THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

How Do Students Learn Together?

Social Regulation and Collaboration in Project-based Groupwork

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Abstract

Recent years have seen a shift in engineering education as universities seek to produce engineers capable of dealing with the complex challenges facing society. When facing these challenges, engineers will not only need to rely on technical knowledge and skills but will also be expected to collaborate with others from different fields and backgrounds. Engineers will also need to be aware of the impacts their solutions will have on society and in terms of sustainability. In response, an increasing number of universities are turning to programs based on project-based learning, where groups of students from different disciplines work on complex real-world problems.

Existing research tends to view such programs through the lens of learning outcomes and benefits rather than through the students' experiences and their process of learning. There is a lack of studies that address the social aspects of project-based learning, in particular how groups engage in the social regulation of learning over the length of a project in interdisciplinary groups. This thesis aims to address these gaps in the research by examining collaborative learning and the regulation of learning in student groups taking part in project-based interdisciplinary groupwork at Chalmers University of Technology.

Two papers are incorporated within this thesis. The first paper analyses reflective writings by students to examine the challenges groups faced when taking part in undergraduate research and the coping strategies they employed in response. This revealed the actions and processes the groups engaged in during collaborative learning. The second paper uses qualitative interviews with students to investigate how groups regulate their learning as a group in interdisciplinary, project-based courses. The findings identify the different kinds of social regulation of learning employed by the student groups during the different phases of the project and factors that affected their regulation. When looked at together, the papers show the impact that desirable challenges, uncertainty, autonomy, and group composition have on both collaborative learning and social regulation of learning.

The thesis concludes with a discussion of how groups' learning, and regulation of learning can benefit from scaffolding and the introduction of suitable coping strategies while maintaining the groups' autonomy.

Keywords: Social Regulation of Learning, Collaborative Learning, Project-based Learning, Socially Shared Regulation of Learning, Co-regulation of Learning, Self-regulation of Learning, Desirable Challenges

List of appended papers

The thesis is based on the following papers:

Paper 1 O'Connell, M. T., Adawi, T., Dobsicek Trefna, H., Ström, A., Stöhr, C. (2021). Challenge episodes and coping strategies in undergraduate engineering research. In *Proceedings of the 49th European Society for Engineering Education (SEFI) Conference 2021, Berlin, Germany*

TA, HDT and HS designed the study and collected the data. MoC, TA and CS contributed to the overall conceptualisation (RQs, aims, problem statement). MoC performed the data analysis and wrote the first draft. MoC, TA and CS reviewed and edited the draft to produce the final manuscript.

Paper 2 O'Connell, M. T., Wallin, P., Negretti, R., Stöhr, C. Social regulation of learning in interdisciplinary groupwork

Submitted to the European Journal of Engineering Education

MoC conceived and developed the idea of the paper with input from CS. MoC and CS contributed to the overall conceptualisation (RQs, aims, problem statement) of the study. The data collection was performed by MoC. Data analysis was performed by MoC with input from RN, CS, and PW. MoC wrote the original draft, all four contributors reviewed the draft. MoC, PW and CS then edited the final draft.

Other relevant contributions

O'Connell, M. T., Stöhr, C., Wallin, P. (2022). Using Challenge Episodes to Identify Social Regulation in Collaborative Groupwork. In *Proceedings of the 18th International CDIO Conference 2022, Reykjavik, Iceland.*

O'Connell, M. T., Wallin, P., Negretti, R., Stöhr, C. (2023). Tracking Social Regulation of Learning in Interdisciplinary Groupwork. In *Proceedings of the 9th International Research Symposium on Problem-Based Learning: Transforming Engineering Education Conference 2023, Boston, USA.*

Kjellberg, M., O'Connell, M., Bergman, B., Stöhr, C., Larsson, J. (pending review) Teachers' Reflections on their Experiences Teaching Interdisciplinary Project-Based Courses. *Submitted to the 51st European Society for Engineering Education (SEFI) Conference 2023, Dublin, Ireland.*

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Table of Contents

1 Introduction

Recent years have seen a change within engineering education as universities seek to produce engineers capable of dealing with the challenges facing society. The modern engineer is expected to be aware of issues such as sustainability and the societal impact of their work (Hadgraft & Kolmos, 2020). The problems they are expected to solve are complex and will require collaboration between individuals from a variety of disciplines and backgrounds. Working with people from different disciplines brings its own challenges as group members can have different content and procedural knowledge, different meaning for words, different ways of working when performing tasks, as well as different perspectives on issues. The need for engineering education to prepare students for this industrial landscape has not been limited to institutions of higher education. Both students and recent graduates have highlighted the need for better preparation for working in work environments (Kolmos et al., 2018; Wallin et al., 2017).

One solution is for universities to shift their focus from mode 1 knowledge production to mode 2. Mode 1 represents a "traditional" university STEM education where knowledge is built in one discipline and students solve problems within that specific context. Mode 2 has students from different disciplines working together on complex problems, often in a group that only exists until the problem is solved or the project ends (Gibbons et al., 1994). Several universities have begun to offer students the opportunity to partake in activities that will promote mode 2 knowledge production (e.g. Crawley, 2018; Enelund & Briggs, 2020; Hadgraft & Kolmos, 2020). These activities are typically in the form of project-based learning (PjBL) – where students work on a project they run themselves - or undergraduate research experiences (UREs) – where students work on authentic research. Students taking part in these activities typically work in interdisciplinary groups – where knowledge from two or more disciplines are integrated - on authentic "real world" problems e.g. Massachusetts Institute of Technology's New Engineering Education Transformation program (NEET) (Crawley, 2018).

These programs, and many universities in general, have an expectation that groupwork will result in collaborative learning (Summers & Volet, 2010; De Hei et al., 2015; Johnson & Johnson, 2009). Collaborative learning is when groups actively learn together, this is desirable as there are many social, psychological, academic and assessment benefits from engaging in collaborative learning (Laal & Ghodsi, 2012). However, simply having students take part in groupwork will not guarantee they will engage in collaborative learning (Summers & Volet, 2010; Johnson & Johnson, 2009). There are several factors which will determine whether or not a group will learn collaboratively (Johnson & Johnson, 1994), one of which is their ability to engage in social regulation of learning (SoRL) -which is when groups and individuals regulate each other's learning (Summers & Volet, 2010; Järvelä & Hadwin, 2013).

There is a tendency to view initiatives such as UREs through the lens of learning outcomes and benefits, however there is a need to consider the students' experiences and the effects that their various choices and decisions throughout a project will have on their learning (Auchincloss et al., 2014). Similarly, few studies on regulation of learning have investigated how it develops over the length of a project and even fewer have tried to document regulation of learning in interdisciplinary groups.

To address this research gap, this thesis focuses on collaborative learning and the regulation of learning in student groups taking part in PjBL and UREs as part of Chalmers University of Technology's Tracks and Genie initiatives. Tracks is a 10-year initiative that began in 2019, it

offers students, and sometimes professionals, a chance to take part in interdisciplinary project-based courses. These courses are electives and sit outside of the regular curriculum. The Genie initiative aims to increase participation of women in STEM. One of the activities that Genie offered in 2020 was the chance for students to take part in UREs.

1.1 Aim and research question

The aim of this thesis is to investigate how interdisciplinary groups engage in collaborative learning when taking part in projects based on authentic problems. This will include the choices and decisions they make throughout their projects e.g. how they organize and manage the groups, what processes they engage in. This thesis will also investigate how regulation of learning unfolds within interdisciplinary groups over the course of a project.

This thesis addresses the following research question:

RQ: How do groups collaborate and regulate their learning in interdisciplinary groupwork?

To answer this question this thesis will look at the actions and decisions groups take in terms of collaborative learning, and how groups engage in the regulation of learning. **Paper 1** addresses the former by examining the challenges groups experienced when taking part in UREs within the Genie initiative, and the coping strategies they employed in response. **Paper 2** examines how groups taking part in Tracks projects regulated their learning.

1.2 Overview of the thesis

The thesis is organised as follows:

Chapter 2: Theoretical and Conceptual Framework

This chapter introduces the theories and paradigms that underpin this thesis. It also outlines my position in relation to the existing landscape of learning theories.

Chapter 3: Methodology

In this chapter I outline my epistemological position and introduce the methods of data collection I used with an explanation why they were chosen. A summary of both papers' methodologies is also provided.

