in Course XA learning environment. In light of the approaches to learning, all student subgroups seemed to have benefited from Course XA learning environment, the context-sensitive surface approach subgroup benefiting the most. The qualitative investigation of the student subgroups applying different approaches to learning suggest that the subgroups are distinguished firstly, by their aims for learning, secondly, by their ability to reflect on their learning, and thirdly, by their readiness to utilise the possibilities for guidance and student collaboration. The aims were stable across the two contexts while reflecting on learning and utilising student collaboration was realised in different ways in different contexts and subgroups.

Self-efficacy had a central role when quantitatively contrasting the two learning environments. On a group-level, the students in Course XA learning environment scored statistically significantly higher in the factor measuring self-efficacy. Also, self-efficacy in Course XA learning environment was the only factor differentiating the surface approach and context-sensitive surface approach subgroups as the latter subgroup reported statistically significantly higher scores. Furthermore, the trend is similar when considering gender differences; men reported statistically significantly higher self-efficacy than women in Course A learning environment, but this difference was not present in Course XA learning environment as men's and women's mean scores were on the same level.

In the quantitative investigation of students' self-regulation of learning, the group-level results showed that the learning environments were mostly distinguished by the factor measuring lack of regulation; students lacked regulation skills more often in Course A learning environment. The qualitative analysis of the students' challenge episodes revealed that the majority of them were resolved via self-regulation of process or low-level co-regulation. Still, about a third of the challenge episodes remained unsolved, indicating a lack of regulation; this was created by out-of-reach teaching and tasks causing challenges in goal setting and motivation. To some extent, lack of regulation in Course A learning environment was substituted by low-level co-regulation of learning in Course XA learning environment, in which low-level co-regulation was provided more intensively through scaffolding and peer support.

7 DISCUSSION OF THE MAIN FINDINGS

In this doctoral dissertation, the same group of undergraduate mathematics students was investigated in two parallel student-centred learning environments; Course A learning environment functioned within the traditional lecture-tasks-small group setting but included student-centred elements, while Course XA learning environment used the Extreme Apprenticeship method (see Rämö et al., 2021) combining inquiry-based mathematics education (cf. Artigue & Blomhøj, 2013) and flipped learning approaches (cf. Talbert, 2017). This section provides a discussion on how the results presented in the previous section resonate with the theoretical framework presented in section 2. First, the two student-centred learning environments are contrasted on a group level. This group-level contrasting includes the perspectives of students' approaches to learning, academic self-efficacy and its relation to gender, and regulation of learning. Second, in order to highlight the importance of investigating student variation, the learning environments are contrasted from the perspective of the student subgroups. The subgroups were identified based on the students' approaches to learning, and the interaction of these subgroups and the learning environments is discussed from the perspective of the students' aims for learning, processes for learning, and academic self-efficacy.

7.1 CONTRASTING THE LEARNING ENVIRONMENTS ON A GROUP-LEVEL

The two student-centred learning environments were contrasted on a group level in Study I from the perspective of approaches to learning and self-efficacy, in Study III from the perspective of gender and self-efficacy, and in Study IV from the perspective of regulation of learning. These perspectives are discussed one at a time in the following three subsections.

7.1.1 STUDENTS' APPROACHES TO LEARNING

In Study I, the same group of students (N=91) was investigated in two learning environments and their approaches to learning were compared quantitatively. The students reported higher levels of deep approach to learning (MD=.15*, d=.18) and organized studying (MD=.18, d=.20), and lower levels of surface approach to learning (MD=-.79***, d=-.89) in Course XA compared to Course A learning environment. Based on the mean differences and effect sizes, the context had the strongest effect on the factor measuring surface approach to learning; in contrast, the role of the context was relatively small in the factors measuring a deep approach and organised studying. Based on previous literature, it could be concluded that, on average, the students in Course XA were applying more of those approaches to learning that elicit learning and studying of proof-based mathematics (cf. Maciejewski & Merchant, 2016), leading to a holistic understanding (cf. Biggs, 1991; Coertjens et al., 2016; Marton & Säljö, 1984) and a less fragmented knowledge base (cf. Lindblom-Ylänne et al., 2018), a cohesive conception of mathematics (cf. Crawford et al., 1998), and better academic achievement (cf. Richardson et al., 2012; Maciejewski & Merchant, 2016; Murphy, 2017) compared to Course A learning environment.

7.1.2 ACADEMIC SELF-EFFICACY AND ITS RELATION TO GENDER

Students' academic self-efficacy was investigated quantitatively by comparing the two learning environments in Study I and men and women in Study III. The students reported higher levels of self-efficacy in Course XA learning environment (MD = .58***, d = .64). This result indicates that on average, the students had more mastery and/or social modelling experiences, and/or their physical and emotional well-being was supported more in Course XA learning environment compared to Course A learning environment, as these are the sources that elicit self-efficacy (cf. Bandura, 1977; 2021, Pajares, 2005). This result is significant considering the extensive role self-efficacy has on academic achievement (see e.g., Richardson et al., 2012; Peters, 2013; Zakariya, 2020). In addition, the effect size implies a moderate role of the context in the students' levels of self-efficacy, further emphasising the significance of the results. Overall, this result is in line with Alt (2015) and Van Dinther and colleagues (2011) stating that it is possible to promote higher education students' self-efficacy through instructional practices. However, the result adds to the literature on the role of the type of learning environment on self-efficacy. Peters (2013) found that mathematics students' self-efficacy is higher in teacher-centred learning environments compared to student-centred learning environments. However, in this doctoral dissertation, the results show that there can be substantial variation also between student-centred learning environments – highlighting the importance of looking beyond the teacher-centred – student-centred dichotomy and understanding contextual factors within student-centred learning environments.

In Study III, self-efficacy was investigated in the two learning environments from the perspective of gender. In Course A learning environment, men reported statistically significantly higher levels of self-efficacy compared to women (MD = -.54**, $F(1, 89) = 6.602$, $\eta2 = .079$); in contrast, there was no statistically significant differences between men and women in the Course XA learning environment. This indicates that in Course A learning environment, women were, on average, less confident in their mathematical abilities compared to men, but such a difference disappeared in Course XA learning environment. Previous research has shown that men tend to have higher mathematics self-efficacy at university (see e.g., Huang, 2013;

Kogan & Laursen, 2014; Peters, 2013), and this was the case in the Course A learning environment. However, research also shows that student-centred learning environments can support women's self-efficacy (see e.g., Ellis et al., 2016; Kogan & Laursen, 2014); it can be assumed that this was the case in the Course XA learning environment. The results are important, because self-efficacy plays a significant role especially in women's retention and willingness to pursue a mathematics(-related) major (see e.g., Ellis et al., 2016; Raelin et al., 2014). In this vein, the results are in favour of the idea that instructional practices can be used to support women to pursue a career in mathematics. However, these group-level quantitative results do not offer any explanations for Course A learning environment failing to support women's self-efficacy to a similar extent.

7.1.3 REGULATION OF LEARNING

Students' regulation of learning was investigated both quantitatively and qualitatively in Study IV by contrasting the two learning environments. In the quantitative part, the students' self-regulation of learning was measured with four factors: self-regulation of process, self-regulation of content, external regulation, and lack of regulation. The results show that on average, the students reported statistically significantly more self-regulation of process (MD = .15*, d=.19) and less lack of regulation (MD = -48***, d=.63) in Course XA learning environment compared to Course A learning environment. Both in terms of the mean difference and the effect sizes, the lack of regulation factor had a more substantial role in differentiating between the learning environments. This result is important as self-regulation mediates individual and contextual characteristics and performance (Pintrich, 2000), and furthermore, self-regulation skills are required in problem-solving and proof-based mathematics (de Corte et al., 2011; Talbert, 2015), and in higher education studies in general (Coertjens et al., 2013; Coertjens et al., 2017; Jansen et al., 2019). From the quantitative results, it cannot be concluded in which phases of the regulation, preparatory, performance, or appraisal (cf. Panadero, 2017; Puustinen & Pulkkinen, 2001), or in which types of situations the students experience challenges in regulating their learning. However, the overall levels of self-regulation of learning can be considered low in both learning environments. Perhaps this is due to the participants being mostly first-year students who had not had enough time to participate in regulated learning (cf. Coertjens et al., 2017), especially when considering the dominating teacher-regulation in secondary education mathematics classrooms (de Corte et al., 2011).

