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Student-centred learning environments supporting undergraduate mathematics students to apply regulated learning: A mixed-methods approach

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ABSTRACT

The importance of students' regulation of learning in university mathematics is widely acknowledged, but research approaching regulation of learning from the perspective of learning environments is scarce. The aim of the present study is to deepen our understanding of how mathematics learning environments can promote regulated learning by investigating the same students in two parallel but pedagogically different student-centred learning environments. The quantitative measurement of students' course-level self-regulation of learning (N = 91) is accompanied with a qualitative analysis of student interviews (N = 16). The results indicate that the learning environments are distinguished by the factor measuring lack of regulation, and that unregulated learning is created by out-of-reach teaching and -tasks causing challenges in goal setting and motivation. In contrast, co-regulation of learning in the form of scaffolding and a positive social environment has a central role in supporting regulated learning. Practical implications for how to support students' regulated learning are discussed.

1. Introduction

In recent years, one of the focuses of higher education research has been on students' regulation of learning (SRL). Self-regulation is related to learning outcomes; for example, Sitzmann and Ely (2011) conclude in their meta-analysis that students who engage in self-regulated learning learn more. Regulation of learning is central also in the disciplinary context of mathematics, as it is essential in problem solving and building up mathematical competence (de Corte, Mason, Depaepe, & Verschaffel, 2011; de Corte, Verschaffel, & Op't Eynde, 2000) and a prerequisite for proof-based mathematics (Talbert, 2015). The socio-cognitive models of regulated learning see the individual, social, and contextual factors as being interdependent, and often conceptualising the social and physical environments as mediators for developing regulatory skills (Pintrich, 2004; Zimmerman, 2000). Given the central role of the context, it is surprising that within the research on higher education SRL interventions (de Bruijn-Smolders, Timmers, Gawke, Schoonman, & Born, 2016; Jansen, van Leeuwen, Janssen, Jak, & Kester, 2019), research focusing on the relationship between regulation of learning and

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Table 1
Summary of the instructional practices of courses A and XA (slightly modified from Lahdenperä, Postareff, & Rämö, 2019).

	Course A	Course XA
Stage	1st year	1st year
No. of students enroled	approx. 200	approx. 200
Content	Analysis course emphasising exact definitions and proof construction	Linear algebra course emphasising skills such as reading mathematical text, oral and written communication, and proof construction
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 h a week; lectures focus on how to approach the main content of the course	3 h a week; lectures come after students have solved problems; the lectures are based on students' discussions and focus on a holistic understanding of 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 every week 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 with a tutor; Presemo (anonymous online chat platform)	Open learning space on a drop-in basis with tutors; Presemo (anonymous online chat platform)
Tutors	Older mathematics students	Older mathematics students who attend weekly pedagogical meetings with the lecturer
Grading	Final grade based on a written 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* $f(x)\le f(a)$ *holds for all* $x\in\mathbb{R}$. *NB: It is not useful to consider the derivative here!*	Final grade based on a written 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* $(\overline{v}_1,\ldots,\overline{v}_n)$. *Assume that* $L:V\to W$ *is a linear mapping. Show that if* $(L(\overline{v}_1),\ldots,L(\overline{v}_n))$ *is a basis, then* L *is an isomorphism.*

learning environments is scarce (de Bruijn-Smolders et al., 2016). In the disciplinary context, Talbert (2015) touches upon self-regulation of learning in their description of the mathematics 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). To address this research gap, the present study takes a socio-cognitive approach and shifts the attention from an individual learner to the learning environment. This is realised by investigating the same undergraduate mathematics students in two parallel student-centred learning environments; as the students remain the same, it is possible to address the role of the learning environments on students' regulated learning.

The present study conceptualises 'learning environment' similar to Fraser (1998) in the first editor's introduction of the *Learning Environments Research* journal; a learning environment refers to "the social, psychological and pedagogical contexts in which learning occurs and which affect student achievement and attitudes" (Fraser, 1998). University students have many years of experience of learning in formal educational settings and might no longer need support in developing regulation processes; instead, they need opportunities and support to develop factors influencing these skills and applying them in learning situations (Jansen et al., 2019; Vrieling, Stijnen, & Bastiaens, 2017; Wigfield, Klauda, & Cambria, 2011, 34). Therefore, regulatory skills should not necessarily be 'taught' at university, but students need to be provided with opportunities to apply regulated learning. However, mathematics students, at least in primary and secondary education, are often denied these opportunities as external regulation – teacher regulating students' learning – prevails over students' self-regulation (de Corte et al., 2011). Furthermore, the challenge of the secondary-tertiary transition in mathematics is widely conceptualised in the literature (see e.g., Clark & Lovric, 2009; Gueudet, 2008; Hoyles, Newman, & Noss, 2001); students' failure to apply regulated learning can result in dropping-out in transition-to-proof and proof-based courses (see also Talbert, 2015). This further emphasises the need to understand contextual factors related to regulated learning in the context of university mathematics. De Corte et al. (2011) state that although challenging, it is possible to support mathematics students to develop regulation skills through instructional practices. For example, student-centred learning environments can promote the kind of activity and independence (see Baeten, Kyndt, Struyven, & Dochy, 2010) that offer students the opportunities to apply regulated learning. However, the literature does not reflect the nuanced ways that student-centred learning environments contribute to students' regulated learning (see Stefanou, Stolk, Prince, Chen, & Lord, 2013).

The opportunities for regulated learning are investigated in this paper through *challenge episodes*. Challenge episodes refer to the instances when students have difficulties in reaching their learning goals, and they provide students with an opportunity to apply and develop regulation skills (Hadwin, Järvelä, & Miller, 2011). In the disciplinary context of mathematics, it is common practice to study by solving weekly mathematical tasks; solving these tasks is central to students' learning experiences (Lahdenperä, Rämö, & Postareff, 2021) but challenging, making challenge episodes a common experience among mathematics students. Furthermore, these challenge episodes are the instances when learning should be regulated. Acknowledging that different student-centred learning environments might support different dimensions of regulation (Stefanou et al., 2013), the present study investigates the same students in two parallel student-centred learning environments and with a mixed-methods approach. In it we hope to understand what factors support and hinder undergraduate mathematics students to resolve their challenge episodes and provide practical implications on how student-centred mathematics learning environments can promote regulated learning at university.