Chapter 4: Summary of the papers

This chapter provides a summary of the results from both papers.

Chapter 5: Discussion

The results and findings from both papers are examined through the thesis' theoretical framework to address the research question.

Chapter 6: Conclusion

This chapter summarizes the contributions of this thesis.

2 Theoretical and Conceptual Framework

Research on learning in groups draws on different theoretical perspectives which often overlap but have different foci. I will outline four of these theoretical perspectives: PjBL, collaborative learning, the role of disciplines, and SoRL, and their contribution to my conceptual framework as a basis for this thesis. This thesis draws on the following paradigms: social constructivism, socio-cultural theory, and socio-cognitive theory. I will introduce each learning theory throughout this section.

2.1 Project Based Learning

Working on authentic or real-world challenges allows students to apply their academic knowledge and engage in collaboration in order to solve them (Brundiers et al., 2010). The prospect of working on such problems can lead to an increase in engagement and motivation (Guardiola et al., 2013). It can also introduce students to challenges that engineers encounter in the "real-world" such as scope creep, taking stakeholders or end users into account and dealing with ambiguity among others (Guardiola et al., 2013). PjBL is one way that universities can incorporate working on authentic problems into their programs (Brundiers et al., 2010). In PjBL students conduct projects that require them to plan, design, implement, and evaluate their own solution to a problem (Frank & Barzilai, 2004; Ríos et al., 2010). PjBL courses can have groups or individuals working on projects. This thesis is centred on group based PjBL with one of its papers focusing on the project-based courses of Tracks and the other focusing on the project-based undergraduate research experiences (UREs) of Genie.

PjBL is built upon social constructivism, which is one of the grand learning theories stating that the construction of knowledge through interactions or collaboration with others (Singer et al., 2000); it differs from cognitive constructivism which sees knowledge as being constructed within individuals (Kalina & Powell, 2009). Social constructivism sees learning as a social process, influenced by society and culture, where learners actively construct meaning and knowledge together (Adams, 2006). By taking part in PjBL students will construct and give meaning to new knowledge that they gain over the project (Issa & Khataibeh, 2021), while also drawing on and applying previous knowledge, including individual disciplinary knowledge (Hsu & Liu, 2005). The process of knowledge creation takes place when the interactions and the knowledge created by them adds to existing knowledge to create new knowledge (Ríos et al., 2010). This process of knowledge creation, described by proponents of PjBL, completely aligns with social constructivism (Kalina & Powell, 2009).

Participation in PjBL results in deeper learning (Garcia & Garcias, 2012) and promotes critical thinking skills (Issa & Khataibeh, 2021). Taking part in PjBL can provide students with a deeper comprehension of subject matter and processes, as well as competencies and skills that can later be applied to "real" problems in industry (Frank & Barzilai, 2004). This includes improvements in students' communication and discourse skills, self-esteem, and how to make decisions as a group (Frank & Barzilai, 2004). This is an important aspect of PjBL as professional competencies will prepare students for their future careers and will require students to become aware of and develop their own competencies leading them to create their own learning trajectory (Hadgraft & Kolmos, 2020).

PjBL can be used to introduce students to complicated and complex problems, which can also lead them to interdisciplinarity as such problems cannot be adequately solved within one discipline (Hadgraft & Kolmos, 2020), though it should be noted that not all PjBL is interdisciplinary. From a learning perspective, broad and complex tasks lead to better collaborative learning as they require groups to engage in discussions and rely on all members' contributions (Scager et al., 2016). However, as PjBL requires students to plan their projects, such complex problems can result in uncertainty and frustration in the beginning (Frank & Barzilai, 2004). To help groups navigate this uncertainty teachers can provide scaffolding in the form of questions, technology, learning environments, coaching (Singer et al., 2000), and weekly meetings (Frank & Barzilai, 2004). Student's previous knowledge is also very important in these early phases (Hsu & Liu, 2005).

One of the papers that make up this thesis is based on UREs which share many commonalities with PjBL, but also some notable differences and therefore need their own introduction. UREs aim to engage students in real research in an authentic STEM environment. There are a number of different forms UREs can take e.g. internships with industry where one student works with professionals or course based UREs which are embedded into the curriculum (Kumbhar et al., 2018; Gentile et al., 2017). While it is important to note that not all UREs are project-based, the UREs for **paper 1** took the form of projects with student groups working over the summer period for which they received a wage. However, while learning was an important outcome, they were not courses with clearly defined learning outcomes or credits.

Taking part in UREs helps students develop their identity as a researcher as well as the relevant skills needed for such a role (Olivares-Donoso & González, 2019; Lopatto, 2004; Wallin et al., 2020). These skills include data collection and analysis, being able to effectively communicate one's work, performing tasks in the laboratory, communicating effectively with teammates, understanding the research process and gaining a researcher's thought processes (Lopatto, 2004; Wallin et al., 2020). It is important that participants actually engage in proper research work and not simply following a list of directions like a recipe (Kumbhar et al., 2018). This can be difficult on the students as they might expect the work to be similar to their usual laboratory classes or projects that will have clear guidance and predictable outcomes (Cartrette & Melroe-Lehrman, 2012). This is why UREs should expect the students to form their own research questions and project plans within the laboratory's overall project (Wallin et al., 2020).

UREs are seen as valuable learning experiences by students as they can gain the ability to work independently in the laboratory and become more resilient when faced with challenges (Lopatto, 2010; Wallin et al., 2020). However, there is another dimension to UREs and that is to promote research at post-graduate levels and careers in the area. Taking part in UREs usually cements students' intentions to pursue further education, and career paths, in research (Lopatto, 2004). UREs can also make previously disinterested students consider a research career, alternatively previously interested students may decide that such a career is not for them.

As students become acquainted to the world of research through UREs they are inherently introduced to communities of practice. Communities of practice was initially used to describe apprenticeships and professional communities (Wenger, 2010) which seems especially relevant to UREs. However, the term has since been co-opted to be applied to an educational perspective (Palincsar et al., 1998). Taking Wenger's definition of a community of practice being "people who engage in a process of collective learning in a shared domain of human endeavor" (Wenger, 2010 p1), then we can apply it to groups taking part in PjBL even if said groups are

only formed for the duration of their projects. Forming a community of practice provides a space for groups to learn collaboratively.

2.2 Collaborative Learning

This thesis looks at groups in PjBL, however the conceptual work on PjBL tends to focus on the "project" aspect such as the problems to be worked on rather than collaborative learning. I will therefore draw on collaborative learning research to identify how groups learn when taking part in group work. It is difficult to provide an absolute and concise definition of collaborative learning, so I will use Dillenbourg's, which describes it as, "a situation in which two or more people learn or attempt to learn something together" (Dillenbourg, 1991 pg1). Though, as Dillenbourg admits, this broad description can be a little unsatisfactory.

There is a difference between engaging in collaborative learning and simply focusing on completing the task (Volet et al., 2009). Focusing on learning and seeing the value in their work will have a positive impact on a group's interdependence (Scager et al. 2016). This is important as positive interdependence is a key element for successful collaborative learning (Johnson & Johnson, 2009). Positive interdependence occurs when group members realise their success is tied to the other group members' success, in other words no one can achieve their goals unless everyone in the group does so (Johnson & Johnson, 2009). It creates a feeling of responsibility for one's own work and for helping others. Individual group members have to ensure that not only do they learn their own parts, but other members learn their parts too, and all group members need to coordinate their efforts/work (Johnson & Johnson 1994). In practice then we want to see a sense of unity within a group where all members feel that they are working towards a shared goal rather than a team of individuals only focusing on their own work. Collaborative learning therefore requires a common goal that the whole group works towards and not having one member do most or all of the work (Johnson & Johnson 1994). In successful collaborative learning with positive interdependence group members will hold themselves accountable for their own contributions (Scager et al., 2016). Positive interdependence will see a group engage in a high level of trust and help prevent "free riding" (Scager et al., 2016). Group size will also have an effect on both interdependence and "free riding". Ideally groups should be made up of three to four members to get the maximum benefits of collaborative learning; larger groups make it harder to achieve interdependence, to manage, and opens the possibility of having free riders in the group (Johnson & Johnson, 1994; Scager et al., 2016). This is significant as "free riding" – where one member does not contribute but shares in the grade – is a source of dissatisfaction for many students that take part in groupwork (Miles & Rainbird, 2015; Tucker & Abbasi, 2016).