As the quantitative results indicated that the most substantial difference between the learning environments was in the lack of regulation factor, the qualitative part focused on the students' challenge episodes and why they were sometimes but not always able to resolve them. The results show that the vast majority of the analysis units were in the self-regulation of process, lack of regulation, and low-level co-regulation categories. The amount of challenge episodes show that the students had many opportunities to apply and develop self-regulation skills in both learning environments (cf. Hadwin et al., 2011; Vermunt & Verloop, 1999). Furthermore, the distribution of the analysis units suggests that the lack of regulation in Course A learning environment is partly replaced by low-level co-regulation of learning in Course XA learning environment. In a closer investigation of the students' challenge episodes, the instances of challenge were linked to four central learning environment characteristics: the weekly tasks, teaching, peer support, and scaffolding. Self-regulation of process and lack of regulation was linked to all of the four elements, and peer support and scaffolding were linked to low-level co-regulation of learning. These results are in line with Pintrich (2000) and Zimmerman (2000) who conceptualise the learning environment as a mediator for self-regulated learning. The categories of (un)regulated learning are now described with the links students made from each category to the learning environments.

The tasks were very central in the students' descriptions of challenge episodes that were resolved by self-regulation of process. Through challenge episodes, the tasks provided the students with plenty of opportunities to make judgements on learning, monitor comprehension, reflect on goals, and evaluate performance, all indicating regulation of cognition and metacognition (Pintrich, 2000). The tasks also contributed to regulation of emotions; for example, the students regulated their affective reactions (cf. Pintrich, 2000) by solving the weekly tasks and, as they received bonus points for doing that, reduced the pressure from the course exam. Furthermore, the tasks provided opportunities to regulate behaviour; many students reflected on their regulation of cognition and adjusted their learning process accordingly, for example by investing more time and effort in studying or seeking help from the tutors (cf. Pintrich, 2000).

Lack of regulation was present in challenge episodes that remained unsolved. The instances of not regulating cognition and metacognition were shown in students' accounts of identifying learning challenges but not having goals to reflect upon or not knowing how to adjust the learning processes to reach them (cf. Pintrich, 2000; Zimmerman, 2000). This emphasises the fact that self-regulated learning is not self-evident, but students in different contexts can have different sets of skills and resources for engaging in this active and constructive process (Pintrich, 2004; Zimmerman, 2000). Regarding the learning environments, the students linked their instances of lack of regulation to the weekly tasks; too challenging tasks deflated persistence and caused frustration, indicating challenges in regulating motivation and emotions (cf. Pintrich, 2000). These types of challenge episodes were more prominent in Course A learning environment, because, as described by the students, there were fewer tasks to choose from and all of them were demanding. This can be viewed as the students not having access to the learning opportunities provided by the weekly tasks.

Furthermore, lack of regulating behaviour caused many challenge episodes to remain unsolved. The students linked unsolved challenge episodes to the lectures. The challenges derived from the lectures creating more confusion because the students could not ask questions or participate in the peer discussions during the lectures. These types of unsolved challenge episodes were more prominent in Course A learning environment, as in Course XA learning environment, the flipped approach supported the students' preparation for the lectures. Zimmerman (2000) posits lack of social opportunities as one of the sources of unregulated learning. It is interesting that, for these students, lack of regulation does not originate from not having social opportunities but from not having a meaningful contribution to these opportunities. Challenges in regulating behaviour also showed in the students' inability to seek help (cf. Pintrich, 2000) from the tutors in Course A; the tutors were present only in the scheduled small group sessions, but some students needing help also outside of the sessions did not seek help in any other form, (e.g., the chat platform, other students, other tutors).

To continue, in line with Pintrich's (2000; 2004) and Zimmerman's (2000) notion of the potential negative effect of the social environment, the social environment in the small group sessions created challenges for some students' regulation of emotions. For example, the students could be afraid that others would think that they are stupid because they could not solve a particular task and, to protect themselves, the students did not ask for help from the tutors or other students. This can be seen as the students' lack of regulating emotions denying them access to scaffolding and peer support – both forms of co-regulation that could have supported them to develop their self-regulation skills (see e.g., Hadwin et al., 2011; Volet, Vauras, et al., 2009; Winne, 2005). However, these students did not report on negative emotions in Course XA learning environment to a similar extent. It is notable that both learning environments were encouraging social interaction. It might be the case that in Course XA learning environment, where students were scaffolded, and perceived the teaching and tasks to be reachable (see De Bruijn-Smolders et al., 2016), the students also perceived the social environment more positively. All this indicates that the social and emotional dimensions of regulated learning are not separate from the cognitive processes.

Self-regulation of learning is not only an individual practice (see e.g., Hadwin et al., 2011; Pintrich, 2004; Volet, Vauras, et al. 2009; Zimmerman, 2002). Indeed, students reported on low-level co-regulation and linked it to scaffolding and peer support. Low-level co-regulation in the form of scaffolding was realised when the tutors supported the students in solving the weekly tasks in the small group sessions or in the open learning space. As mentioned previously, the students reported not having enough access to scaffolding in Course A learning environment, but similar accounts were not present in Course XA learning environment. It can be due to the open learning space offering guidance multiple hours a day. Furthermore, it is notable that as the Course XA tutors attended weekly professional development sessions, they may have been more capable of maintaining and adjusting the degree of teacher regulation according to the students' needs (see Vermunt & Verloop, 1999; Vrieling et al., 2017). Students also linked low-level co-regulation to peer support. These instances were present especially when solving the weekly tasks and participating in the lecture discussions. Both scaffolding and peer support indicate that the social environment supported the students' use of regulated learning (cf. Hadwin et al., 2011; Pintrich, 2000; 2004; Winne, 2005; Zimmerman, 2000).

The results bear significance as research focusing on regulation of learning and learning environments is scarce, both in higher education (for a literature review, see de Bruijin-Smolders et al., 2016) and university mathematics (de Corte et al., 2011) contexts. As a possibility stated in literature (see e.g., Stefanou et al., 2013), the two student-centred learning environments supported different dimensions of regulation. Course XA learning environment supported especially the co-regulation dimensions of regulated learning as it partly replaced the lack of regulation present in Course A learning environment. The co-regulation dimension of regulated learning was present in all of the learning environment elements that students connected to their challenge episodes, namely when solving the tasks, when participating in teaching (especially in the form of lecture discussions), and in scaffolding and peer support. Still, especially in Course A learning environment, many of the students' challenge episodes remained unregulated – the students were not always able to regulate their learning optimally (cf. Pintrich, 2000; Winne, 2005). This indicates that there were many instances in which the friction between the student's capabilities for regulating their learning and the demands of the learning environment was destructive (cf. Vermunt & Verloop, 1999). Vermunt and Verloop (1999) point out that it is unlikely that self-regulation skills would develop under these circumstances. It is important that the learning environments can be adjusted to support students to develop their regulation skills (cf. Jansen et al., 2019; Vrieling et al., 2017), as regulation of learning has a substantial role in learning university mathematics (cf. de Corte et al., 2011; Talbert, 2015), and lack of regulation is co-existing with many negative learning-related factors (see e.g., Räisänen et al., 2020; Vanthournout et al., 2012). This type of support can be crucial; as self-regulation of learning is cyclical in nature (Pintrich, 2000; Schoor, 2015; Zimmerman, 2000), it is important that these students do not enter an adagio of failure right from the beginning of their university studies. Furthermore, all of this emphasises Pintrich's (2000) point that self-regulation of learning should be considered as a learning outcome in its own right.

7.2 CONTRASTING STUDENT SUBGROUPS WITH DIFFERENT APPROACHES TO LEARNING

As students applying different approaches to learning can interpret the context differently (Coertjens et al., 2016; Wilson & Fowler, 2005), and different approaches to learning are sensitive to contextual changes to a different degree (Hailikari & Parpala, 2014; Lindblom-Ylänne et al., 2013; Quinnell et al., 2012; Varunki et al., 2017), it was important to identify and examine student subgroups applying different approaches to learning. In Study I, three student subgroups were identified: 1) students applying a deep approach to learning in both learning environments, 2) students applying a surface approach to learning in both learning environments, and 3) students applying a context-sensitive surface approach to learning. The students in the third subgroup applied a surface approach to learning in Course A learning environment but a deep approach to learning in Course XA learning environment. From the perspective of approaches to learning as contextual responses (cf. Trigwell et al., 2012; Wierstra et al., 2003; Öhrsted & Lindfors 2016), the students in the context-sensitive subgroup responded differently to the two learning environments as seen in their actualised course-level approaches to learning.

As a deep approach to learning can be more stable across contexts compared to a surface approach to learning (Coertjens et al., 2016; Wilson & Fowler, 2005), the three student subgroups are supported by prior literature. Also, approaches to learning can be considered as a continuum along which students can transition (Fryer & Vermunt, 2018; Kember, 2016), and it is rare for a student to apply a pure surface approach to learning (Lindblom-Ylänne et al., 2018). Because of these, it is more typical for a student applying a surface approach to learning in one context to apply a deeper approach to learning in another context – especially if the other context promotes student-centred learning activities (cf. Wilson & Flower, 2005).