2. Theoretical background

In regulation literature, the typical socio-cognitive perspective usually conceptualises regulated learning through the notion of the self-regulation of learning. Self-regulation of learning refers to students planning, monitoring and reflecting on the different but interconnected areas of regulation, namely cognition, behaviour, motivation, and emotions, to reach learning goals (Pintrich, 2004; Zimmerman, 2000). 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, for example, in time and effort management, persistence, self-handicapping, or help-seeking. Compared to the other SRL models, the socio-cognitive perspective emphasises the motivational aspect of regulated learning (cf. Panadero, 2017; Pintrich, 2000). 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, a student who self-regulates can set goals for their learning, monitor and reflect the progress, and if needed, adjust the learning process in a dynamic manner (Pintrich, 2000, 2004; Zimmerman, 2000). This socio-cognitive perspective acknowledges that self-regulation is a goal-oriented, active, and constructive process that is guided by the learning context (Pintrich, 2004). The role of the context can be elaborated further as a learning environment that supports students' participation in these active and constructive processes is promoting self-regulated learning. The context-dependency of self-regulated learning is further emphasised by the cyclical nature of regulation processes as contextual motivational beliefs related to learning experiences are used to adjust future learning processes (Pintrich, 2004; Zimmerman, 2000). From the socio-cognitive perspective, these motivational beliefs can be viewed as a part of regulated learning or as a predisposition for regulated learning (see Pintrich & Zusho, 2007); either way, the role of the context in regulated learning is substantial (Panadero, 2017; Pintrich, 2000).

The socio-cognitive perspective sees self-regulation of learning as both an individual and a social practice (Hadwin et al., 2011; Pintrich, 2004; Volet, Vauras, & Salonen, 2009; Zimmerman, 2002). Often, the social dimension of regulated learning is further elaborated by the notion of co-regulation of learning, a dynamic process of co-constructing knowledge relying on *intersubjectivity* and *scaffolding* (Hadwin et al., 2011; Järvelä & Järvenoja, 2011; Volet, Vauras, et al., 2009). Intersubjectivity refers to the psychological relation between individuals and has been 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 disappearing support helping students to accomplish tasks that would otherwise be beyond their reach, often described as the 'constructive friction' between teacher-regulation and student-regulation, or the 'SRL balance' (Vermunt & Verloop, 1999; Vrieling et al., 2017). Both intersubjectivity and scaffolding can be viewed as social characteristics of the learning environment. Winne (2005) argues that although scaffolding is not necessary for regulated learning, it serves as a guided practice to support students to regulate more efficiently. To conclude, the socio-cognitive perspective sees co-regulated learning as something to support the development of self-regulation skills and views it as a transitional process of acquiring self-regulation skills (Hadwin et al., 2011). Because co-regulation of learning can be conceptualised through social characteristics of the learning environment, the learning environment can be advanced as a key element in developing self-regulation skills.

The theoretical assumptions behind self-regulated learning indicate that all individuals have the potential to develop regulatory skills; however, the quality and quantity of these skills, and the motivational and emotional factors orchestrating the application of these skills vary between individuals and learning contexts (Pintrich, 2004; Zimmerman, 2000). This implies that a learner is not always able to regulate their learning optimally (Pintrich, 2000; Winne, 2005). In these occasions, the regulation can be taken over for example by the teacher – this is referred to as external regulation (Vermunt & Verloop, 1999; Vermunt, 2005). Learning can also remain unregulated. For example, Vermunt (2005) uses the notion of lack of regulation to refer to these instances in which student has difficulties in regulating their learning in one or multiple phases and/or areas of regulation. Unregulated learning has severe consequences as it has been identified as a part of the undirected learning pattern indicating challenges in developing study habits up to the level required in tertiary education (in the context of higher education, see Vermunt, 2005; in the context of university mathematics, see Talbert, 2015), and having a negative relationship to academic performance (Vanthournout, Gijbels, & Coertjens, 2012; Vermunt, 2005), dropping out (Vanthournout et al., 2012), and study-related exhaustion (Räisänen, Postareff, Mattson, & Lindblom-Ylänne, 2020). The socio-cognitive literature often refers to this non-optimal regulation as regulatory dysfunctions (Zimmerman, 2000). However, instead of seeing unregulated learning as an individual learner's cognitive functional failure, it can also be viewed as an outcome of the learning environment failing to offer the learner the opportunity to apply self-regulated learning (see Lindblom-Ylänne & Lonka, 1998). Indeed, Pintrich (2000) points in the same direction stating that some learning environment characteristics can support or hinder students' use of regulated learning. In essence, by looking up from the cognitive processes of an individual learner and highlighting the contextual factors, it is possible to shed light to the reasons behind students' (un)regulated learning.

From the limited number of studies investigating the connections between learning environments and regulation of learning (cf. de Bruijn-Smolders et al., 2016), it can be concluded that to stimulate students to apply and develop their regulation skills, the learning environment should provide enough challenge episodes (Hadwin et al., 2011). This is supported by the notion of constructive friction referring to situations in which students are challenged to increase their degree of self-regulated learning (Vermunt & Verloop, 1999). Furthermore, Zimmerman (2000) notes that one of the origins of unregulated learning is the lack of social experiences. Therefore, the learning environment should encourage social interaction and promote co-regulation of learning which, in turn, supports the development of self-regulation skills (Hadwin et al., 2011; Volet, Vauras, et al., 2009; Vrieling et al., 2017; Winne, 2005). The connections between regulation of learning, challenge episodes, and social interaction emphasises that the different dimensions of self-regulation are highly interrelated (cf. Sitzmann & Ely, 2011). In this vein, the relationship between student-centred learning environments and regulation of learning can be assumed to be complex (cf. Stefanou et al., 2013).

3. Aims and research questions

The present study addresses de Bruijn-Smolders et al. (2016) call for research that investigates the relationship between regulation of learning and learning environments. With a mixed-methods approach, the study broadens the common socio-cognitive approach by shifting the attention from an individual learner towards the learning environment. As students both need and are expected to develop regulation skills during their university studies (Coertjens, Brahm, & Trautwein, 2017; Coertjens, Donche, De Maeyer, Vanthournout, & Van Petegem, 2013; Jansen et al., 2019), and these skills are essential in becoming a mathematician (de Corte et al., 2000, 2011; Talbert, 2015), the present study offers essential knowledge on the practical orchestration of university mathematics learning environments. The first research question is:

1. How do the learning environments show in students' self-regulation of learning?

   This research question is addressed with a quantitative measurement of students' self-regulation of learning in the two student-centred learning environments. The second research question is:
2. How do the two learning environments support and hinder students in applying regulated learning?