Positive interdependence leads to another important aspect of successful collaborative learning: promotive interactions (Johnson & Johnson, 2009). Promotive interactions include group members providing guidance and support to each other and includes the exchange of ideas and resources (Johnson & Johnson, 1994). The connection with interdependence is needed as group members need to be aware of each other's skills and abilities so that they can offer or ask for help when needed. The recognition that everyone's success is dependent on all group members – that comes with interdependence – therefore drives the interactions that will ensure said success.

Johnson & Johnson (1994) list two other essential factors for collaboration; the group's ability to evaluate itself, and interpersonal skills. The former is when a group looks at how they work, what they produce, and decide if changes are needed to function more effectively or to increase efficiency. It is similar to the reflection phase in theories of self-regulation (Zimmerman & Moylan, 2009) which will be described in in greater detail later. The other factor, interpersonal skills, can be simplified as how group members interact, support, and communicate with each other (Johnson & Johnson, 1994). The value of interpersonal skills cannot be understated as they result in a more harmonious group. Such skills may be especially helpful when dealing with group members from other disciplines.

2.3 The Role of Disciplines

While the focus of this thesis is concerned with groups learning together, a major component of both of the initiatives that are studied – Tracks and Genie – is their mandate to have interdisciplinary groups work on interdisciplinary projects. This is unsurprising as many researchers associate PjBL with interdisciplinarity or at least as an opportunity to introduce it to students (e.g. Frank & Barzilai, 2004; Hsu & Liu, Rios et al., 2010). It is important therefore that I include a theoretical perspective on interdisciplinarity as its effects can be seen in both papers.

Interdisciplinarity occurs when knowledge from two or more disciplines is integrated to form a more comprehensive understanding (Newell, 2001). A key point is integration, if group members were to work separately within their own disciplines the project would be multi-disciplinary (Klein, 2010). It is possible then for groups to take part in projects that were intended to be interdisciplinary, but to only engage in multi-disciplinarity. This thesis does not set out to determine if groups achieved interdisciplinarity, only the effects that different disciplines have on groupwork. As the initiatives this thesis is based on designed themselves to be interdisciplinary, I will take it for granted that they were.

I have already introduced social constructivism which looks at learning through interactions, however, it has little focus on the relevance of a group or students' culture and backgrounds. This is especially relevant for this thesis due to the potential differences in culture, both disciplinary and societal, that interdisciplinary groups can experience. I will, therefore, incorporate sociocultural theory in my theoretical framework in order to address this important aspect. In addition to acknowledging the importance of social interactions on learning, sociocultural theory considers how learning is affected by culture and environment (Ameri, 2020). It is learner centred and considers learning to be ingrained in social and cultural contexts (Wang, 2011). In terms of authentic learning, giving projects a sociocultural context helps students to relate their learning to the real world and makes it something tangible or practical (Adams, 2006).

Sociocultural theory is relevant for this thesis as interdisciplinary groups will inherently have members view tasks through different contexts with disciplines that have their own cultures. Initiatives such as Tracks also have many students from diverse cultural backgrounds taking part. How then will this affect learning in interdisciplinary groups from a sociocultural standpoint? Collaborative learning with a sociocultural perspective sees students form a community of learners with themselves as members working to achieve a common goal (Wang, 2011).

Incorporating a sociocultural perspective will allow us to view the interactions and learning of the group through a cultural lens and will show how culture can influence both language and communication. Relatedly, according to social constructivism, group members need to get to know and understand each other and communicate using a common language e.g. using the same terms for laboratory tasks, for effective learning to occur (Kalina & Powell, 2009). This is one example of how close these two paradigms, sociocultural theory and social constructivism, are to each other and how they fit together for this thesis. There are different opinions on how they relate to each other. Cobb (1994) sees both paradigms as being complementary or two sides of the same coin. Personally, I prefer Packer & Goicoechea's (2000) view that social constructivism explains how a student constructs knowledge through interactions and sociocultural theory places that learning within a cultural context. Thus, both paradigms contribute to our understanding of learning during group work.

2.4 Collaborative Learning and SoRL

All of the elements I have discussed so far are what I consider to be collaborative learning on a relatively general level. I will now discuss it from a deeper level that explains the processes involved. These different explanations should not be seen as contradictory or exclusive to each other, but supplementary to each other. To use an analogy, I see it as a race car driver describing how they race (speed, braking, tyre changes, refuelling etc) and then an engineer explaining it from a technical point of view (tyre friction, grip, performance,). As my future research will be centred on SoRL, I will provide a more in-depth overview of its theoretical foundations.

Looking deeper, collaborative learning is in made up of two complementary components: content processing, and the regulation of content processing (Volet et al., 2009; Järvelä & Hadwin, 2013). These are in essence the construction of knowledge and how a group socially regulates said construction. How groups go about these two components will determine the quality of their learning. Volet et al. (2009) created a framework which allows us to determine the quality of learning a group can achieve based on how they worked. The framework had two axis, one that represented knowledge -acquiring knowledge to constructing meaning- and one that represented regulation – self regulation in a group to social regulation.

Using Volet's framework as a base, I have created an adapted version – see Figure 1 – which represents the various ways that groups can work in relation to both social regulation and the construction of knowledge. It demonstrates how groups can engage in a high level of one component of collaborative learning but a low level of the other resulting in poorer learning. The optimal situation for learning to occur is for a group to co-construct knowledge and meaning together and engage in high level social regulation. This framework adds to the pure observation of features of good collaboration as it describes the learning processes that occur.

	Regulation of Learning		
Construction of Knowledge		Low-quality	High-quality
	High Quality	Group works together to try and co-construct knowledge, but engages in low-quality regulation	Group engages in high-quality regulation and works together to co-construct knowledge
	Low Quality	Group engages in low-quality regulation and constructs knowledge as individuals	Group engages in high-quality regulation, but constructs knowledge as individuals

Figure 1: A framework that outlines the different ways a group can regulate their learning and construct knowledge.

There are two predominant paradigms through which social regulation is viewed: social cognitive and sociocultural theory (Volet et al., 2009; Grau and Whitebread, 2012; Olakanmi, 2016). While there are differences between these perspectives, they are not insurmountable and can be combined to achieve a clearer picture of regulation (Rogat and Linnenbrink-Garcia, 2011; Grau and Whitebread, 2012; Olakanmi, 2016). As mentioned at the beginning of this chapter, this framework incorporates both sociocultural and social cognitive theory. Social cognition looks at cognitive processes in social interactions (Frith, 2008). When combined with social knowledge e.g. knowing social norms, social cognition helps us to interact, form relationships and work with others (De Jaegher et al., 2010). These interactions can be via social referencing or can involve unconscious processes e.g. seeing an angry face invoking fear (Frith, 200). Which leads to learning by observing others, this and learning by doing are the two primary ways students learn according to social cognitive theory (Bandura, 2008). Through observation, a student can see if a certain method is successful which will then influence how they will approach similar problems.

An important element of social cognition is agency of which there are three properties: forethought, self-reactiveness, and self-reflectiveness (Bandura, 2018). These three properties roughly align with Zimmerman's model of regulated learning which will be presented in the next section. Additionally, there are three modes of agency: individual, proxy, and collective (Bandura, 2008). Through individual agency one can influence or enact change in areas they control such as their own functions and perhaps elements of their environment. Proxy is when a student enacts their agency over another to make use of their abilities or resources to achieve said student's outcomes (Bandura, 2018). Collective agency sees groups come together and combine their knowledge, skills and resources in an effort to achieve a goal as a group (Bandura, 2008). These three modes of agency align with the three components of SoRL that will be introduced in the next section.