7.2.1 STUDENT SUBGROUPS AND SELF-EFFICACY

The student subgroups applying different approaches to learning differed in their accounts for self-efficacy. In Course A, the deep approach subgroup reported higher self-efficacy in Course A learning environment compared to the other two subgroups, and in Course XA learning environment, the deep approach and context-sensitive surface approach subgroups reported higher self-efficacy compared to the surface approach subgroup. It is notable that the student subgroups did not differ statistically significantly in terms of gender, so it is unlikely that gender was the reason behind the differences between the three subgroups. As mentioned earlier, self-efficacy is a central predictor of academic achievement (see e.g., Richardson et al., 2012; Peters, 2013; Zakariya, 2020). In this vein, it is interesting that in Course A learning environment there was no statistically significant difference between the student subgroups in self-efficacy but in Course XA learning environment there was. Whether it is the course exams that differently distinguished students' competence, or the contexts that made the effect of self-efficacy on achievement (un)visible, remains an unanswered question.

When investigating the student subgroups individually, the results show that the difference in self-efficacy between the two learning environments was the largest for the context-sensitive surface approach students (MD = 1.01***, Cohen's d = 1.36). This is a distinctively large mean difference when considering all the factors included in all the studies. Another factor distinctive to the context-sensitive surface approach subgroup was the factor measuring peer support; there was no statistically significant difference in the other two student subgroups, but the context-sensitive students reported higher levels of peer support in Course XA learning environment (MD = .35*, Cohen's d = .52) compared to Course A learning environment. This is important as one of the sources of self-efficacy is social modelling experiences (cf. Bandura, 1977; 2021, Pajares, 2005).

7.2.2 STUDENT SUBGROUPS AND AIMS FOR LEARNING

The quantitative results in Study I showed that some (subgroup 3) but not all students (subgroup 2) shifted towards a deeper approach to learning in Course XA learning environment. To understand this further, and to distinguish between the intention and process components of an approach to learning (cf. Marton & Säljö, 1984; Wierstra, 2003), the qualitative analysis in Study II examined the students' aims for learning and the actualised learning processes within the two learning environments.

Prior literature has reported on students having multiple aims for learning (Lindblom-Ylänne et al., 2018; Marton & Säljö, 1984). This was also the case in this doctoral dissertation; the students reported on three distinctive aims for learning: understanding, *surviving*, and fulfilling degree requirements. Also, these aims were distinctive to each student subgroup as the students in the deep approach subgroup aimed at understanding, the students in the surface approach subgroup aimed at *surviving*, and the students in the context-sensitive surface approach subgroup reported having all of the identified aims, often all three simultaneously. In other words, the quantitatively determined deep approach was linked to qualitative accounts of aiming for understanding, and the quantitatively determined surface approach was linked to qualitative accounts of *surviving*. The results are in line with the theoretical conceptualisation of an approach to learning stating that an approach consists of both the aims for learning and the processes utilised to achieve them (Marton & Säljö, 1984). This is also an indication of the validity and reliability of the quantitative instrument – the factor structure indeed differentiated between students with different aims, as suggested by theory.

The students in all three subgroups reported having similar aims for both courses, so the aims were stable across the two learning environments. This is interesting, as it seems that the aims for learning are not context-sensitive but a part of the predisposition, the tendency towards a certain approach to learning when entering a certain learning environment. This finding supports Wierstra and colleagues' (2003) call for distinguishing the aims and processes when investigating changes in students' approaches to learning. Also, it is notable that the context-sensitive surface approach subgroup was distinctive in reporting multiple, typically simultaneous aims for their learning. Perhaps diverse aims are the origin of or at least increase the context-sensitivity of an approach to learning; with multiple aims, there is more room for the context to influence the choice of the aim a student starts to pursue. This is also an indication of the importance of distinguishing between the two levels, the predispositions (general-level) and actualised (course-level) approaches to learning; it might be that besides the deep approach students making strategic decisions on applying a temporary surface approach (cf. Fryer & Vermunt, 2018; Schneider & Preckel, 2017), short-term changes are possible only for students with multiple aims. Anyways, as pure surface approach is rare (cf. Lindblom-Ylänne et al., 2018), the possibility for short-term changes is present for the majority of the students.

7.2.3 STUDENT SUBGROUPS AND PROCESSES FOR LEARNING

But how did the student subgroups' learning processes differ in the two learning environments? Prior research states that a deep approach to learning is linked to more positive perceptions of the learning environment (Baeten et al., 2010; Coertjens et al., 2016; Entwistle & Tait, 1990; Parpala et al., 2010; in the context of mathematics Crawford et al., 1998; Mji, 2003). In this doctoral dissertation, this shows in both of the learning environments – the students in the deep approach subgroup reported statistically significantly higher values in many of the factors measuring their perceptions of the learning environment compared to the other two subgroups. Based on the deep approach student subgroups' qualitative accounts, their learning processes were stable across the learning environments, so both their aims as well as their processes were stable, as suggested by theory (Coertjens et al., 2016; Wilson & Fowler, 2005). The students in the deep approach subgroup were persistent in their studying and learning, which showed, for example, in their determination of utilising the Course A course book despite seeing it as challenging and unclear. This is in line with their higher self-efficacy levels compared to the other two subgroups; self-efficacy influences the choice of activities students engage with and the effort and persistence with which the engagement takes place (Bandura, 1977; 2012; Pajares, 2005).

The students in the deep approach subgroup also interacted with the learning environment based on perceived relevance. For example, a student stated that they attended the Course A lectures but not the Course XA lectures because they had already understood the topic through the introductory tasks. It is notable that there was no statistically significant difference between the learning environments for these students in the quantitative factor measuring interest and relevance. Therefore, interest and relevance can show in different ways in different contexts. In addition, students' interaction with the learning environments, for example attending or not attending lectures, is not in itself a determinant of quality of learning.

For the deep approach subgroup, peers were important for the students' learning. For example, the students in this subgroup named the Course A small group sessions the most positive element in the two learning environments. In the small group sessions, the students reported receiving peer support and possibilities for social appraisal. Also, the students reported on solving the problems beforehand by themselves and then teaching the other students in the small group sessions. The students did not utilise the open learning space to a similar extent in Course XA. It is known that a deep approach is essential for proof-based mathematics (Maciejewski & Merchant, 2016) such as the mathematics in these two learning environments. It may be that students who apply a deep approach to learning can, to some extent, solve the tasks by themselves, and therefore require structural support to seek peer interaction – which they will eventually find useful.

In line with literature, the surface approach subgroup's processes for learning were indicative of unreflectivity (cf. Lindblom-Ylänne et al., 2018). The students in this subgroup had a narrow repertoire of actions to solve any challenges they experienced while studying; for example, they did not do anything, even if they realised that they did not know how to proceed in solving the weekly tasks and that they should seek help for it. Unreflectivity also showed in the students' inability to participate in the lecture discussions. Uiboleht and colleagues (2019) conclude that social interaction promotes a deep approach to learning – but only when students are prepared for it. It may be that these students were not prepared for the social interaction during the lectures, nor in the small group sessions or in the open learning space. The students in this subgroup, who reported on receiving help from the tutors or peer students, described the social support as *safety* and as *catering for you*. The open learning space provided the students in this subgroup with more of these possibilities of individually tailored teaching. However, they did not report on collaborative knowledge construction in either of the learning environments – perhaps due to missing skills for it.

Prior research shows that the learning environment needs to be challenging enough to promote the development of a deep approach to learning; however, if the learning environment is too challenging, it can promote a surface approach to learning (Coertjens et al., 2016; Postareff et al., 2015; Postareff et al., 2014). The latter was true for the students in the surface approach subgroup. The students perceived the weekly tasks high in workload and reported not having many experiences of success. Kyndt and colleagues (2011) state that too much work can lead to a surface approach to learning, but challenging tasks can lead to a deep approach to learning – but only if the student eventually succeeds. The students in the surface approach subgroup reported a high workload both in terms of quantity and quality and were not successful in completing the tasks. This can be one of the reasons behind them dominantly applying a surface approach to learning. On one hand, this puts a special emphasis on the quality of guidance (cf. Hailikari & Parpala, 2014, Uiboleht et al., 2019) – these students would have required more of it. On the other hand, the students reported not reflecting on their studying and learning during the courses, only doing so retrospectively during the interviews. This can indicate that the first semester of university mathematics studies challenged the students' studying and learning, and that they might be able to apply more favourable approaches to learning later in their studies. Similarly, the role of guidance is substantial in supporting them in adjusting their studying and learning habits to the level required in higher education.