To answer the second research question, the quantitative results are used to guide the qualitative analysis of student interviews

Table 2
The students' background information on both quantitative and qualitative data collection points.

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

aiming to investigate students' experiences on how the learning environments create challenge episodes, how the challenge episodes are resolved, and why they sometimes remain unsolved.

4. Methods

4.1. Context

The research was conducted in a mathematics department in a research-intensive university in Finland. In Finland, the five-years of university study consist of a three-year bachelor's degree and a two-year master's degree. Based on the Universities Act (2009), the teachers have academic freedom to decide on their teaching and assessment methods.

This study investigated the same students in two mathematics courses, namely Course A and Course XA. 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. The interest in these two courses arose from their well-established different student-centred pedagogical practices and from the large number of students taking the courses at the same time. The instructional practices of the courses are summarised in Table 1. The main practical differences between the courses centred on the design of the tasks (gradually increasing difficulty in XA), the form of support given to the students by the tutors (in scheduled small group sessions in A vs. in an open learning space in XA), and on the role of lectures (lectures first in A vs. tasks first in XA). The instructional models are not new; at the time of data collection, both had been implemented more than five years previously.

4.2. Participants

The participants are students who attended both the courses. The students' background information is given in Table 2. The major subject is reported in three ways: '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.

4.3. Data collection and analysis

The present study follows a qualitative-dominant mixed-methods research design (Johnson, Onwuegbuzie, & Turner, 2007) with a sequential approach (Teddlie & Tashakkori, 2009). This indicates that the quantitative part of the present study is conducted first. The quantitative results are used to inform the choice of the analysis unit in the following qualitative part. The rationale is that the quantitative results offer an overall picture, but as they cannot reveal the types of situations students experience challenges in regulating their learning, the more detailed qualitative results are used to supplement the quantitative results. Both the quantitative and qualitative parts are considered important in answering the research questions (Johnson et al., 2007). 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.

In the quantitative data collection point, students voluntarily answered an electronic questionnaire at the end of the courses in Autumn 2016. In the questionnaire, students were asked to evaluate how well each statement describes their own studying in the course. The data was collected on a five-point Likert scale (1 =completely disagree, 5 =completely agree). The questionnaire consisted

Table 3
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 worked on the tasks, [.] it gradually started to unfold.*
Self-regulation of content	Consulting literature and sources outside the syllabus (Vermunt, 2005).	*The text book 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, & Thurman, 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 draw 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.*

Table 4
Students' means, standard deviations, mean differences and effect sizes on the factors measuring self-regulation of learning in the two learning environments, as determined by two-tailed paired samples t-test (* for $p < 0.05$, and *** for $p < 0.001$ significance levels) and Cohen's d.

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

of a 15-item scale measuring self-regulation of learning. The items originate from the Inventory of Learning Styles (ILS; Vermunt, 1994, 2005) and have been modified to the Finnish higher education context (Heikkilä & Lonka, 2006; Räisänen et al., 2020). Self-regulation of learning is operationalised via two factors: self-regulation of process (four items) and self-regulation of content (three items). In addition, the scale includes factors measuring external regulation (four items) and lack of regulation (four items). Self-regulation of process refers to a student's ability to regulate their learning processes; self-regulation of content measures the extent of a student's seeking for literature beyond the course material; external regulation indicates the extent the teacher regulates the student's learning, and lack of regulation refers to possible problems in regulating the learning process (Vermunt, 2005).

Due to the small sample size, the factor structure of the self-regulation scale was analysed with an exploratory factor analysis using principal axis factoring and direct oblimin rotation. The four factors identified in previous research (Heikkilä & Lonka, 2006; Räisänen et al., 2020; Vermunt, 1994, 2005) emerged. The factors were computed as the mean of all items in the factor. The factors' internal consistency (Cronbach's Alphas; 0.658 for self-regulation of process, .657 for self-regulation of content, .710 for external regulation, and .642 for lack of regulation) can be considered to be acceptable (Taber, 2018). As the study follows a repeated measures design, a two-tailed paired samples t-test was used to investigate the mean differences between the courses. Furthermore, Cohen's effect size d is reported (0.2,.5,.8) for small, moderate, and large effect size respectively (Cohen, 1992).

All students who participated in the quantitative data collection point were invited to an interview, and the qualitative data consist of interviews of 16 students who attended both the courses and gave an active consent to participate in the research. The interviews were conducted by the first author who was not part of the courses' teaching teams. In the semi-structured interviews averaged 1 h 13 min (Min. 49 min, Max. 1 h 51 min), the students reflected on their studying and learning in both courses. The data were analysed through a theory-driven qualitative content analysis (Miles & Huberman, 1994). The results of the quantitative analysis guided the choice of unit of analysis; it was defined as 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 a 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 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 quantitative difference between the learning environments. The students were not asked directly about their challenge episodes, but these emerged while the students were answering questions such as how they studied, what aims they had, and what supported and hindered their learning in the courses.

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. Four of the categories derived from the factors of the quantitative instrument used; the factors were 1) self-regulation of process, 2) self-regulation of content, 3) external regulation, and 4) lack of regulation. As social interaction has been identified as an important way the learning environments can support students to apply and develop their regulation skills (Hadwin et al., 2011; Volet, Vauras, et al., 2009; Vrieling et al., 2017; Winne, 2005), the coding scheme was extended with two categories used by Räisänen, Postareff, and Lindblom-Ylänne (2016) to also cover co-regulation of learning; these categories were 5) low-level co-regulation, and 6) high-level co-regulation. The categories are described in Table 3. The coding started with the first author coding three interviews. Then, the second author coded the same interviews, after which the results were compared and discussed. Based on the discussions, the first author's initial coding was changed in four out of 92 cases. Because the degree of agreement was strong, the first author then coded the rest of the data.

Table 5
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%)

5. Results

The results are reported in two sections. The first section addresses the first research question with quantitative analyses (N = 91) and reports students' self-regulation in the two student-centred learning environments. The second section addresses the second research question with qualitative analyses (N = 16) and reports on how the learning environments provided students with opportunities to apply regulated learning.