2.5 The components of SoRL

There are three forms of SoRL; self-regulation of learning (SRL), co-regulation of learning (CoRL), and socially shared regulation of learning (SSRL). While SRL is a long-established theory, there are different models that attempt to describe and define it. CoRL and SSRL are relatively new theories that expand upon SRL but have different theorists providing conflicting definitions for them. I will, therefore, outline all three forms according to the theorists and models that best align with my own opinions and which I have chosen for both this thesis and **paper 2.**

SRL is the ability to take control of one's learning through processes related to metacognition, cognition, behaviour, emotion, and motivation through iterations of activities such as planning, monitoring, evaluation, and change (Pintrich, 2004; Zimmerman, 2015; Hadwin et al., 2017). For my research, I use Zimmerman's model which takes a social cognitive approach and aligns with where I positioned myself in terms of learning theories. The model contains three phases: forethought, performance, and self-reflection (Zimmerman & Moylan, 2009). The forethought phase is when the student analyses the task they are about to do, then they set themselves a goal and create a plan to achieve it. This phase also considers their motivation and interest in the task and their expectations or standards. The performance phase is where the student enacts their plan and works on the task. In this phase they will employ strategies and processes while also monitoring their work to ensure it is up to standards set in the forethought phase and will be completed on time. In the evaluation phase the student determines whether the goals were achieved, and their standards met. If they were not met, then they will determine why this was so. They will also engage in self-reflection on their work and learning which will affect the forethought phase of their next cycle e.g. do they need to raise their standards. While the model is presented as an iterative cycle, with each phase contributing to the next, students can jump to different phases if needed. An example would be if during the performance phase the student realises the plan is missing something, they can jump back to the forethought phase to rework the plan. As SoRL is built upon SRL (Hadwin et al., 2017) Zimmerman's phases can equally apply to SoRL.

The definitions provided for CoRL vary considerably, but for this thesis I will use the following definition: "co-regulation occurs when individuals' regulatory activities are guided, supported, shaped, or constrained by and with others" (Järvelä and Hadwin, 2013, p28). I prefer this definition for two reasons: it shows how the person(s) doing the regulating can be a help or a hinderance, and it shows how CoRL is not always a "1 on 1" process. CoRL requires group members to be aware of other members' personal goals, progress and contributions, and to monitor them, stepping in when they need help (Miller & Hadwin, 2015). CoRL can be initiated by either the subject or object, an example of the former would be a group member taking control and regulating others or seeing someone needs help and providing it. An example of the latter would be if a member expresses a lack of knowledge or uncertainty to the group, or the group could look for help from a knowledgeable other.

SSRL is the joint regulation of a group by the group itself, in other words the group shares the regulation (Vauras et al., 2003). This joint regulation requires consensus and possibly negotiation as groups create joint goals, standards, plans, monitor the work and the group, and evaluate the work and learning when completed (Hadwin et al., 2017). For a group to engage in SSRL effectively they will all need to be aware of the joint goals, to have the same

perspective of what is expected of them, and know the group's strengths and weaknesses (Miller & Hadwin, 2015).

The difference between all three forms of regulation is determined by the subject and object of the regulation i.e. who is being regulated by whom. However, these three forms of SoRL are not completely independent of each other, rather a certain synergy exists between them - see Figure 2. SRL is ingrained in episodes of both SSRL and CoRL (Malmberg et al., 2017), and the better group members are at SRL the better the group itself will be at SSRL (Panadero et al., 2015). Meanwhile, CoRL can be seen as transitional as it can result in the emergence of SRL or SSRL within a group (Hadwin et al., 2017, Malmberg et al., 2017).

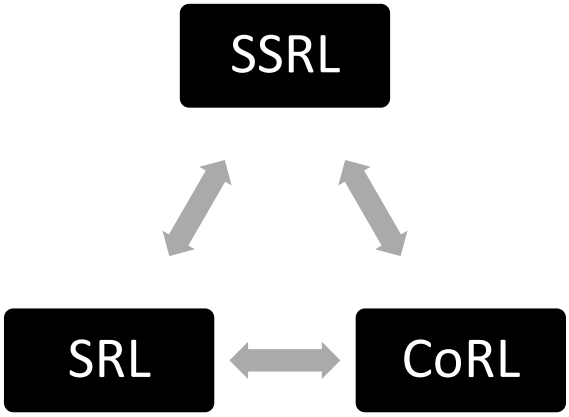

Figure 2: The different modes of regulation are intertwined.

As previously mentioned, the theories I outlined earlier, positive interdependence and interactions, should be seen as complimentary to SoRL. Summers & Volet (2010) also refer to them when discussing SoRL and their framework. One might very well ask why they are important. My view is that without positive interdependence and positive interactions, we will not see effective SoRL. Instances of SoRL can be hard to identify depending on the methods used, see **paper 2**, so signs of positive interdependence and positive interactions can serve as flags for teachers, who might struggle to identify or understand SoRL. It should be noted that negative or a lack of interdependence and negative interactions does not necessarily mean no regulation of learning was taking place. Such things would prevent true SSRL from occurring, but the definition I used for CoRL includes the caveat that it can also hinder a person's learning.

From a theoretical perspective this thesis combines social constructivism, social cognition, and sociocultural theory to create a theoretical lens that allows us to examine student experiences when learning in groups. It will allow us to see how they construct knowledge through interactions, identify the cultural perspectives that influenced those interactions, and how those perspectives affected students in terms of cognition. When combined with theories of collaborative learning and SoRL we get a conceptual framework that will help us to better understand the processes and experiences of students taking part in interdisciplinary groupwork.

3 Methodology

In this chapter I will outline the epistemology that I align with and upon which the methodologies I have used are based. I will then outline the methods of data collection I used and why, after which I will give a brief synopsis of the method sections of both papers. For convenience I will restate my research question:

RQ1: How do groups collaborate and regulate their learning in interdisciplinary groupwork?

3.1 Epistemological Perspective

The field of engineering education research (EER) leans heavily towards positivism or post-positivism as these theoretical perspectives are predominant within STEM (Bernhard & Baillie, 2016). Positivism asserts that there is one "truth" or reality which can only be described using scientific methods, post-positivism still attempts to adhere to the scientific method while acknowledging a level of uncertainty (Crotty, 1998). When engineers move into EER they tend to continue to use these perspectives as they view them as rigorous and hope that their former peers will see value in their research (Bernhard & Baillie, 2016).

Positivism and post-positivism belong to the epistemology objectivism which assumes that the data collected has independent value and meaning without the researcher, e.g. a rock exists as such without someone needing to observe and classify it (Crotty, 1998). The data gathered is typically quantitative which may allow for replicability, but which does not have the same richness in meaning as qualitative methods (Bernhard & Baillie, 2016). However, positivism and post-positivism are not limited to quantitative methods and positivists have utilized qualitative methods (Crotty, 1998). Similarly, other paradigms and epistemologies are not strictly limited to either qualitative or quantitative methods, what is important is that the data is interpreted correctly according to the paradigm chosen (Crotty, 1998). As someone with an engineering background, I can understand the appeal of positivism and objectivism, however in my opinion they would be insufficient when trying to identify abstract concepts such as collaborative learning and regulation.

I find myself drawn to constructionism as it views knowledge, and meaning, as something we construct as we interact and decipher the world around us. In its true sense it is neither purely objective or subjective but looks at the interaction between subject and object (Crotty, 1998). Constructionism can be used to provide contextual solutions to complex problems (Moon & Blackman, 2014). Following from this my philosophical perspective would be (social) constructivism as it considers how individuals interpret the world and construct their individual meaning (Moon & Blackman, 2014). While they share a similar name there is a key difference between constructionism and constructivism. Constructionism is primarily focused on the knowledge built by interactions between individuals, in other words the group's knowledge, while constructivism is focused on the knowledge built by the individual based on their interactions with others. By combining this epistemology with this philosophical lens, I will be able to examine the processes related to learning at both the group level and individual level (within the same group).

3.2 Data Collection

I chose to take a qualitative approach for my papers as it provides rich, deep data and allows for "an in-depth exploration of a central theme" (Creswell & Guetterman, 2021 p240). Due to my epistemological approach, I am drawn towards methods that both construct knowledge and which place the student and their experiences at the centre of the data collection. As I needed to find out what students have done and what their experiences were, I rationalised that I must therefore give them a voice and allow them to tell me their stories.