The students in the context-sensitive surface approach subgroup were distinctive in their extensive reflections on the social elements of the learning environments. The frustration reported in Course A learning environment was replaced with social interaction and student collaboration in Course XA learning environment. This also showed in the quantitative factor measuring peer support; this was the only subgroup with a statistically significantly higher level of peer support in Course XA compared to Course A learning environment (MD=.35*, d= .52). As Uiboleht and colleagues (2019) mention, and as discussed above with regard to the surface approach subgroup, social interaction can promote a deep approach to learning, but the students need to be prepared and have the skills for it. It may be that the students in the context-sensitive surface approach subgroup had the skills already. However, they also mentioned not preparing for the lectures, but in Course XA being prepared anyway, since they had already completed the introductory tasks. This indicates that their engagement in social interaction was supported by the flipped learning approach present in Course XA learning environment.

Another distinctive characteristic for this context-sensitive subgroup is the substantial difference in the factor measuring self-efficacy (MD=1.01***, d=1.36). In fact, the students in the context-sensitive subgroup and in the surface approach subgroup are distinguished only by the factor measuring self-efficacy in Course XA learning environment. This indicates that the students in the context-sensitive subgroup had multiple, often simultaneous aims for learning, and – by engaging in social interaction and with increased self-efficacy – they were able to apply a deep approach to learning in Course XA learning environment. This is indicative of the reported deep shifts in student-centred learning environments (cf. Baeten et al., 2012; Fryer & Vermunt, 2018; Kember, 2016; Wilson & Fowler, 2005). It is also notable that the context-sensitive surface approach subgroup preferred Course XA learning environment and the deep approach subgroup the Course A learning environment – both for their preferable learning environment providing access to student collaboration, further emphasising the role of the student collaboration on their learning.

8 GENERAL DISCUSSION

This doctoral dissertation synthesises four studies investigating two student-centred learning environments in university mathematics context. Course A learning environment functioned within the traditional lecture-tasks-small group setting but included student-centred elements, and Course XA learning environment used the Extreme Apprenticeship method (see Rämö et al., 2021) combining inquiry-based mathematics education (cf. Artigue & Blomhøj, 2013) and flipped learning approaches (cf. Talbert, 2017). As the same students were investigated in the two student-centred learning environments, the overall aim was to investigate how changes in the learning environments induced changes in the students' quality of learning. As suggested by Miles and Huberman (1994, 267), this section presents a synthesis of the various ways triangulation was utilised in this doctoral dissertation and discusses how student-centred learning environments can support students' quality of learning within the university mathematics context.

8.1 QUALITY OF LEARNING AND LEARNING ENVIRONMENTS

As discussed in the last section, the major differences between the two learning environments were that students reported more positive approaches to learning, self-efficacy, and regulation of learning in Course XA learning environment. However, examining the student subgroups with distinctive approaches to learning, as well as students' various ways of (not) resolving their challenge episodes offered a more nuanced understanding of students' quality of learning mathematics at university. As a major contribution to literature, this doctoral dissertation has identified four central elements of student-centred learning environments that together can both support and hinder students' quality of mathematics learning. These elements are tasks, lectures, scaffolding, and student collaboration, and they are described below in more detail.

The **tasks** – solving mathematical problems – are central to students' learning of mathematics. So, what types of tasks should the students solve? Regarding the tasks, the main difference between the two learning environments was the gradually increasing difficulty implemented in Course XA. Because some of the tasks were designed to take less time to solve, they were more numerous. Also, due to the flipped learning approach, the tasks were the entry point to the new mathematical content in Course XA learning environment. In both contexts, the students were provided with a new set of tasks weekly.

In general, the tasks provide students with opportunities for mastery experiences that promote self-efficacy (Bandura, 1977); as a student put it, *I constantly had small experiences of success*. For promoting self-efficacy, the tasks need to be challenging enough, because repetitive tasks with low cognitive demand can even reduce students' self-efficacy (Pintrich, 2000). Tasks providing enough challenges are also important for the development of a deep approach to learning (Coertjens et al., 2016; Kyndt et al., 2011; Postareff et al., 2015; Postareff et al., 2014) as they demand students seek meaning and understanding. Kyndt and colleagues (2011) also point out that tasks that are too challenging can further promote a deep approach to learning – but only if the students eventually succeed. Furthermore, challenging tasks promote self-regulation skills through challenge episodes (cf. Hadwin et al., 2011) providing opportunities to regulate cognition and metacognition (e.g., monitoring comprehension, evaluating performance), emotions (e.g., reducing pressure from exams by completing weekly tasks), and behaviour (e.g., adjusting learning processes to meet the set goals for learning by investing more time, seeking help) (cf. Pintrich, 2000).

However, if the tasks are too challenging and students are not able to get started with the solving process or to complete them, the tasks do not provide mastery experiences – and self-efficacy is deflated (cf. Bandura, 1977). Furthermore, tasks that are too challenging promote the application of a surface approach to learning (Coertjens et al., 2016; Postareff et al., 2015; Postareff et al., 2014), as students might not be able to get started with them or they elicit frustration and decreased effort. This notion seems even more important in the STEM context, in which students are more likely to apply a surface approach to learning compared to other disciplinary contexts (see e.g., Parpala et al., 2010). Self-efficacy and a surface approach to learning come together when solving tasks; students applying a surface approach reported about the tasks being too challenging and not creating many successes. As a student described, *there were fewer tasks to choose from and they were all so difficult*. To continue, tasks that are too challenging are linked to lack of regulation, as not being able to solve the mathematical problems created amotivation, frustration and other negative affective reactions, and furthermore, challenges to set goals for learning – and reaching them (cf. Pintrich, 2000, Zimmerman, 2000). This further emphasises Kyndt and colleagues' (2011) point that too large a workload has the potential of promoting quality of learning only if the students eventually succeed. The importance of a balanced challenge level of the tasks emphasises the importance of support structures such as guidance (cf. Hailikari & Parpala, 2014, Uiboleht et al., 2019) and student collaboration (Hadwin et al., 2011; Volet, Vauras, et al., 2009; Zimmerman, 2000).

When students were able to complete the tasks, it had implications on student collaboration. First, working on the tasks provided students with plenty of opportunities to collaborate in the small group sessions and the open learning space. Especially for the students in the deep approach subgroup, mastering the tasks offered them opportunities to teach other students in the small group sessions; by being able to solve the tasks, they got access to student collaboration. Second, especially for the context-sensitive surface approach subgroup, solving the introductory tasks in Course XA learning environment prepared them for the lectures and the social interaction during them. As later discussed, these instances of student collaboration in the small group sessions, open learning space, and lectures can be seen as further promoting the students' quality of learning.

Lectures are an integral part of many learning environments. In both learning environments, the mass lectures were activating, promoted student discussions, and focused on the main content of the course. The difference was that the lectures were the entry point to the mathematics content for the students in Course A learning environment. In Course XA learning environment, the students had already solved tasks prior to the lectures.

Although not necessary, the lectures and the support they offered – as noted by Baeten and colleagues (2013) – played a central role in many students' quality of learning. However, it is notable that not all students benefited from the lectures. As Uiboleht and colleagues (2019) concluded, social interaction is beneficial only if students are prepared for it. This was the case with the students in the surface approach subgroup – they were not able to participate in social interaction during the lectures as their experience was that the teaching was out of their reach. This caused amotivation and challenges in setting goals and forming a holistic understanding of the mathematical topics – all essential parts of quality of learning (see e.g., Biggs, 1991; Entwistle, 2009; Marton & Säljö, 1984; Pintrich, 2000; Zimmerman, 2000). To continue, these challenges are to be taken seriously as lack of social opportunities is one of the sources of unregulated learning (cf. Zimmerman, 2000). It is notable that the challenge was not the learning environment not promoting student collaboration but the students not having a meaningful contribution to these opportunities. In this vein, taking or not taking part in the social interaction during the lectures seems very relevant to students' learning. The students in the deep approach subgroup in Course A learning environment and the context-sensitive surface approach students in Course XA learning environment were able to participate in the lecture discussions by asking the lecturer questions, answering the lecturer's questions, and thinking and discussing with other students when instructed to do so. It is notable that especially for the context-sensitive students, the flipped learning approach, meaning that they had already completed tasks prior to the lectures, supported them in taking part in these social opportunities. It may be concluded that if students are able to participate in the social interaction during the lectures, it is on one hand an indicator of an appropriate challenge level of the lectures, but on the other hand provides the lecturer with information about the appropriateness of the level – and a possibility to adjust it accordingly. This further emphasises the negative effect of not being able to take part in the social interaction during the lectures.