5.1. Students' self-regulation of learning in the two learning environments

The results from the quantitative analyses are presented in Table 4. There are statistically significant differences between the learning environments in self-regulation of process and lack of regulation; an average student applies more self-regulation of process (MD=0.15 *) and more seldomly lacks regulation of learning (MD=−48***) in the Course XA learning environment. The effect size for the self-regulation of process factor is below the.2 boundary (Cohen's d=0.17) suggesting an insignificant role of the learning environment. However, the effect size for the lack of regulation factor (Cohen's d=0.63) implies a moderate impact of the learning environment. In essence, the learning environment showed to a significant degree only in the lack of regulation factor.

To sum up, the quantitative results indicate that the context shows in students' self-regulation of learning mostly through the lack of regulation factor. This indicates that to understand contextual differences in regulated learning, investigating lack of regulation is fruitful. Therefore, the following qualitative part analyses students' challenge episodes and the consequent (non)action taken to overcome them. The aim is to understand how and why students can sometimes but not always resolve their challenge episodes.

5.2. The learning environments providing possibilities for regulated learning

5.2.1. The numeric results from the qualitative analysis

The numeric results of the qualitative coding process are presented in Table 5. Self-regulation of process, lack of regulation, and low-level co-regulation categories covered approximately 90 per cent of the analysis units in both learning environments. The biggest proportional differences in the number of analysis units between the learning environments could be found not only in the lack of regulation category, as suggested by the quantitative results, but also in the low-level co-regulation category. This indicates that lack of regulation in the Course A learning environment could be partly replaced by low-level co-regulation in the Course XA learning environment.

Next, the three main qualitative categories, self-regulation of process, lack of regulation, and low-level co-regulation are described more in detail. From the quantitative results, it cannot be concluded in which types of situations the students experience challenges in regulating their learning. Therefore, the challenge episodes in the qualitative categories are also linked to the elements of the learning environment in which they occur. Students mentioned four central learning environment characteristics for their (un)regulated learning: the weekly tasks, teaching, peer support, and scaffolding. All of these were connected to both self-regulation of process and lack of regulation; in addition, students connected scaffolding and peer support to low-level co-regulation of learning.

5.2.2. Self-regulation of process

In the students' accounts for challenge episodes that were resolved using self-regulation of process, the students reported on regulating all areas of regulation, namely cognition, behaviour, and motivation and emotions. Unsurprising in the context of mathematics, the weekly tasks had a significant role in both learning environments. The tasks provided plenty of challenge episodes that students solved by regulating their cognitive processes; they reported that through the tasks, they identified learning outcomes and monitored their progress and understanding. This is demonstrated by the three following student quotes:

> 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)

> I like it when you realise […] that you really have learned something new, like you notice that I […] was able to complete these more challenging tasks. (Course A)

> I like to challenge myself with [the more challenging tasks] and I like when I succeed and learn and know. (Course XA)

Furthermore, the students reported on *learning from the mistakes* they initially made while solving the tasks. The monitoring of progress through the weekly tasks offered the students further opportunities to regulate their cognitive processes. When the tasks were difficult and not knowing how to proceed, the students reported on reflecting the overall aims of the course and setting goals for their own learning. For example, a student stated:

> It is just not possible to remember every single theorem by heart. So, I wanted the main points, that I understand the overall picture, like how everything is connected to each other. That was what I wanted to learn. (Course XA)

Besides identifying learning outcomes, monitoring progress, and reflecting on own goals, the tasks supported students in regulating their behavioural processes, such as planning, and time and effort management. These were essential ways of overcoming the challenge episodes. When realising that the tasks were challenging, students largely reported on *making schedules*. For example, a student stated:

> Every week I checked the days when I have time to work on the tasks, because it took a lot of time as they were plenty. (Course XA)

Another largely reported way of overcoming the challenge episodes was *just spending more time* to resolve them. This is demonstrated by the following student quote:

> 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 worked on the tasks, [.] it gradually started to unfold. (Course XA)

The interconnections between the areas of regulation were revealed in students accounts for regulating their cognitive and behavioural processes in tandem. Here, the tasks, teaching, scaffolding and student collaboration were central. The students reported on monitoring their progress in the tasks and adjusting their participation in teaching accordingly. For example, a student stated:

> The tasks become a little more challenging and somehow more applied, [...] so you had to [...] go to ask from the tutors and sit in the lectures. (Course XA)

To continue, in terms of scaffolding, a student explained that the tutors had directed them towards the course material so many times that they eventually did it by themselves before asking for help. As a further demonstration of the interconnections between regulating cognitive and behavioural processes, the tasks accompanied with student collaboration provided a regulation opportunity for students who thought they needed to learn even better; to improve their own learning, they planned their studying so that they could teach the other students and, in that way, broaden their own perspective and understanding.

Besides cognition and behaviour, the students reported regulating their motivational and emotional processes. For example, a student reported on regulating their goal orientations and affective reactions in the exam:

> In exam situations I'm under a lot of pressure and I make so stupid mistakes. So, I don't use my energy to or focus on grades as long as I know myself that I have understood the topics. It's much more important to me, like it was the goal that I would understand. (Course XA)

The instances of regulating motivational and emotional processes also revealed interconnections between the different areas of regulation. Typically, they were reported in tandem with regulating behavioural processes. For example, a student changed from one small group to another because the tutor *made you feel stupid*. Another student reported on an influence of a statement the lecturer had made:

> When I looked at [the exam] I felt that no, just the kind of questions that I don't know. [...] But then I somehow thought that well, I give this some time, [...] like don't hurry, take your time, and I sat in [the exam hall] until the very end and thought about the problems, because I remembered what [the lecturer] had said, that also the exam is a learning situation. (Course A)

Besides these single incidents, some students reported on regulating their emotional and behavioural processes in tandem during the entire course. This is demonstrated by the following student quote:

> I was explaining the formulas in my own words, the ones that at first sight looked a bit scary, [...] like what each symbol is and what they mean in Finnish [refers to plain English]. (Course A)

To continue, the tasks supported students in regulating their behavioural, motivational, and emotional processes as investing time and effort into solving them required *this certain type of courage*. Also, it was possible to gain bonus points for the exam by completing the tasks, so the students reported on relieving the *exam panic* during the courses by completing them; when having those bonus points, *you don't need to be distressed about passing the exam*.