According to Creswell & Guetterman (2021), my options in terms of qualitative methods were limited to: observations, interviews and questionnaires, documents, and audiovisual materials. Observations and audiovisual materials -which in this case would be recordings of observations- were rejected for two reasons. First, there is no guarantee that groups would spend any significant amount of time working together in one physical place, especially considering covid-19 restrictions were in place for at least part of both papers. Second, observations require my interpretation of physical actions and interactions, they do not give the students a chance to tell their experiences in their words. It was decided then that reflective writing using prompts and open-ended questions would be used for **paper 1.** This would fall arguably between Creswell & Guetterman's (2021) documents as those include journals and diaries, and questionnaires. Interviews were chosen for **paper 2**. I will now introduce both methods in more detail.

3.2.1 Reflective Writing

I find reflective writing interesting as it can serve two purposes, it allows for the collection of data and can contribute to students' learning (Jasper, 2005). From a learning perspective, reflective writing helps students access knowledge and experiences and with reflection they can gain a deeper learning (Scanlan et al., 2002). It also aids students in making the connection between theory and practice. Students describing how they understand a topic will help them make meaning of their experiences and link them to what they have previously read or covered in class (Scanlan et al., 2002). The act of reflecting upon their actions and thinking, as well as those of others, will help facilitate critical thinking (Jasper, 2005; Kathpalia & Heah, 2008). Self-reflection is also one of Zimmerman's phases of SRL where students can evaluate their work against their original goals and criteria (Zimmerman & Moylan, 2009). If the work is deemed successful this should then lead to new goals and standards that are more ambitious, otherwise the student can identify where they failed and try to prevent it next time. Reflective writing should activate this self-reflection and evaluation in students (Kathpalia & Heah, 2008).

From a research perspective studies that utilise reflective writing (e.g. Hoover, 1994) are able to gain access to students motivations, goals, thinking and feelings along with descriptions of what happened. We will also gain an insight into the students' use of metacognitive, cognitive, and SRL strategies (Wallin & Adawi, 2018). Reflective writing gives students' ownership of their own story as they decide what should be included (Jasper, 2005). This will require students to order their thoughts and place them, and events, in sequence.

Reflective writing is a skill and so many students, particularly engineering students, may not be very capable if it is their first time doing it. We also need the reflections to be on specific topics or experiences for them to be useful for our research. Additionally, students are most

likely to remember incidents or episodes that came with strong emotions, positive or negative (Scanlan et al., 2002). A way to counteract these potential issues is through scaffolding using prompts or open-ended questions that elicit an "I" or "we" response, or asking students to complete reflective statements e.g. My biggest challenge was ….. I solved it by …….. (Kathpalia & Heah, 2008), or the students can be given a series of writing tasks (Hoover, 1994). Personally, I prefer to use open-ended questions as they provide focus by requiring an answer, however they also allow the student to clarify or elaborate on their answer (Cohen et al., 2011).

From an analysis perspective, reflective writing can be considered a form of narrative data and requires researchers to use their own experiences, knowledge, and creativity to adequately analyse and reveal the truth (Jasper, 2005).

3.2.2 Interviews

Interviews are similar to reflective writing in some respects. They are centred around a student who is given ownership of their story where they can talk about what they feel is important (Doody & Noonan, 2013). One major difference between the two is the opportunity for the interviewer to clarify misunderstandings or dig deeper with further questions if something of interest is revealed (Cohen et al., 2011).

The literature describes various types of interviews with the following appearing to be most common: structured, semi-structured and unstructured. Structured interviews have set questions and do not allow the interviewer to ask non-scripted questions, or at least severely limit their ability to do so (Cohen et al., 2011). The questions will typically only provide for limited or yes/no answers (Alshenqeeti, 2014). While this can allow for more answers to be taken and easier data analysis it lacks the possibility of richer data that other interview types can provide. I would, therefore, view this type of interview as being closer to reflective writing than the others.

Despite what the name suggests unstructured interviews are not simply a free for all as the interviewer follows a guide and themes (Doody & Noonan, 2013). They are difficult to analyse as researchers need to find and connect different themes and statements, this is especially so if the interviewee wanders and talks about trivial subjects. They also require a skilful interviewer that can properly phrase questions, recognise interesting information and be able to probe deeper if needed.

Semi-structured interviews are similar to structured interviews in that the interviewer has a predetermined list of questions, however they have the flexibility to ask additional questions to reveal interesting information (Alshenqeeti, 2014). There is a danger that novice interviewers may not be able to recognise when to probe an answer or new information further which can result in missed opportunities (Doody & Noonan, 2013). I decided to use a semi-structured format for the interviews in **paper 2** as its shares some aspects of reflective writing while also allowing some freedom to the interviewer.

There are some potential pitfalls for interviewers. If an interview is very open and the interviewee becomes relaxed, they may reveal information they later regret or the interview may turn into a form of therapy for which the interviewer is not prepared or trained (Alshenqeeti, 2014). We also need to remember that interviews rely on recall and so the

interviewee's answers can be subjective and liable to change over time (Alshenqeeti, 2014). Similarly, the interviewee might not be able to articulate their thoughts clearly or might be influenced, unintentionally, by the interviewer and their line of questioning (Creswell & Guetterman, 2021). This is especially so in unstructured interviews with which novice interviewers can struggle (Doody & Noonan, 2013).

Interviews therefore need careful planning. Researchers need to first determine the theoretical lens of their study and develop research objectives or questions which they hope to solve and from this determine which type of interview is best (Cohen et al., 2011). With the research questions in mind the researcher needs to make out a guide for the interview including themes and questions, especially for complex or potentially sensitive questions for semi-structured interviews (Doody & Noonan, 2013). The types of questions need to be considered according to the responses that are expected – e.g. what do you like about X vs tell me 2 things you like about X – and the type of data wanted – e.g. factual answers, opinions, interpretations (Cohen et al., 2011). Interviewers should try to ensure the questions are neutral and that they appear empathetic to the interviewee (Doody & Noonan, 2013).

Interviews allow for the interviewee to provide insight, context, and detailed responses, as well as allowing for the interviewee to ask questions on the research or for clarification (Doody & Noonan, 2013). Interviews also provide the opportunity for the researcher to include visual, verbal, and non-verbal details e.g. the interviewee sighs, grips their pen tightly and in a stern voice said… (Cohen et al., 2011). While not an equivalent learning experience to reflective writing, interviews do allow for the interviewee's to potentially benefit from self-exploration (Doody & Noonan, 2013).

3.3 Methodology Summaries

3.3.1 Paper 1

Empirical Setting

Paper 1 looked at participants in a URE that was run by the Genie project over the summer period for which the participants received payments. There were 14 participants from a variety of disciplines, all 14 were about to enter their fourth year of a five-year master's programme. They were divided into four groups, not all groups were interdisciplinary, however the projects they worked on were all designed to be interdisciplinary. As it was a paid position most of the participants were expected to work 40 hours per week, though some only worked part time. Each URE lasted roughly five weeks. All groups had one to two hours contact time with a teacher and/or external stakeholder scheduled each week. Each group were given their own project with a list of criteria their end product was expected to fulfil.

Data Collection & Analysis

As previously mentioned a qualitative approach was taken for this paper, specifically a qualitative case study design was used as it would allow us to contextualise the participants experiences (Yin, 2009). Reflective writing was then chosen as the means of data collection.

Data was collected in three waves: one near the beginning, middle and end of the URE. For each wave the participants were given open-ended questions for prompts. These questions were designed to gather their views on research – with an emphasis on research as a career – and their experiences with their group including how they worked and what they learned. Consent was obtained from all participants. In compliance with Swedish policy, formal ethical approval was not obtained as the collected data are anonymous and contain no sensitive information.

It was decided that a thematic analysis would be the best option for data analysis as it would allow us to identify overarching themes and patterns within the data (Braun & Clark, 2006). Through inductive coding (Braun & Clark, 2006) we identified challenge episodes and corresponding coping strategies. These were then amalgamated under common themes.

3.3.2 Paper 2

Empirical Setting

Paper 2 looked at participants in PjBL courses that are part of the Tracks initiative. All of the courses were "advanced" which limited participants to master's and PhD students. Three Tracks courses containing a total of 34 students were selected. Each course had groups of two to four students work together on projects. The participants were from a variety of disciplines and countries. All courses provided lectures before and during the project work. This was to ensure the participants had the relevant theoretical and conceptual knowledge required to complete the projects.