Scaffolding is regarded as gradually decreasing instructional support provided for students to help them accomplish their learning tasks. Scaffolding was mostly provided in the scheduled small group sessions in Course A learning environment, and in the open learning space in Course XA learning environment. In both learning environments, the scaffolding was provided by more advanced mathematics students working as tutors. Besides the place of the scaffolding, the learning environments differed in that the Course XA tutors attended pedagogical meetings every week.

As mentioned, the weekly tasks are central to students' mathematics learning. However, as described above, they are not enough, especially in cases where students perceive them to be too challenging. This is important, as for example in Course A learning environment, half of the students' challenge episodes remained unsolved, resulting in lack of regulation. Therefore, tasks need to be accompanied with scaffolding to support students in solving them (Lazonder & Harmsen, 2016; Mayer, 2004; Pepin & Kock, 2021; Uiboleht et al., 2019). As seen especially in the case of the students in the context-sensitive surface approach subgroup, with scaffolding that supports student engagement, it is possible to provide more opportunities for mastery experiences and increase effort and persistence through increased self-efficacy (Bandura, 1977; 2012; Pajares, 2005).

Both learning environments provided students with plenty of support in the form of scaffolding. There are certain benefits of offering scaffolding in scheduled small group sessions. For students, especially in the deep approach subgroup, the small group sessions were the place for student collaboration; it provided them with opportunities to discuss and teach each other and in that way solidify their own understanding. If students were able to complete the tasks in self-study, they did not seek guidance or social interaction from the open learning space. This indicates that for some students, structural support of the scheduled small group sessions is needed to support them to access student collaboration – which they value in settings where they have access to it. However, for some other students, the small group sessions were places of negative social environment (cf. Pintrich, 2000; Zimmerman, 2000); they were not able to ask for help due to being afraid that others would find one to be *stupid*. Challenges in regulating one's affective reactions – a form of unregulated learning (cf. Pintrich, 2000) – further promoted lack of regulation as the student did not have access to the scaffolding that could eventually support them in developing their self-regulation skills (see e.g., Hadwin et al., 2011; Volet, Vauras, et al., 2009; Winne, 2005).

As the open learning space offers more flexibility, the students have plenty of opportunities to engage in contextual control and regulation (cf. Pintrich, 2000). For some students, the flexibility of the open learning space was central; some students require shorter teacher-student distance, and students could adjust this in the open learning space (cf. Wierstra et al., 2003). Some students require more specific scaffolding, for example the students in the surface approach subgroup describing the open learning space as providing individually tailored help. It may be that some students need help in adjusting their studying and learning habits, especially in the first year of university studies. This emphasises the importance of the quality of scaffolding (cf. Hailikari & Parpala, 2014, Uiboleht et al., 2019). Furthermore, an open learning space in the middle of the department can be considered more neutral than a typical classroom setting; it has been connected to reduced power imbalances between over- and underrepresented student subgroups in previous research (cf. Solomon et al., 2011). Flexibility is also important because self-efficacy is supported through physical and emotional well-being (Bandura, 1977); the flexibility and possibility for contextual control and regulation provides more students with suitable study environments.

In general, the role of the tutors in both learning environments is interesting: they are the teachers in the teacher-learner-balance in scaffolded learning (see Vermunt and Verloop, 1999; Vrieling et al., 2017) but at the same time, they stretch beyond the teacher-learner interaction (see Volet, Summers, et al., 2009) when serving as capable others in co-regulated learning (see Hadwin et al., 2011). When providing scaffolding, it seems crucial to provide the tutors with professional development support. Increasing the pedagogical understanding of the tutors support them in adjusting the type and level of guidance according to the needs of the students. The professional development of the Course XA tutors can be viewed as increasing their ability of maintaining and adjusting the degree of teacher regulation according to the students' needs (see Vermunt & Verloop, 1999; Vrieling et al., 2017). This way they are more likely to both cultivate students' beliefs and provide support in effective action, improving their effort (Bandura, 1977). All this indicates that the scaffolding itself is important, but its effectiveness can be improved by the flexibility of the setting and pedagogical training of the tutors. The relationship with tutors can be even more central to women; tutors support their self-efficacy but also provide an access to mathematics itself in ways that are not supported for example through office hours (Solomon et al., 2011). Also, students with lower self-efficacy are more sensitive to social modelling experiences and seeing others perform well (Pajares, 2005), indicating that the tutors' dual role as the teacher and the capable other is significant for all but especially for women.

Student collaboration was promoted in both learning environments during the lectures and when solving the weekly tasks. Student collaboration is central to the quality of learning in many ways; it supports the development of self-regulation of learning (cf. Hadwin et al., 2011; Volet, Vauras, et al., 2009; Winne, 2005; Zimmerman, 2000) and provides social modelling experiences that enhance self-efficacy (Bandura, 1977; 2021; Pajares, 2005). Self-efficacy is also enhanced by improving physical and emotional well-being (Bandura, 1977). For some students, the social environment had a negative effect on their learning (cf. Zimmerman, 2000) as they were not able to ask for help from the tutors or other students or participate in the lecture discussions as they were afraid of seeming *stupid*. This is not to say that the open learning space and the flipped learning approach directly supported students' emotional well-being, but in Course XA, the students found the tasks more reachable and received more guidance (cf. De Bruijn-Smolders et al., 2016), so they also reported on experiencing the social environment more positively. This highlights the conclusion made by Uiboleht and colleagues (2019) that students need skills and knowledge for student collaboration to be beneficial; being successful in terms of learning within a learning environment supports successful social interaction – and the other way around.

It is worth noting that student collaboration and peer support is not one-dimensional; the students utilised student collaboration differently. The students in the deep approach subgroups received cognitive support, the students in the surface approach subgroup received *safety*, and the students in the context-sensitive surface approach subgroup received multiple types of support, both social and emotional. One of the reasons behind the differences between the subgroups was how prepared they were for student collaboration (cf. Uiboleht et al., 2019). The context-sensitive students were prepared and had previously acquired the skills, so they could employ them readily when the learning environment offered the opportunity. This supports the development of a deep approach to learning (Uiboleht et al., 2019) and self-efficacy through vicarious experiences (Bandura, 1977). This is central specifically to students with lower levels of self-efficacy, as they are more sensitive to social modelling experiences (Pajares, 2005). However, the students in the surface approach subgroup did not have access to a similar boosting effect due to lacking access to student collaboration. It is worth noting that positive experiences of student collaboration boost students to seek collaboration even more (Sun et al., 2018). This highlights the importance of supporting all students in finding access to student collaboration.

When considering all these elements together, it can be concluded that to support the quality of students' mathematics learning, the students need enough challenges but also the means to overcome them. It can be considered that proof-based mathematics – especially during the first year of university studies – provides a multitude of challenges for students. However, the differences found between the two learning environments emphasise the importance of the support structures students are provided with to overcome these challenges. In Course A, the lectures were aimed at scaffolding the solving of the tasks in self-study and during the small group sessions. However, the results demonstrate that the flipped learning approach that disrupted the typical lecture-tasks-small group structure elicited multiple benefits for the quality of students' learning; in Course XA learning environment, the tasks solved prior to lectures supported lecture participation and engagement, the social interaction during lectures supported student collaboration, and the student collaboration supported the solving of the tasks, all promoting experiences of mastery. This highlights the complexity of developing second-generation student-centred learning environments (cf. Freeman et al., 2014); structural changes are required. Furthermore, the focal elements of the learning environments, tasks, teaching, scaffolding, and student collaboration, are interconnected in multiple ways and therefore, should be considered together. For example, if the scaffolding role of the tasks is removed from the learning environment, all the scaffolding structures are to be redesigned. In line with Uiboleht and colleagues (2019), it can also be concluded that the open learning space with pedagogically trained tutors provided students with flexible access to guidance and peer support. This leads us to the final point. As the investigation of student subgroups revealed, there are various ways in which students go about learning mathematics at university. Therefore, mathematics learning environments should aim for structural changes, such as flipped learning, to be flexible in creating constructive friction (cf. Vermunt & Verloop, 1999) for various learners.

8.2 TRANSFERABILITY OF FINDINGS

This doctoral dissertation is described as discipline-based higher education research. This indicates that instead of a general-level perspective, the aim was to investigate the quality of students' learning specifically in the disciplinary context of university mathematics (cf. Singer et al., 2012, 9). This aim, combined with the Pragmatic Approach, emphasises the need for reflecting on the transferability of the findings (cf. Morgan, 2007). So, to what extent are the findings of this doctoral dissertation transferrable to other contexts? The findings can be considered transferrable to other university mathematics contexts, especially within undergraduate education that is rooted in proof-based approaches. However, an appropriate level of caution should be taken when transferring the results to master's level courses as it is not currently clear how students' learning and studying develops during their university studies. This type of caution is needed because the specific results, regarding for example changes in approaches to learning, can be part of the students' first-year experiences and more consideration is needed to maintain the constructive friction within the learning environment (cf. Vermunt & Verloop, 1999). However, the general findings about the elements of the student-centred learning environments supporting or hindering students' learning can be considered applicable globally in university mathematics contexts.