5.2.3. Lack of regulation

Similar to the regulation of process category, the students reported on lack of regulation in all areas of regulation, namely cognition, behaviour, and motivation and emotions. In terms of insufficient regulation of cognition, the students reported on various instances in which their challenge episodes remained unresolved. Some students had general challenges in regulating their cognition as they reported that *it has been difficult to set goals because you feel that you just barely hang in there*. In terms of the learning environment elements, the tasks were again central; students reported on challenges in getting started with the tasks and completing them. These are demonstrated by the following student quotes:

> 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)

> I found some tasks very difficult, and it felt that I have no tools with which to start doing them. (Course A)

> Very often the challenge with the tasks is the start, like where do a start from. I just somehow didn't know. (Course A)

Furthermore, student reported on having challenges in making judgements whether their current answer was of sufficient quality. For example, a student stated:

> Often, you didn't know whether you had solved a task correctly, because there are multiple ways of solving them. And like what is then a sufficient proof, it remained unclear to me. (Course A)

Besides the tasks, the teaching could create challenges in regulating cognition. For example, the students reported that they were not able to follow the teaching or connect the new material with their prior knowledge, and were even more confused after the lectures, and therefore they lacked a holistic understanding. This is demonstrated by the following:

> 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 the lectures I had challenges to recognise the things I had to learn, things like this is related to this and that. So, I had a lot of challenges in connecting how they all were related to each other or so, like I don't know, it was a bit difficult. (Course A)

Also, insufficient level of regulation of behaviour resulted in many unresolved challenge episodes. This was shown in students' reports on challenges in time and effort management in relation to the tasks. For example, students stated:

> There was a lot of work [.] and I think that [this course] was not always the first one I worked on, so when you were here [in the open learning space] you worked on the tasks but if you didn't finish them, you didn't get back to them so easily at home. (Course XA)

> [The tasks were challenging because] we didn't have enough […] examples of similar type, or well, okay, maybe I just didn't read the course material. (Course A)

> Because the tasks were so difficult […], I postponed the starting, like you might have given them a look but because the tasks didn't start to unfold, you postponed and postponed it. (Course A)

In addition, students reported having challenges in adjusting their behaviour, even if they had recognised it as unproductive; for example, some students did not attend lectures, seek help from the tutors, or work with other students, although they knew that doing so would have addressed their unanswered questions. Also, students reported on monitoring their behaviour but not being able to change it accordingly:

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

> I could have get [help] to many of my problems if I had turned to the tutors more often. Like if someone could have explained and demonstrated to me what it was all about. […] But because I didn't utilise the tutors, I missed an element that ties the theory and practice together. (Course XA)

> We didn't really get help but maybe we didn't know how to ask for it. But somehow it felt that there was no guidance for the take-home tasks, except in the small group sessions. (Course A)

> People get stuck with this kind of misconceptions that [working on the tasks alone] definitively works a lot better, but then it doesn't. (Course A)

The challenges in regulating cognition created by the tasks and the teaching being out of reach caused a variety of challenges for the students to regulate their behaviour in an optimal way. Some students reported that it created an inability to take part in the discussions during the lectures or formulate questions even when they recognised that they had not understood. For example, students stated:

> Although we had discussions […] [in the lectures], if the topic was so difficult that you had fallen off the track already […], it was very challenging to even start to discuss. (Course A)

> In the lectures, I had many questions that I, after all, usually didn't ask, which annoys me a little. (Course A)

Lack of regulating motivation and emotions resulted in many unresolved challenge episodes. Here, the tasks and the social elements of the learning environments, namely scaffolding and peer support, were central. For example, when prompted with tasks perceived as being too difficult, the students reported that it was hard to stay motivated. Here, three student quotes are provided:

> Perhaps I already had that attitude about [the tasks], if it was more difficult, I didn't care to work for it. (Course A)

> The tasks were so difficult that I sometimes felt that I don't even want to begin to try these, because I know they will go wrong. Somehow it was really frustrating that you try but still know that it won't work out. (Course A)

> It was really frustrating, because the tasks were so challenging. Like […] 75 min [in the small group session] and sometimes you had proceeded only to the second task, like even the first task caused challenges despite working in a group. I was left with a feeling of frustration. (Course A)

To continue, the social encounters were not always positive, resulting in unregulated learning. Students reported largely on impostor syndrome – being afraid that they will be caught out as being *stupid*. This left them with feelings such as *anxiety*, *helplessness*, and *frustration.* These feelings constrained students from applying regulated learning as they reported that it prevented them from asking questions, seeking help, and participating in mathematical discussions within the learning environment:

> 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 don't, how can I talk to these people and ask for help with the tasks. (Course A)

> It's this social pressure thing, that you don't necessarily always dare to say that you don't understand. (Course A and XA)

> Perhaps it's more difficult to communicate with somebody to whom everything is just super easy. Of course, this person can be good at explaining, but it can be scary or a bit embarrassing to ask a lot about a topic that the other finds easy. (Course A)

> I didn't make a lot of contact [with the lecturer], like I don't raise my hand that easily. […] It's the insecurity. Like what if this is wrong, so then you don't necessarily have the courage to do so. (Course A)

5.2.4. Low-level co-regulation of learning

Low-level co-regulation was shown in two ways, namely scaffolding and peer support. The low-level co-regulation category is unique compared to the regulation of process and lack of regulation categories presented above in that seeking help from the tutors or peers can be already seen as indicative of regulating behaviour. Scaffolding was provided by the older mathematics students working as tutors, and it was realised in the small group sessions (Course A) and in the open learning space (Course XA). In addition, scaffolding was provided through Presemo, the anonymous online chat platform (Course A and XA), as demonstrated by the following:

> You try to write in [the online chat platform] that I didn't get this, can someone help me, and usually there was someone who could help. (Course A)

In the students' accounts for scaffolding, the regulation of behaviour was linked to regulating cognitive, as well as emotional processes. For example, students 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)

> When I was working on the tasks in the open learning space, [the tutors] effortlessly came to ask 'do you need help' […]. So, even if you had just a minor thing, you could ask it because they were already there asking if I needed help. (Course XA)

> The tutor gave examples when we asked. And then they helped with the tasks so that they didn't reveal the answer or anything but […] guided so that 'look at this thing, could it have something to do with this'. So, I got these eureka moments myself, like oh, it's like this. It was quite fun. (Course XA)

Peer support was present in both course learning environments; it occurred in the small group sessions (Course A), in the open learning space (Course XA), and during lectures (Course A and XA). In both learning environments, peer support consisted of students asking for advice or sharing ideas, usually while working on tasks or during lectures. Again, the students' accounts for regulating behaviour through peer support were connected to regulation of both cognitive and emotional processes. These are demonstrated by the following student quotes:

> 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 don'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)

> If you hadn't done the tasks yet [.], in the lecture you were a bit like, how will this turn out, but then again things clarified when you discussed with others in there. (Course XA)