Data Collection & Analysis

A qualitative approach was taken with **paper 2**, using a comparative narrative case study design. This would allow us to collect data from a number of participants, which would be formed into narratives about common events that would then be analysed and interpreted (Baron & McNeal, 2019). Narratives allow for events to be presented chronologically and give voice to the participants' stories and experiences (Creswell & Guetterman 2021; Jovchelovitch & Bauer 2000). For this reason, one to one semi-structured interviews with open-ended questions were chosen as the method of data collection. All participants provided informed consent. In compliance with Swedish policy, formal ethical approval was not obtained as the collected data are anonymous and contain no sensitive information.

A protocol was designed for the beginning of the interview which: introduced the researcher, topic of the research, a request to record the interview, an outline of how the data will be handled and the participants right to withdraw consent at any point. It also contained the interview questions, as well as statements for the end of the interview. The interview questions were based on the following: the three phases of Zimmerman's SRL model (Zimmerman, 2000) as these are commonly found in SoRL literature; questions on the challenges they faced and their coping strategies based on the findings of **paper 1**; and the participants' reflections on the courses.

For each interview episodes of SoRL were identified using Miller & Hadwin's (2015) table of definitions. These episodes were formed into clusters that related to similar events which were then formed into readable episodes. Episodes were combined when they referred to the same

events within the same group. Plots were then formed for each group using the episodes, this allowed us to decide which ones to include and to delimit the narratives' beginning and end (Jovchelovitch & Bauer, 2000). Narratives were constructed from the plots, which were then interpreted according to SoRL theories.

4 Summary of the Papers

This chapter provides a summary of the two appended papers focusing on the results of each.

4.1 Paper 1

Title: *Challenge Episodes and Coping Strategies in Undergraduate Engineering Research*

Research on UREs has predominantly relied on quantitative methodologies and focused on their outcomes (professionally and personally), but not the students' experiences and how they worked. To address this knowledge gap in the literature a qualitative case study was conducted driven by two research questions:

- What challenges do students experience during UREs?
- What coping strategies do students use in response to those challenges?

Three themes of challenges emerged from the data analysis: organizing, planning and executing tasks; managing the group and its members; and receiving support from the teachers.

Organizing, planning and executing tasks. The participants were expected to manage their projects from beginning to end which caused several challenges. Some of these challenges were directly related to the nature of the UREs as students were unused to their unstructured nature, the length of their projects, and conducting academic tasks. Coping strategies ranged from cooperative activities such as discussions, to some groups doing nothing until they received more instructions. In addition to planning the project, some groups found having to decide on which tasks to do next or which direction to take after tasks a challenge also. Strategies ranged from trial and error to having a member take a lead or expert position. Groups also reported challenges such as performing unfamiliar tasks, becoming stuck in tasks, learning how to process results, and being given last minute project changes. As with the other challenges the groups would typically engage in cooperative activities, make use of experts, or sometimes they simply adapted and continued to work as best they could.

Managing the group and its members. Groups needed to decide how to assign work; some tried to work together on tasks when possible while others simply split tasks among members. Both paths saw them make use of members' experiences and knowledge when possible. Part of managing their work meant dealing with dependencies, which usually meant trying to find something useful to do while waiting. Managing the group required them to deal with knowledge gaps or misunderstandings, usually dealt with by having an internal expert explain a concept or having a group discussion to help member(s) grasp a concept. One group did have to deal with a "problem" member that was disruptive in the few meetings they went to and non-communicative outside of them. In this case the rest of the group worked together as best they could.

Receiving support from the teachers. Teachers were seen as valuable sources of knowledge, however there were some reported challenges in relation to gaining that knowledge. Sometimes groups felt the instructions they were given were unclear, few, non-existent or late. Other times a combination of summer holidays and covid-19 restrictions meant that groups had limited communication with their teachers. Some groups found that their teachers, each group had at

least two, would sometimes give conflicting answers to questions. The coping strategies for all of these typically involved communication. This included asking more questions, learning to be specific or to ask questions a certain way, or finding someone else to contact for information.

The paper concludes by noting that groups experienced desirable and undesirable challenges. Desirable challenges, such as having to plan the whole project, will typically result in better learning. Conversely undesirable challenges which will result in a lack of progress. Teachers should attempt to ensure that their UREs contain desirable challenges while avoiding undesirable ones. There should also be a promotion of appropriate coping strategies.

4.2 Paper 2

Title: *Social Regulation of Learning in Interdisciplinary Groupwork*

The field of SoRL is relatively young and there are few studies that document groups' regulation over the course of a project. Similarly, most studies in the field are focused on mono-disciplinary groups with little to no research on interdisciplinary groups. To address this gap in the literature a qualitative case study approach was used and was driven by the research questions:

- How do interdisciplinary groups regulate their learning during project-based courses?
- What factors can aid or hinder a group's regulation?

The results were presented in the form of narratives which told the story of each group through episodes that were interspersed with interpretations that highlighted the regulation with each episode. Please note that for this paper the term supervisor was used as the groups had individual supervisors assigned to them who may not have been the course teacher. However, for consistency I will use the word teacher in this thesis in place of supervisor.

Group 1 were the most diverse in terms of disciplines with all three members coming from very different bachelor's and master's programs. The topic of the course was also different to their "home" disciplines. The group engaged in SSRL in the planning phases, however intervention from a teacher resulted in disagreements among the group which resulted in aggressive CoRL where members would try to convince the teacher to back their ideas and force the rest of the group to comply. There were disagreements within the group which were attributed to their different cultural backgrounds, personalities, disciplines, and their unfamiliarity with each other. As time went on and the members got to know each other there were less disagreements and they were more successful in engaging in SSRL. Most of the work was performed by two members as the third one was too busy with work for other courses. Their project was scaffolded by weekly class presentations where all groups in the course were required to present their work and their progress in terms of their original plan. This helped ensure effective monitoring and evaluation of their work.

Group 2 were the most homogenous of all the groups as two members had bachelor's degrees in the same discipline and master's in similar disciplines. The project topic was also in their discipline. The third member's bachelor's and master's were in a different discipline to the others. The group were quite successful in terms of regulation. They engaged in SSRL in the formation of a plan, but then decided it was too ambitious and changed it to something they

felt was more achievable. The group opted to split tasks among themselves and would share their results before each meeting where they would then discuss them. Meetings were typically where they would discuss their work, asking questions if something was unclear. Sometimes a member would take the lead in a topic they were specialising in for the project, but still decisions required consensus within the group. They would have group discussions anytime an issue came up e.g. a member becoming stuck on a task. Towards the end of the project the group realised there was some misalignment between their work and the original plan which they quickly rectified. Ultimately the group was disappointed with the completed project. This was partly due to covid-19 campus restrictions which hampered their data collection, and partly because they felt they could have done something more challenging.

Group 3 were also quite homogenous. Three members had bachelor's degrees in the same discipline, two of them were also doing master's in the same program with the third in the same discipline but different program. The fourth member had a bachelor's in a different discipline and was taking a master's in the same discipline but a different program to the others. The group made a concerted effort in the beginning to get to know each other and to decide on what project they wished to do. They preferred to work together, but lab requirements meant they often had to split into sub-groups to complete tasks. They would update each other regularly by walking between labs and by having weekly meetings. As with group 2 they would use group discussions to solve any issues that might arise e.g. a member has trouble understanding a concept. Their meetings were also an opportunity for them to monitor and evaluate their work as well as deciding what needed to be done next. For their final report they worked on their own parts but read each other's work in order to ensure it was readable for "non-experts".

The paper concludes by outline the various factors that aided or hindered the groups' regulation of learning. It also gives suggestions for teachers on how to support SoRL within groups as well as issues to be aware of e.g. differences in discipline cultures.

5 Discussion

This chapter discusses both papers' contribution to answering the overall research question of this thesis through my theoretical framework. I will begin by reiterating the research question:

RQ: How do groups collaborate and regulate their learning in interdisciplinary groupwork?

To do this I will address the question in two main parts: first in relation to collaborative learning, then in relation to social regulation of learning. I will outline how each paper has a direct contribution to one of those parts, I will then examine the result sections of both papers through the theoretical lens of this thesis. Additionally, I will examine the effects that the PjBL environment and disciplines had on the groups' learning processes.

As I mentioned in section 2, SoRL theories can help explain the processes behind collaborative learning. For example, Laal & Ghodsi (2012) state that consensus within groups is important for collaborative learning to take place. Through the lens or SoRL theory we would consider a group reaching consensus on a decision or path to be an example of SSRL (Hadwin et al., 2017). There will therefore be some crossover between the different sections of this discussion section.