The primary audience for discipline-based higher education research is other discipline-based researchers and the faculty teaching in that discipline (cf. Dolan et al., 2018). In this vein, the results are transferrable to other disciplinary contexts within higher education. Discipline-based higher education researchers are used to doing educational research in close contact with context. Regardless of the contexts, these researchers have combined the macro and micro levels in their research and can zoom in and out when needed (cf. Onwuegbuzie & Leech, 2005). Similarly, it is suggested that researchers in other disciplinary contexts reflect on the disciplinary differences and with appropriate modifications, integrate their own discipline into the results provided by this doctoral dissertation.

Considering higher education in general, the main findings need to be generalised with caution. The extensive role and distinctive nature of the tasks – the proof-based mathematical problems – need to be carefully considered when moving from disciplinary to general higher education contexts. However, the role of the mathematical content did not emerge as central when students reported on their learning and studying in the two learning environments. From this perspective, the main results contributing to the quality of students' learning can be viewed as general – whether the challenges derive from the proof-based nature of the tasks or from something else, context is not so relevant, as long as the students have challenges of appropriate levels and then the means to overcome them. To continue, the results concerning changes in students' approaches to learning are relevant to researchers investigating changes in SAL – within or outside a context.

8.3 ETHICAL REFLECTIONS AND LIMITATIONS

This doctoral dissertation was conducted in line with the ethical principles of the mathematics education research group (Hannula et al., 2018) and the Finnish Advisory Board of Research Integrity (2012). The ethical considerations were part of all the phases of the research process and showed besides careful planning, data collection, data analysis, data storage, and reporting results, in the participants' active consent and anonymity. The students participated in the research on a voluntary basis. In both data collection points, the students were informed about the research aims and procedures so that they were able to give an active consent for participating. The interviews were conducted by the doctoral candidate who was not a part of the courses' teaching teams, and it was emphasised that participating in the research does not affect the students' course assessment or future studies in any way. The original data were handled by the doctoral candidate, and in Studies II and IV in which another researcher joined the data analysis, they could handle anonymised data only. Also, the students' anonymity was carefully considered when reporting the results.

There are four perspectives to limitations regarding this doctoral dissertation to be discussed. The first limitation derives from the research design. Focusing on the level of a learning environment is challenging because the definition of a learning environment is broad and sometimes ambiguous (cf. Fraser, 1998). Despite this challenge, the course-level investigation is recommended with respect to all the theoretical concepts utilised in this doctoral dissertation (see Asikainen & Gijbels, 2017; Bandura, 1994; 2012; Marton & Säljö, 1976; Pintrich, 2000; 2004). To follow this theoretical recommendation, the challenges caused by the possible ambiguity of the definition of a learning environment were addressed with triangulation (cf. Meijer et al., 2002; Miles & Huberman, 1994). Moreover, the data analyses reported as a part of this doctoral dissertation covered all the topics students reported in the interviews. In this vein, it can be concluded that the ambiguity of the definition was addressed well through the research design.

The second limitation derives from the choice of context. Choosing two parallel learning environments aimed at controlling the student variation – as the students remained the same for example in terms of their prior knowledge and experiences (cf. Huang., 2013; Zakariya, 2020), it was possible to examine the differences and similarities caused by the variation in the context. This indicates that the students remaining the same is a major strength for this dissertation. However, it was not possible to keep the same students and the same mathematical content. As the two learning environments differed in their mathematical content, it is not possible to articulate the role of the content separately from other contextual factors. This was deliberate – for contrasting the learning environments, a choice was made for having the same students over having the same mathematical content. Still, it can be an interesting question what the role of the content within a context is. This question was considered when analysing the student interviews for Study II; mathematical content was one of the a priori themes in the framework analysis. However, it was rare that a student connected the content to their learning and instead, discussed the other elements of the learning environment (e.g., lectures, tasks, and guidance) extensively. For this reason, the mathematics content was left out of the analyses. As a conclusion, it is assumed that the subject content can have a role in students' quality of mathematics learning. However, based on the data in this doctoral dissertation, it is not always extensive.

Besides mathematical content, the two courses were led by different lecturers. Both have been recognised as 'good teachers' by both the students and the university, and they can be regarded as excellent lecturers. However, the data analysis in this doctoral dissertation was not able to account for the variation caused, for example, by the lecturers' approaches to teaching (cf. Baeten et al., 2010) or gender (cf. Basow et al., 2013; Drury et al., 2011) separately from other contextual factors. Additionally, the more senior mathematics students acting as tutors were different in the two learning environments. In this regard, the results of this doctoral dissertation are not to be considered as absolute descriptors of the learning environments; instead, the learning environments should be reflected against each other, and the primary focus should be placed on the results describing the changes between them.

The third limitation concerns the data collection; this doctoral dissertation draws on self-selected samples and self-reported cross-sectional data. This was partly addressed by combining the questionnaire and interview data with data collected during the courses (number of completed tasks, participation, and course exam results) to also consider the students' actual activity within the learning environments (cf. Diseth, 2011). In addition, the quantitative instruments utilised in this doctoral dissertation are developed based on much used higher education instruments and modified and validated in the Finnish higher education context (see e.g., Hailikari & Parpala, 2014; Parpala et al., 2013). Furthermore, 80 percent of the students who attended both courses participated in the quantitative data collection which can be considered a high response rate. Regarding the response rate, it should be noted that at the time of data collection, it was common for students to enrol in a course but never actually start it. Also, the dropout rates after the first week used to be substantial. Therefore, it was not possible to use the course enrolment student list; instead, the response rates were computed based on all students who had any notations in the course data, for example at least one completed task, presence in at least one small group session, or taking the course exam. It can be hypothesised that the response rates for students who actually aimed at studying the course could have been even higher. Considering the interviews, one should note that the number of student interviews in this dissertation was 16. In the context of this doctoral dissertation, the number of interviews can be considered sufficient; the interviews were on average over an hour long during which the students reflected on and contrasted their studying and learning within the two learning environments. This created a solid base for drawing conclusions on the differences between the learning environments. Also, it should be noted that the interviewees equally represented the student subgroups, indicating that various types of aims and cognitive processes are present also in the interview data.

The fourth limitation is related to the data analyses. It was not possible to use a second coder to analyse all the qualitative data. This was addressed in Study II by choosing a qualitative framework analysis with well-defined and systematic analysis procedure, and in Study IV by using a second coder for a part of the interviews. In addition, the qualitative results are in line with the quantitative results, supporting the trustworthiness of the overall findings. Further, Patton (1999) reflects on the role of the researcher especially in qualitative research and encourages researchers to report on their personal connections to the research context. The research context of this doctoral dissertation is where the doctoral candidate gained her master's degree. This indicates that the candidate is familiar with the faculty and the instructional practices within the mathematics department. This contextual understanding has increased the trustworthiness of the qualitative data analyses and it provided the candidate with tools to make the arguments presented in this dissertation. It should be noted that this type of contextual understanding is an essential characteristic of discipline-based higher education research (cf. Singer et al., 2012, 9; see also Nieminen & Lahdenperä, 2021).

As a final note, the results of the studies included in this doctoral dissertation have been presented in numerous international scientific conferences on mathematics, mathematics education, university mathematics education, education, and higher education. Furthermore, as the author is one of the founding members and coordinator of the Finnish Network for University Mathematics Educators (NUME), the results of this doctoral dissertation have been utilised within the network to support mathematics instructors to engage in research-based development of university mathematics education. The discussions with the national and international research and educational communities have supported the validity, reliability, and trustworthiness of the research process and its outcomes.

9 IMPLICATIONS

This section provides a discussion of the implications of this doctoral dissertation. First, implications for theory are presented, followed by a discussion of implications for methodology. The section is concluded by offering implications for practice.