> I had a strategy that the easy tasks, the ones that felt straightforward, those I could complete at home in the morning. And then I came [to the open learning space] to work on the rest of them. […] There were friends at the same time working on [the tasks], so it was a lot nicer to work together than to be in agony and all alone. (Course XA)

> Surely, it's easier to say to another student that hey, I don't understand this, compared to saying during a lecture that I don't still get this. (Course A)

5.2.5. Synthesis of the quantitative and qualitative findings

To provide a general description of regulated learning in the university mathematics context, it is important to note that regulation of learning is always goal oriented. Our reading of the reported challenge episodes is that students had two types of goals. The first type includes goals student report on a more general manner, such as understanding the mathematical content present in teaching situations. With this type of goals, the data falls short in identifying a clear pattern in the regulation activities students engage with. However, students also report on more context-specific goals; the second type of goal, solving the tasks, was present throughout the data. In this case, the regulation activities started with commencing the solving process and continued by monitoring one's own progress and learning outcomes. If needed, the students adjusted their regulation activities by managing their time and effort accordingly and/or seeking help. If the students' own resources were not sufficient to adjust their regulation activities to achieve the learning goal, they sought for resources provided by the other elements of the learning environment, namely teaching, scaffolding, and peer support. As the regulation processes are interconnected and cyclical in nature, the monitoring and adjusting phases were altered until the task was solved.

However, as seen in the data, the students were not always successful in regulating their learning; lack of regulation was in all stages of the solving process. The students reported on failing to regulate their motivation and emotions and therefore not being able to even start solving the tasks. The students also reported difficulties in monitoring their progress and learning outcomes (not knowing when an answer is of sufficient quality) or adjusting their behaviour accordingly (not taking the extra time needed, giving up, or not seeking help). Furthermore, the students were not always successful, even when attempting to adjust their behaviour; the students reported on invested time but no results, and not receiving the needed help even though seeking support from the lectures, tutors, or peers.

In terms of regulating motivation and emotions, the students' challenge episodes show that motivational and emotional aspects are both part of the regulation processes and predispositions for regulated learning. As the tasks provided bonus points for the exam, students relieved *the exam panic* by solving them and in this vein, the goal of completing the tasks was in itself a way to regulate motivation and emotions. Students also regulated their motivation and emotions during the regulation activities as they reported on *explaining scary formulas in their own words*, changing their small group to find a tutor that does not make them *feel stupid*, having fun because of the *eureka moments* in scaffolding, or working with peer and *not in agony and all alone*. However, students also reported on unsuccessful attempts to regulate their motivation and emotions. Some students stated that they were not motivated to even start working on the tasks or being frustrated for knowing in advance that they were not able to solve the tasks. In addition, the students had challenges in regulating their motivation and emotions during the regulation activities, as they reported experiencing frustration and helplessness for not receiving the help needed in the small groups, and feelings of anxiety, insecurity, and embarrassment in social situations preventing them from participating in mathematical discussions in the lectures or asking for help from tutors or peers. The cyclical nature of regulated learning is central from the motivational and emotional perspective, as it posits that the negative experiences influence the predisposition when moving on to solve another task; for example, not even starting the solving process can be a result of the experienced frustration for not receiving help for previous tasks from the tutors.

If the above is the general description of regulated learning in university mathematics context, how did the two learning environments differ in supporting or hindering the students in applying regulated learning? Based on the quantitative investigation, the learning environments differed statistically significantly, in favour of the Course XA learning environment, in the factors measuring regulation of process and lack of regulation. In the qualitative investigation, these quantitative differences showed in multiple ways. The students compared the number of tasks in each learning environment and reported that in course A, as there were fewer tasks to choose from, they more easily got frustrated and lost motivation to complete them. The students also compared the difficulty of the tasks between the courses and reported that they perceived the Course A tasks more challenging. This experience can be (partly) explained by the three other elements of the learning environments, teaching, scaffolding, and peer support. Overall, it seems that these elements have the potential to address the instances that create unregulated learning; however, in light of the quantitative results, our reading of the students' qualitative accounts is that the Course A learning environment was less successful in doing so. More prominent to the Course A learning environment, the students reported that the teaching was out of their reach; this showed in challenges in participating in the discussions, formulating questions, and forming a holistic picture of a topic during lectures. Furthermore, the quantitative difference in the lack of regulation factor shows in the students' qualitative accounts for low-level co-regulation. More prominent to Course A, the students reported not getting enough help from the tutors, referring to the availability of scaffolding in the scheduled small groups compared to the continuous scaffolding offered in the open learning space in the Course XA learning environment. To continue, there were students who reported on negative social encounters in Course A and therefore not participating in discussions or asking for help, but not in Course XA, referring to availability of scaffolding and peer support, having more tasks to choose from, and being prepared for lectures because of the flipped learning approach. All the above indicates that the tasks have a central role in students' self-regulated learning and that the learning environment elements (tasks, teaching, scaffolding, peer support) are highly interconnected with the different dimensions of regulated learning. Overall, the synthesised results largely agree that of the different dimensions of regulated learning, lack of regulation is the most sensitive to contextual changes, and that positive changes can be promoted with learning environments that support co-regulation of learning, in this case, by providing access to scaffolding and peer support.

6. Discussion

The present study investigated undergraduate mathematics students' experiences on the relationship between regulation of learning and learning environments (see de Bruijn-Smolders et al., 2016). The aim was to broaden the common socio-cognitive approaches and shift the attention from an individual learner towards the learning environment. To address an unresearched territory (de Bruijn-Smolders et al., 2016; de Corte et al., 2011), the study investigated the same students in two parallel student-centred learning environments and focused on how student-centred learning environments can promote regulated learning. The study began with a quantitative measurement of students' self-regulation (Pintrich, 2004) and identified the lack of regulation factor as showing the most significant differences between the learning environments. The study continued with a qualitative analysis of student interviews combining both self- and co-regulation of learning (see Järvelä & Järvenoja, 2011; Volet, Vauras, et al., 2009). The qualitative analysis was guided by the quantitative result, as the focus was on students' challenge episodes and the consequent actions aiming to capture reasons behind students' (un)regulated learning. Overall, the results from the quantitative and the qualitative analysis largely agree that of the different dimensions of regulated learning, lack of regulation is the most sensitive to contextual changes. The qualitative results suggest that these changes can be promoted with learning environments that provide scaffolding and peer support.