5.1 Collaborative Learning

The first paper documents the experiences and actions of groups as they attempt to engage in collaborative learning while taking part in UREs. It directly contributes to the collaborative learning part of the research question. **Paper 1** identified the challenges groups experienced and the coping strategies enacted in response. It shows how the uncertainty of UREs proved quite challenging for the groups. Despite the frustration caused by uncertainty, all groups were eventually able to enact collaborative coping strategies. In terms of challenges related to project management, group interactions, and knowledge gaps students employed solutions drawing on their past experiences and knowledge. Groups supported each other's learning in different ways, either through an expert sharing their knowledge or the whole group taking part in cooperative activities.

Paper 1 also contributed to the research question, and the literature, by documenting examples of student experiences in collaborative learning. A key contribution of this paper was the introduction of desirable challenges and their benefits. Desirable challenges borrow from Bjork & Bjork's (2011) concept of desirable difficulties which shows how experiencing difficulty can encourage learning. When students experience challenges that are surmountable by the group e.g. determining why a calculation or result is incorrect, then we consider these to be desirable and conductive to learning. By contrast a challenge that results in a lack of progress or motivation e.g. not having lab access for the first week of the project, is considered an undesirable challenge. Teachers should aim to promote desirable challenges and limit undesirable challenges.

Applying the theoretical lens of this thesis to the results of both papers provides even more insight into the ways the groups engaged in collaborative learning. A popular strategy for groups in both papers was to split tasks among members, though some groups only did so out of necessity or because working together was not possible, which resulted in the groups

becoming reliant on each member's contribution for their overall success. This dependence on members to complete their tasks for the group to succeed aligns with Johnson & Johnson's (2009) criteria for positive interdependence. Crucially, almost all groups had a system of meeting and reporting progress and results when they assigned tasks to members. This is important as interdependence, when splitting tasks, requires that group members communicate their work and results (De Hei et al., 2015). Only one group had a member not share their results which saw a break down in their ability to collaborate and in their socio-emotional environment. Of course, interdependence is not limited to groups that work on tasks individually as groups working together on a task can also experience positive interdependence (Johnson & Johnson, 2009). Some groups worked together on tasks or showed a preference for working together when the situation provided for it, which would have resulted in the co-construction of knowledge and therefore better learning (Summers & Volet, 2010).

A common thread throughout the groups in **paper 2** was the recognition that group members contributed what they could. All groups were understanding if a member's workload for other courses affected their work for the project. That they took this approach rather than labelling members "free loaders" shows they achieved positive interdependence as they valued each member's contributions (Johnson & Johnson, 1994). While the groups' acceptance of having some members contribute less than others appears to be similar to findings by Scager et al. (2016), there are significant differences. The perception in Scager's paper was that stronger students simply did more, which was seen as natural by the groups. In contrast groups in **paper 2** made active allowances for members to do less. This included groups making allowances for members being late completing tasks and one group accepting that a member would do little to no lab work. While these actions suggest positive interdependence and a good group environment, we must question the quality of learning that the aforementioned members achieved.

Cooperative activities such as brainstorming and discussions on which direction their project should take were observed in **paper 1**. Similarly p**aper 2** saw instances where group members would make proposals to the group and then defend them while others made counterpoints. This is one of the benefits of collaborative learning as having to make such arguments while also considering those of others leads to better critical thinking skills (Gokhale, 1995). Such conversations and debates within a group can be a double-edged sword as one participant in **paper 2** noted that repeated debates on a topic were good on one level but were ultimately a distraction for the group. Discussions and brainstorming sessions also meant the groups experienced different methods of decision making which is one of the competencies, along with communication and project management, that PjBL promotes according to Frank & Barzilai (2004). However, not all cooperative activities ended in consensus or on a positive note. There were examples in **paper 2** which saw discussions break down and group members attempting to force their idea on the group via the teacher.

Sharing of results via group discussions and communication was documented in both papers as groups tried to ensure all members were aware of each other's work. This, combined with the previously mentioned brainstorming and discussions on project directions, shows that the groups performed activities that align well with how learning takes place according to social constructivism as a theory.

5.1.1 Effects of the PjBL Environment

As mentioned in section 2, PjBL differs from other group work as it requires the students to plan, design, implement, and evaluate their solution to a problem which is typically a complex or authentic problem (Frank & Barzilai, 2004; Ríos et al., 2010). I will describe how this affected the groups as part of my answer to the research question.

Working on an authentic project, with the prospect of succeeding where a commercial company had failed was a motivating factor for one group in **paper 2**, as was the prospect of working on an ongoing research project for another group. Groups also mentioned their motivation increased as they became more familiar with the work and each other. The positive effect that the authenticity of the projects and working on them had on the groups' motivation supports similar findings on the benefits of PjBL by Garcia & Gracias (2012). However, both papers have shown how teachers cannot simply rely on this authenticity for motivation as there can be break-downs in group cohesion resulting in low motivation. It was also shown in **paper 2** how a group had high motivation from working on an authentic project but were ultimately disappointed with their end product. It therefore should not be assumed that motivation equals quality learning.

An advantage the UREs in **paper 1** had over the Tracks courses in **paper 2** was scheduling. As the UREs were held over the summer period participants generally had few limitations on their time. By contrast, Tracks students had different schedules which made finding time to meet and work together difficult and they had to manage their workloads from different courses. This reflects similar findings by other studies into interdisciplinary group work (e.g. Taajamaa et al., 2014) and studies that focused on PjBL (Garcia & Garcias, 2012).

Both UREs and Tracks projects required groups to form their own goals and plans, and both programs saw groups engage in these tasks with a certain amount of uncertainty. However, the responses to this uncertainty were vastly different between the groups. **Paper 2** unanimously saw groups hold discussions and attempt to engage in SSRL to determine their own learning goals, with varying levels of success initially. By contrast **paper 1** saw groups struggle from a lack of instruction with some refusing to do any work or to progress until they received what they considered to be adequate instructions. I speculate that this might have been due to two possible reasons: first the structure of the UREs was very different to the Tracks courses, with no supporting classes and less access to teachers. Secondly, the participants' disciplines may have left them ill-prepared for the way they were expected to work. This is highlighted in the next section by discipline cultures. All groups indicated that this uncertainty was eventually overcome which aligns with observations by Frank & Barzilai (2004) who similarly found students struggle when first introduced to PjBL due to their unorganized nature. However, this thesis contributes to the literature by documenting the activities groups engaged in when faced with uncertainty. It is clear from the group responses that just as there are desirable challenges, in this case uncertainty, there are also suitable and unsuitable coping strategies.

5.1.2 Effects of Disciplines

One of the arguments for both the UREs and Tracks courses was that the projects were set up to be interdisciplinary, though sometimes the groups themselves were not. This is not unusual as some researchers consider PjBL as an opportunity to include different disciplines (Frank &

Barzilai, 2004). As part of my attempt to answer the research question I will examine the effects that different disciplines had on the groups in both papers.

A group's interdisciplinarity can have positive effects on their learning as seen in **paper 1** and **paper 2** where more diverse groups would often make use of internal experts and were better able to develop coping strategies linked to the interdisciplinarity of their projects. However, one of the groups in **paper 2** exposed a potential challenge of having group members from vastly different disciplines. It highlighted how differences between disciplines extends beyond content knowledge to procedural knowledge and discipline culture. **Paper 2** showed how students from different disciplines approached laboratory work; some expected it to be akin to following a recipe while others expected far less support. This aligns with findings by Wallin et al., (2017) who also cautions teachers to be mindful of their own discipline's culture when interacting with interdisciplinary groups. From a sociocultural perspective this is an example of how individual's knowledge and its application was directly related to their (discipline's) culture. We can see how these differences in discipline cultures affected the groups learning until they found common understanding.