9.1 IMPLICATIONS FOR THEORY

Considering students' approaches to learning, the results of this doctoral dissertation show that students' course-level approaches to learning are sensitive to contextual variation. The results support theory in that a deep approach to learning was more stable and a surface approach to learning was more context-sensitive (cf. Coertjens et al., 2016; Hailikari & Parpala, 2014; Lindblom-Ylänne et al., 2013; Quinnell et al., 2012; Varunki et al., 2017; Wilson & Flower, 2005). Due to the context-sensitivity of a surface approach to learning, the learning environments were most substantially distinguished by the factor measuring the surface approach to learning. As an original theoretical contribution, the results of this doctoral dissertation indicate that the reason behind the context-sensitivity lies in the students' aims for learning. The shift from a surface approach to a deep approach to learning was induced by the students' multiple aims for their learning. The students who had only one aim for their learning (to understand or *to survive*), did not change their contextual responses (cf. Trigwell et al., 2012; Wierstra et al., 2003; Öhrsted & Lindfors 2016). In contrast, students who had multiple aims for their learning (a combination of to understand, *to survive*, to fulfill degree requirements) also changed their dominant approach to learning depending on the learning environment. This indicates that having multiple primary aims enables students to choose the aim they will start to pursue, based on the clues provided by the learning environment. Furthermore, the students' aims for learning were stable across the learning environments. This indicated that the aims were not a part of the contextual responses but a part of the predispositions, the tendencies towards a certain approach to learning. This finding emphasises the benefits of investigating the aims and the processes of an approach to learning separately (cf. Marton & Säljö, 1984; Wierstra et al., 2003). It may be that the challenges in supporting the development of a deep approach to learning through instruction (cf. Baeten et al., 2013) derive from the fact that students' aims for learning are beyond the influence of the contextual variables such as the ones investigated in this doctoral dissertation. However, it is worth noting that the learning environments were assessed through a typical course exam; recent studies investigating undergraduate mathematics assessment practices (see e.g., Nieminen et al., 2021; Nieminen

& Lahdenperä, 2021) demonstrate that learning environments utilising formative assessment, as well as self- and peer assessment can support students to become aware of their aims and furthermore, to set better aims for their learning.

When investigating the students' processes of learning, the results of this doctoral dissertation show that the motivation to learn can be demonstrated differently in dissimilar learning environments. This indicates that there is not necessarily one-to-one correspondence with students' behaviour and their approaches to learning across contexts. However, the results of this doctoral dissertation demonstrate that the skills required for meaningful student collaboration have a central role in developing approaches to learning. As demonstrated by Uiboleht and colleagues (2019), social interaction promotes a deep approach to learning but only when students have the skills and resources for it. A surface approach to learning is linked to missing these skills, and it can be one of the reasons behind their dominantly surface approach to learning. The results of this doctoral dissertation show that the context-sensitivity of an approach to learning was linked to having these skills – along with increased self-efficacy and multiple aims for learning. Prior research states that promoting active engagement is important, especially for students who typically apply a surface approach to learning, as this active engagement is an element of student-centred learning environments that support the development of these approaches (Hailikari et al., 2021). The results partly support this claim, as active engagement indeed had a positive effect on some of the students applying a surface approach to learning. However, as some of the students who applied a surface approach to learning were not able to utilise social opportunities for active engagement, more theoretical and empirical research is needed to understand how to also support these students to get access to these activating elements of the learning environments.

Overall, the results of this doctoral dissertation support the significant role of self-efficacy on students' learning (cf. Honicke & Broadbent, 2016; Peters, 2013; Richardson et al., 2012; van Dinther et al., 2011). Furthermore, the changes between the learning environments support the notion that it is possible to use instructional practices to promote students' self-efficacy (cf. Alt, 20158; Dinther et al., 2011) and more specifically, womens' self-efficacy (cf. Ellis et al., 2016; Kogan & Laursen, 2014) in university mathematics context. However, the results contest Peters' (2013) finding that, compared to student-centred learning environments, teacher-centred learning environments are more successful in supporting students' self-efficacy. As an original contribution, the results of this doctoral dissertation show that there can be substantial variation in students' self-efficacy levels between two student-centred learning environments. It may be that some students perceived the learning environments differently with regard to the learning environments' intensity of student-centredness. This is further highlighted in the results concerning self-efficacy and its relation to gender. Previous research has described teacher-centred learning environments as settings in which men have higher self-efficacy compared to women (see e.g., Huang, 2013; Kogan & Laursen, 2014; Peters, 2013), and student-centred learning environments as settings in which the gender differences in self-efficacy decrease (see e.g., Ellis et al., 2016; Kogan & Laursen, 2014). The substantial variation in students' self-efficacy within different student-centred learning environments, as well as gender differences being present in a student-centred learning environment emphasise the need to open up the notion of student-centred and investigate learning environments beyond the typical teacher-centred – student-centred dichotomy. Given the central role of the social interaction in the results of this doctoral dissertation, and as Lahdenperä and Nieminen (2020) report on broader understanding of mathematical competence supporting students' sense of belonging to the mathematics community, it could prove fruitful to reach outside of the socio-cognitive approach and investigate the relationship between students' confidence in their mathematical abilities and learning environments from the socio-cultural perspectives, as well.

Of the dimensions of regulation of learning, the learning environments were most substantially differentiated by students' accounts of the lack of regulation. This suggests that lack of regulation is sensitive to context, and to continue, the context-sensitivity can be explained by the presence of co-regulation of learning. This supports the theoretical assumption that co-regulation can be viewed as a transitional process towards self-regulation of learning (cf. Hadwin et al., 2011; Pintrich, 2000; 2004; Winne, 2005; Zimmerman, 2000). In this vein, and further supported by Zimmerman (2000), the role of the social is substantial in developing self-regulation skills. However, to specify Zimmerman's (2000) notion that lack of social opportunities is one of the sources of lack of regulation, the results of this doctoral dissertation demonstrate that lack of regulation is not created by lack of social opportunities but by not having a meaningful contribution to these opportunities.

9.2 IMPLICATIONS FOR METHODOLOGY

This doctoral dissertation demonstrates the benefits of investigating students' approaches to learning on a course level. Furthermore, the results of this doctoral dissertation demonstrate the benefits of investigating students' aims for learning and processes used to achieve them separately (cf. Wierstra et al., 2003). As there was substantial variation in parallel student-centred learning environments, especially in the context-sensitive student subgroup, it is suggested that future studies should consider the fact that approaches to learning are highly sensitive to the context (see also Öhrsted & Lindfors, 2016). However, as mentioned in the theoretical framework, the idea of a general-level approach to learning is not discarded. With respect to future research, it would be interesting to employ longitudinal research designs to examine the students' course-level approaches to learning over time (cf. Asikainen & Gijbels, 2017). This would provide useful information on how the general predispositions are synthesised from the actualised contextual approaches to learning. Future research could also further examine the students whose approaches to learning are sensitive to contextual changes. Furthermore, the participants of this doctoral dissertation were in their first year of studying mathematics at the university. With longitudinal research designs, it would be possible to address the context-sensitivity and its relation to study year and progress.

In this doctoral dissertation, both learning environments included a closed-book course exam at the end of the course. Approaches to learning have been shown to predict academic achievement in multiple studies (see e.g., Richardson et al., 2012). However, Diseth (2011) points out that in multivariate analysis, the effect of a deep approach to learning on academic achievement can disappear when controlling for the effect of a surface approach to learning; it can be that sometimes course exams do not reward the presence of a deep approach as much as they reward the absence of a surface approach to learning. It would be interesting to further extend the research to investigate not only how approaches to learning promote achievement but how various assessment practices can promote more favourable approaches to learning (see e.g., Nieminen et al., 2021) and increase awareness of the learning and knowing of mathematics (see e.g., Nieminen & Lahdenperä, 2021).

In this doctoral dissertation, two factors were identified – gender and an approach to learning – that can substantially influence the students' self-efficacy in a specific context. It is notable that the group-level self-efficacy (Study I) can be at least partially explained by the changes reported by women (Study III). It may be that the contradictory results reported on the relationship between mathematics self-efficacy and student-centred learning environment (cf. Alt, 2015; Fast et al., 2012; Peters, 2013) can be partly due to the fact that gender was not considered. Also, the three student subgroups did not differ in terms of gender but the variation in the subgroups' efficacy levels was substantial. It is suggested to consider gender and approaches to learning or similar cognitive constructs when investigating learning environments and self-efficacy in the context of university mathematics.

The results of this doctoral dissertation demonstrate that the examination of students' challenge episodes is a relevant way of capturing the lack of regulation. Furthermore, as the results suggest that the lack of regulation can be replaced by co-regulation of learning, and co-regulation is seen as a proxy for developing self-regulation skills (Hadwin et al., 2011; Schoor et al., 2015; Volet, Vauras, et al., 2009; Winne, 2005), future studies should aim to capture these processes from a person-oriented perspective to understand how co-regulation is successfully applied for different students.