6.1. RQ1: Lack of regulation as the source of differences between the learning environments

The first research question was addressed with a quantitative measurement of students' self-regulation of learning in the two student-centred learning environments. According to the results, the learning environment shows to a significant degree only in the lack of regulation factor. This suggests that the possibilities to support students to develop regulation skills through instructional practices (cf. de Corte et al., 2011) are largely related to students shifting from lack of regulation towards regulated learning. The central role of the lack of regulation factor is supported with the numerical results from the qualitative analysis. Furthermore, the qualitative part showed that both learning environments provided students with adequate opportunities to apply regulated learning in the form of challenge episodes (see Hadwin et al., 2011). However, in the Course A learning environment, almost half of the students' challenge episodes remained unregulated. It can be concluded that there are contextual differences between learning environments that show especially in students' accounts for lack of regulation. But what could explain these differences? Based on the numerical results from the qualitative analysis, it seems that in the Course XA learning environment lack of regulation is substituted with co-regulation of learning. This is supported by literature, as co-regulation of learning can be seen as a translational process of acquiring self-regulation skills (Hadwin et al., 2011). This implies that students not only need opportunities to apply regulated learning but also support in doing so (Jansen et al., 2019; Vrieling et al., 2017) – and that this support can be implemented through co-regulation of learning. Here, the results suggest that the Course XA learning environment provided the students with challenge episodes but, in the form of scaffolding and peer support, also with more means to resolve them.

6.2. RQ2: Elements of learning environments that support students in applying regulated learning

As the quantitative results emphasised the central role of the lack of regulation factor, the focus of the qualitative analysis was to understand what causes the differences in the lack of regulation dimension. The frequencies from the qualitative analysis already pointed towards co-regulation of learning, but as literature does not reflect on the different ways student-centred learning environments can support regulated learning (Stefanou et al., 2013), the investigation of the qualitative analysis categories aimed to both describe the categories empirically and shed light to the instances in which students experienced challenge episodes, how the challenge episodes were resolved, and why they sometimes remained unsolved.

The investigation of the qualitative categories reveal that students mentioned four central learning environment characteristics for their (un)regulated learning: the weekly tasks, teaching, peer support, and scaffolding. The general picture is that the tasks and teaching created challenge episodes, and peer support and scaffolding were utilised to resolve them. The results suggest that in the context of the present study, these characteristics form the structure for applying regulated learning. But how were the learning environments different in supporting students to apply regulated learning? More prominent in the Course A learning environment, students reported teaching and tasks being out of their reach. In contrast, students did not report these to a similar extent in Course XA learning environment. It might be because in Course XA, the students started studying a topic independently but with scaffolding afforded; therefore, the students had already completed and submitted tasks before lectures, which could have increased their ability to participate. To continue, the lecturer and the tutors had already given feedback on the tasks, so the lecturer could have been more aware of the students' possible misunderstandings and adjust the level of the discussions accordingly. It seems that to prevent unregulated learning, the learning environment needs to offer students opportunities for independent learning but also support in doing so. If students perceived teaching and tasks as being out of their reach, it was a challenge to stay motivated, create a holistic understanding, and set goals for their learning – all things essential to regulated learning (Pintrich, 2004; Zimmerman, 2000).

Co-regulated learning formed an important way of resolving the challenge episodes. The co-regulation was realised through scaffolding received from the older students acting as tutors, and through a positive social environment for peer interaction. In terms of scaffolding, distinctive to Course A learning environments students reported that they did not know how to ask for help and did not receive enough help for learning. This did not happen in the Course XA learning environment and it seems that it was more successful in affording scaffolded learning. In the Course XA learning environment, scaffolding was offered in an open learning space on a drop-in basis. The open learning space was flexible for the students' needs; if students did not need support to engage in a regulated learning, they would not need to come and suffer from the negative consequences of expertise reversal (see Jansen et al., 2019). However, if a student needed support, it was provided without the constraints created by a scheduled small-group session in a classroom environment. To continue, it is worth pointing out that the Course XA tutors attended pedagogical meetings every week. The professional development might have increased the teaching assistants' ability to maintain and adjust what Vrieling et al. (2017) call the SRL-balance (see Vermunt & Verloop, 1999; Zimmerman, 2000). In general, the role of the tutors is interesting: they are the teachers in the teacher-learner-balance in scaffolded learning (see Vermunt & Verloop, 1999; Vrieling et al., 2017) but at the same time, they stretch beyond the teacher-learner interaction (see Volet, Summers, et al., 2009) and serve as capable others in co-regulated learning (see Hadwin et al., 2011). Overall, it should be noted that also in Course A, students were offered access to support – four hours of small group sessions per week and an online anonymous chat platform. In light of the results, it seems that access alone is not enough to support students' participation in regulated learning; instead, regulated learning was promoted by providing access to flexible scaffolding offered by trained tutors effectively serving the dual role of the teacher and the capable other.

Besides scaffolding, co-regulation of learning was afforded through a positive social environment for peer interaction. However, the social environment can have a negative effect (Zimmerman, 2000) and to some extent, this happened in Course A; the students reported being afraid that the others find out they are *stupid*. This provoked various negative emotions and caused students not to ask help or participate in the discussions while in lectures or working on the tasks. This is in line with Zimmerman (2000) identifying a lack of social opportunities as one of the origins of unregulated learning. However, both learning environments were student-centred, encouraging social interaction. The students did not report on these negative emotions in the Course XA learning environment. It might be the case that in the Course XA learning environment, where students were scaffolded, and perceived the teaching and tasks as being reachable (see de Bruijn-Smolders et al., 2016), the students also perceived the social environment more positively. In this light, it seems that students' social interactions cannot be separated from their other experiences of the learning environment. Perhaps being successful in terms of learning within the learning environment supports students to be successful in their social interactions – or vice versa – further promoting their participation in regulated learning.

To conclude, in addition to the opportunities for regulated learning, the learning environments should also provide the means to use these opportunities, highlighting the central role of social support structures such as scaffolding and co-regulation of learning in general. This was the case here for students at the beginning of their university mathematics study; therefore, in the light of Coertjens et al. (2013, 2017) and Jansen et al. (2019), students need reorganised learning environments (see Lindblom-Ylänne & Lonka, 1998) that support them to set off to their journey of regulated learning at university.