Overall, the role of the social characteristics of the learning environments was central to the quality of students' learning. Future research could approach *the social* in the learning environment with various research designs. What are the premises for meaningful social participation? More specifically, it would be interesting to investigate the students not as individuals but as a collective entity, and with this approach, to grasp *the social* in regulated learning (cf. Volet, Vauras, et al., 2009). Although it would require stepping outside of the socio-cognitive approach, it seems valuable to understand how the notion of socially shared regulation resonates with the context of university mathematics. Furthermore, Lahdenperä and Nieminen (2020) link learning environments and students' sense of belonging to the mathematics community through social interaction and mathematical competence. This line of inquiry seems worth pursuing further.

Quantitative instruments developed for higher education research need to be general as data are collected from any discipline. It may be that discipline-based higher education research requires more fine-grained instruments to differentiate between contextual factors relevant to the discipline. For example, the quantitative instruments utilised for this doctoral dissertation did not differentiate between the various reasons for utilising student collaboration. Therefore, to advance these discipline-based approaches in higher education, we may need to create new instruments or modify existing higher education instruments to fit the needs of a specific subject domain. In the university mathematics context, there are some indications that this is already taking place (see e.g., Liebendörfer et al., 2020).

By using triangulation in multiple ways to investigate the same students in two learning environments, this doctoral dissertation has demonstrated an interesting way to examine contextual differences related to the quality of students' learning. As triangulation aims for testing consistency of the findings (cf. Patton, 1999), and allows new contextual dimensions to emerge (Jick, 1979), the findings of this doctoral dissertation suggest that triangulation is useful when investigating and contrasting learning environments in all their complexity. However, as this holistic approach to the learning environment does not focus on the exact role of the mathematics, it is encouraged that future research should investigate the elements of the learning environments promoting and hindering students' quality of learning, identified in this doctoral dissertation, also individually. To conclude, as the results of this doctoral dissertation promote structural changes for increasing the flexibility of the learning environments to support the quality of learning for all students, it is suggested that future research should examine the institutional structures that support or hinder the implementation of research-based teaching practices (cf. Reinholz et al., 2020; Rämö et al., 2019).

The choice of theoretical framework for this doctoral dissertation was guided by SAL and SRL traditions offering distinctive ways of conceptualising quality of learning in higher education (cf. Pintrich, 2004). However, there is conceptual confusion related to the third approach in SAL and self-regulation of behaviour in SRL. The third approach, namely organised studying, was originally named a strategic approach (Entwistle & Ramsden, 1983) or an achieving approach (Biggs, 1987). In the more recent SAL research, especially related to the development of the HowULearn instrument (see Parpala & Lindblom-Ylänne, 2010) utilised in this doctoral dissertation, the meaning of the organised approach has been reduced to time and effort management (see e.g., Coertjens et al., 2016; Hailikari & Parpala, 2014). However, this doctoral dissertation conceptualises time and effort management through self-regulation, more specifically through self-regulation of behaviour (Pintrich, 2000; 2004). This shows in that the student subgroups were identified and named based on only the factors measuring deep and surface approaches to learning. With these choices, this doctoral dissertation was not able to clarify the conceptual confusion related to the third approach to learning and its relation to regulation of learning. Future research is needed to solidify the present onceptualisation of the third approach within the SAL tradition.

9.3 IMPLICATIONS FOR PRACTICE

It has not always been evident that teaching and learning are intertwined. It may be that we in the university mathematics community are in the middle of the process realising that this certainly is the case. From a practical perspective, this has been the point of this doctoral dissertation – to show how teaching of mathematics is related to learning of mathematics at university. There are two main practical implications – or perhaps hopes – for the future. The first one is that discipline-based higher education research should continue to strengthen itself. As Healey (2000) points out, it is important that higher education is not divorced from the disciplinary content. This is supported by Dreyfus' (2014), who demonstrates that the pedagogical questions mathematicians pose to mathematics educators are of a concrete nature. As higher education researchers sometimes do not recognise and value the instructors' engagement to their own discipline (Healey, 2000; Jenkins, 1996), it is of substantial value that discipline-based higher education researchers can address the instructors' questions and the disciplinary characteristic of that discipline (cf. Dolan et al., 2018). Furthermore, Le Roux and colleagues (2021) point out that the discipline-based researchers are considered more trustworthy compared to higher education researchers by the disciplinary community. Therefore, discipline-based higher education research is needed to advance the research-based development of university mathematics education.

Conducting discipline-based higher education research and applying its research findings to practice are distinct but interdependent pursuits (Healey, 2000; Singer et al., 2012). The second practical implication is about strengthening this interdependence; one day, we should have mathematics departments with research-based teaching throughout the degree programmes (cf. Dolmans et al., 2016; Kember, 2016; Reinholz et al., 2020). At the end of the day, mathematics is taught by mathematics experts – and so it should be. However, the mathematics experts are exemplary learners – their outstanding record as problem-solvers supports the development of pedagogical expertise (Braun et al., 2017), as well. To advance the pursuit of developing pedagogical expertise, Braun and colleagues (2017) promote gradual, consistent, and team-based efforts with feedback and support aiming to increase the application of research-based mathematics education. The results of this doctoral dissertation support these pursuits by pointing towards the central elements of the learning environments and their interdependency. Furthermore, the results of this doctoral dissertation demonstrate that there is not one single superior way of teaching university mathematics. As Braun and colleagues (2017) describe it, "[a]s with all complex real-world problems, [...] there is not an exact solution but rather a collection of approximate solutions". Therefore, in the future mathematics department applying research-based teaching in all its teaching, the courses are not copies of each other; instead, they create a spectrum of student-centred learning environments (cf. Uiboleht et al., 2019; Vermunt, 2003). Furthermore, as students advance in their studies, the courses and their learning environments develop along with the students' increased knowledge and skills and gradually require more self-regulated and independent, active learning (Vermunt, 2003). This indicates that pedagogical expertise is needed not only on the course level but also when designing the mathematics degree programmes. Overall, this research-based development of university mathematics education is supported by the work of university mathematics education researchers. However, it is a two-way street; the mathematics educators' work to develop mathematics education not only enhances the quality of students' learning but serves as a context for future research on university mathematics teaching and learning and supports the posing of even more relevant research questions, which in turn increase the quality of our approximations of best teaching practices. This indicates that the research-based development of university mathematics education is a challenge for all of us in the mathematics community, the mathematics educators, developers of mathematics education, and researchers of mathematics and mathematics education. But as we in the mathematics community know, challenges are not to be avoided but to be solved.

10 CONCLUSIONS

Historically, higher education has not been designed to include but to exclude (Dolmage, 2017). This means that ideas such as *higher education is for all* and *everyone can learn mathematics* are relatively novel. These ideas have challenged the mathematics community and its role as a gatekeeper (cf. Math wars; Schoenfeld, 2004) – it cannot be that a person just walks in and becomes a mathematician just like that! This is (partly) understandable, as it highlights a profound challenge of university mathematics education; due to the cumulative nature of mathematics, the research frontier is far away from what is taught in undergraduate mathematics courses – and a potential future research mathematician has only five years to catch up. This elicits the question of what should be considered good teaching in university mathematics context; often, this is seen as an argument between teaching that is pedagogically good and teaching that covers lots of content. Furthermore, this cumulative nature of mathematics sometimes conflicts with educational research findings; for example, no quantity of promoting the integration of recent research findings into teaching will help, because it is simply not possible to do so in undergraduate-level mathematics courses.

However, the nature of mathematics should not be used as an excuse to exclude. This is also the state of mind of the US professional societies of the mathematical sciences; the goal is to offer "an excellent post-secondary mathematics education to every student" (CBMS, 2016) and "enable any student [...] to develop [...] mathematical knowledge and skills" (Saxe & Braddy, 2015). But how could this goal be achieved? The answer promoted by this doctoral dissertation is discipline-based higher education research and development. In higher education, promoting mastery for students requires knowledge of the discipline and its practices, but also of teaching and learning of that discipline; for this reason, it is important that teaching is not separated from the disciplinary content being taught (Healey, 2000; Singer et al., 2012, 9). This discipline-based doctoral dissertation demonstrates how knowledge of mathematics, learning of mathematics, and higher education can be combined to promote the quality of learning in the university mathematics context. Furthermore, as the elements in learning environments are highly interconnected, this doctoral dissertation argues for a holistic approach to design university mathematics learning environments; with structural changes that disrupt the typical lecture-tasks-small groups setting, it is possible to advance both the fields of university mathematics education and higher education towards the second generation of student-centred learning environments (cf. Freeman et al., 2014). The point of the results provided by this doctoral dissertation is not to offer a prescription of "the single best way of teaching" but to promote joint efforts for effective integration of mathematics and research-based pedagogical practices (cf. Saxe & Braddy, 2015). Let us use this collaborative endeavour to set all our students off on the journey of learning mathematics to their full potential.

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