6.3. Implications for practice

As research on university mathematics learning environments and regulation of learning is scarce (de Bruijn-Smolders et al., 2016; de Corte et al., 2011), the present study provides valuable insights for mathematics instructors planning their teaching practices and orchestrating their learning environments. The results of the present study suggests that lack of regulation is the most context-sensitive dimension of regulated learning. Students need to be provided with challenge episodes to develop and apply their regulation skills (Hadwin et al., 2011); however, it can be that the secondary-tertiary transition in the mathematics context provides them in excess (cf. Clark & Lovric, 2009; Gueudet, 2008; Hoyles et al., 2001). This indicates that by explicitly addressing lack of regulation, mathematics instructors can support their students to apply and develop their regulation skills. The results also suggest that lack of regulation can be addressed by social elements of the learning environment, namely scaffolding and peer support. This is supported by Zimmerman (2000) suggesting that lack of social experiences can create unregulated learning. Besides the learning environments described in this study, the literature reports on other ways of implementing this type of support, such as the mathematics support centres (see e.g., Lawson, Grove, & Croft, 2020). To conclude, mathematics learning environments should offer students enough challenges for regulation skills to develop (cf. Hadwin et al., 2011; Lindblom-Ylänne & Lonka, 1998), but also support to address the challenges.

Self-regulation of learning is important for mathematics learning (de Corte et al., 2000, 2011; Talbert, 2015). When reflecting on the results of the present study, it is notable that the lecturers of the courses investigated in the present study have been rewarded for their excellent teaching by both students and the university. This indicates that the results are not due to a 'good teaching' versus 'bad teaching' dichotomy, suggesting that self-regulation of learning is an important aspect to be considered for all mathematics instructors. As self-regulation of learning has been described as a perquisite for proof-based mathematics (Talbert, 2015), the importance of promoting self-regulation of learning is further emphasised at university level.

As with all contextual research, the point is not for other mathematics instructors to copy either of the learning environments but to consider and reflect on the results of the present study when designing their own learning environments. In this vein, the findings of the present study can be considered transferrable to other university mathematics contexts, especially within contexts where undergraduate education is rooted on proof-based approaches. However, an appropriate level of caution should be taken when transferring the results to master's level courses. In the quantitative part, students reported relatively low scores on all factors measuring the regulation of learning. One explanation for this is that the students are mostly first-year university students; perhaps the new institutional environment created constraints for the students to participate in regulated learning (see Coertjens et al., 2017). Therefore, when designing master's level courses, mathematics instructors should consider how students' self-regulation skills develop during their university studies.

6.4. Limitations of study and future research

The study has certain limitations that need to be discussed here. First, the learning environments differed in mathematical content. This was a deliberate choice. It was not possible to obtain the same students and the same mathematics in two pedagogically different contexts. As mathematical content can be seen as a part of the learning environment, a decision was made to control for student variation and examine the differences and similarities caused by the variation in the context. Although controlling for student variation is one of the strengths of the present study, it comes with a deficit of not being able to articulate the role of the content separately from other contextual factors. However, as reported in a previous study (Lahdenperä et al., 2021), it was rare that a student connected the content to their learning and instead, discussed extensively on the other elements of the learning environment (e.g., lectures, tasks, and guidance). From this perspective, the main results contributing to regulated learning can be viewed as independent of the mathematical content. Still, the role of the mathematical content in regulated learning is worthy of further enquiry.

To continue, another limitation is that the study draws on self-selected samples and self-reported data. Also, the analysis focused on individual students and not on individuals as a collective entity. With this approach, it is challenging to grasp *the social* in regulated learning (Volet, Vauras, et al., 2009). This showed in that the number of analysis units in the high-level co-regulation category was limited. It seems that high-level co-regulation was promoted through peer support in the small group session classrooms (Course A) and the open learning space (Course XA), with white board tables organised in groups guiding students to sit together, draw on the tables, and explain and discuss the tasks at hand. Future research could dig deeper into *the social* and how learning environments support high-level co-regulation with more versatile research designs e.g., with observational data and student groups.

The elements of the learning environments identified in the present study, tasks, lectures, scaffolding, and peer support, supported students' regulated learning differently. However, students in both learning environments reported challenges in time and effort management, as well as in changing their behaviour recognised as unproductive. These challenges seem to be related to challenges in adjusting the learning process (see Pintrich, 2004), and future research could investigate how to support students to regulate these instances of unproductive behaviour. Furthermore, as there is still need for research investigating the relationships between learning environments and regulation of learning (cf. de Bruijn-Smolders et al., 2016; de Corte et al., 2011), the results of this study could point other researchers towards investigating each of these elements individually.

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CRediT authorship contribution statement

Juulia Lahdenperä: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Project administration, **Johanna Rämö:** Conceptualization, Validation, Formal analysis, Writing – review & editing, **Liisa Postareff:** Conceptualization, Writing – review & editing.

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Declaration of Conflicting Interest

The Authors declare that there is no conflict of interest.

Appendix 1. The questionnaire

Covering note.

The questionnaire used in this study is based on the Inventory of Learning Styles (ILS; Vermunt, 1994, see also Vermunt, 2005). It has been shortened and validated to the Finnish higher education context (Heikkilä & Lonka, 2006; Räisänen et al., 2020).

Self-regulation of learning.

Evaluate how well each statement describes your studying during the course.

1. When I was studying, I also pursued learning goals that had not been set by the teacher but by myself.
2. When I had difficulty grasping a particular piece of subject matter, I tried to analyse why it is difficult for me.
3. I studied the course according to instructions given in the course material or provided by the lecturer.
4. To test whether I had mastered the subject matter, I tried to think up other examples and problems besides the ones given in the study materials or by the teacher.
5. During the course I noticed that I have trouble processing a large amount of subject matter.
6. To test my learning progress, I tried to formulate the main points in my own words
7. In addition to the course requirements, I studied other literature related to the content of the course
8. I studied according to the instructions given in the study materials or provided by the teacher.
9. I noticed that it was difficult for me the determine whether I had mastered the content of the course sufficiently.
10. I studied the subject matter in the same sequence as it was dealt within the course.
11. If I did not understand the subject matter well, I tried to find other literature about the subject concerned.
12. I realised that the objectives of the course were too general for me.
13. I did more than I was expected to in the course.
14. I used the instructions and the course objectives given by the teacher to know exactly what to do.
15. I realised that I missed someone to fall back on in case of difficulties.

Factors.

Self-regulation of process: 1, 2, 4, 6.

Self-regulation of content: 7, 11, 13.

External regulation: 3, 8, 10, 14.

Lack of regulation: 5, 9, 12, 15.

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