The effects of disciplines were not just limited to differences between group members. Participants would often find themselves working on projects from disciplines that were different to their own. In **paper 2** we saw how a lack of knowledge of the topic and each other resulted in conflicts and low motivation in one group and minor disagreements in another. However, both groups reported that the more they learned of a topic and each other the bigger the increase in motivation and decrease in conflict. Both groups also reported members were quite friendly with each other by the end of their projects. By contrast the third group in **paper 2** were more homogenous with two of their members from the same discipline as their project. Said group experienced far less difficulties than the other groups partly because they rejected their first project plan for one that was considered more achievable. However, despite completing their project on time they were ultimately unsatisfied with it and felt they could have been more ambitious. They also engaged in less high-quality SoRL which supports Iiskala et al.'s (2011) findings that difficulty stimulates SSRL. However, the group that faced the most difficulty, with members from different disciplines and a project topic they were unfamiliar with, also failed to successfully engage in SSRL a number of times, though they did eventually succeed. This suggests that while difficulty may stimulate SSRL the personalities of the group and their familiarity with each other will determine whether or not they are successful.

While many of the results from the two papers confirm existing research on collaborative learning, my research contributes further to the field in the following ways. First, as pointed out in **paper 1**, teachers should be aware of group composition in terms of the members' disciplines and that of the project. This is something which groups in **paper 2** might have also benefited from. Depending on their previous experiences groups could benefit from relevant training in project management which can include examples of suitable and unsuitable coping strategies. While teacher's are a valuable source of knowledge, they should provide an adequate support structure which would see them coach groups rather than dictate to them. Finally, **paper 1** introduced the concept of desirable challenges and their benefits can be seen in both papers. We should not try to "protect" students from difficulties or challenges, instead we should allow them to experience desirable ones.

5.2 SoRL

The second paper documents how interdisciplinary groups regulated their learning while taking part in project-based courses. It directly contributes to the regulation of learning part of the research question. Four themes emerged in **paper 2**, but only three will be presented here: goal setting and planning; the implementation phase; and the role of teachers. The fourth theme, the impact of disciplines, is broadly similar to section 5.1.2. All groups attempted to engage in SSRL when setting goals and creating plans and despite some upsets all eventually were successful. For two of the groups their SSRL processes in this phase initiated CoRL which then led to SSRL again. The autonomy given to the groups as part of PjBL stimulated SSRL in the goal setting and planning phase. The implementation phase demonstrated the importance of discussions to SoRL. This phase saw more internal and external CoRL which was often either initiated by or embedded into episodes of SSRL. The implementation phase also saw how experiencing more difficulty in a project led to more SSRL which supports Iiskala et al.'s (2011) findings on the same, though as previously mentioned triggering SSRL did not always result in successful SSRL. Teachers were seen as a valuable source of support and when successful their scaffolding helped support SoRL.

While only **paper 2's** results were examined with SoRL as a theoretical lens, for this thesis I will also look at **paper 1** with the same lens where possible. This will be quite limited due to the way **paper 1's** results were presented but will still show some examples of SoRL. Both papers saw groups engage in CoRL when a group member, or members, experienced a knowledge gap, or a misunderstanding. These episodes of CoRL would typically see the groups engage in one of three internal activities: an expert within the group would explain the concept; the member with the misunderstanding would explain how they view the concept and others would reply; the group would have a general discussion where all members explained their understanding and they would try to figure it out together. Another trigger of CoRL seen in both papers was of a member turning to the group for help with a task if they got stuck or had trouble completing it. The triggering of CoRL through a lack of knowledge, a misunderstanding, or seeking help supports the findings of Ucan and Webb (2015). An unusual finding in **paper 2** was how a breakdown in SSRL saw group members engage in aggressive CoRL involving a teacher. While it is not unusual for one member to try and dominate a group through CoRL, it is the first time I have seen a member attempt to do it via the teacher.

The results of **paper 1** refer to groups seeking answers or information from teachers, which suggests that some form of CoRL took place with the teachers supporting or guiding the group's learning. On the other hand, **paper 2** saw clear examples of groups receiving CoRL from teachers, though it did not always have a positive effect on their learning. As I mentioned when defining CoRL, it can hinder learning and there are examples of this in both papers. **Paper 1** saw teachers provide wrong or conflicting information and **paper 2** saw teachers cause disruption when they dictated to their group. While previous literature has shown examples of CoRL hindering learning (e.g. Rogat & Adams-Wiggins 2015), it involved group members as regulators not teachers. Indeed, the effects teachers can have on a group via CoRL appears to be under researched which is surprising considering the value placed on their knowledge by the groups in these papers.

Interestingly **paper 2** often showed how intertwined the processes of SoRL are as SSRL episodes would initiate CoRL as groups looked to external experts for help, before then engaging in SSRL again afterwards. This reinforces Hadwin et al.'s (2017) and Malmberg et al.'s (2017) assertations that CoRL is transitional and aids in the emergence of SSRL as the

groups needed CoRL before they could continue to engage in SSRL. However, there are some key differences between **paper 2** and Malmberg's findings: we did not observe as many episodes of CoRL; said episodes often involved CoRL from an external party; and CoRL was used specifically for help or guidance rather than planning or monitoring as seen in Malmberg's study.

As previously mentioned, the early phase of **paper 2's** projects stimulated SSRL across all the groups as they were required to form their own goals and plans. Additionally, they engaged heavily in SSRL throughout their projects, primarily through regular group meetings where they monitored and evaluated their work and planned what had to be done before the next meeting. This is in contrast with Malmberg et al.'s (2017) findings which found groups engaging mostly in CoRL especially in the early stages of the groupwork. There are two possible reasons for this discrepancy between our findings. First, Malmberg's groups always worked together as opposed to groups in **paper 2** who often worked as individuals and then discussed their work and progress in meetings. Secondly, Malmberg recorded the groups interactions whereas we used interviews. It is possible therefore that some of nuance of what happened within the meetings was lost as we could only code what we were told e.g. "We discussed it and agreed on a plan" would be coded as SSRL, yet a group member might have been co-regulating others for parts of that discussion. Still, this requires further investigation as I would argue that Malmberg's set up is not typical of how groups will work in project-based courses such as Tracks, and their study was based on a cohort that already knew each other.

There were some episodes of groups employing SSRL through work on a shared document in **paper 2**, however the majority of SSRL took place through discussions. This is because the groups had a natural inclination to use discussions as a first port of call when faced by challenges or when decisions needed to be made. This was good practice, not just because communication is key for collaboration (Johnson & Johnson, 1994), but because SSRL relies on the group's perspectives to be aligned and for them to make joint decisions with joint responsibility (Miller & Hadwin, 2015). In **Paper 1** groups periodically share and discuss results which suggests some form of monitoring and evaluation, was taking place. There were also reports of group discussions where groups would try to perform academic tasks – e.g. to form a hypothesis or plans, perform analyses – and discussions where consensus was needed, with one particular group adding that all decisions were made jointly, all of which suggest that the groups engaged in some form of SSRL. There were examples of where groups failed to achieve SSRL, in **paper 1** where a group member disengaged with the others, and in **paper 2** where one group descended into aggressive CoRL. In both cases this breakdown in group cohesion saw them experience low motivation.

I will finish this section by outlining how my findings add to the existing research on SoRL. First, **paper 2** has shown how teachers can support SoRL through scaffolding but must be aware that when interacting with groups they should facilitate rather than dictate. Teachers, also need to be aware of group composition and the differences between the members', teacher's, and project's disciplines. This will include ensuring groups experience desirable challenges, for example groups with members from the same discipline as the project topic should be encouraged to be more ambitious in their goals. Similarly, groups should be encouraged to focus on learning and not just completion of the project.

6 Conclusion

Changes in society and industry are prompting Universities to rethink engineering education. This thesis makes a number of contributions to the field of EER in relation to interdisciplinary groupwork in PjBL. First, it highlights the importance of groups experiencing desirable challenges, and the need for them to be aware of suitable coping strategies. I have shown how groups displayed signs of successful collaborative learning such as interdependence. While this included their accommodations for the workloads of group members, I question whether the accommodated members engaged in effective learning. I have also shown that while working on authentic projects can increase motivation, there is no guarantee that it will remain high as it can be affected by social processes. While it has previously been shown how groups can face and overcome uncertainty in the early stages of PjBL, this thesis goes further by identifying the actual actions and decisions groups make when experiencing uncertainty. This thesis also highlights how the effects of disciplines extends beyond content knowledge to procedural knowledge and discipline culture. Similarly, I have shown how groups whose disciplines are close to their project topic might experience less effective learning due to a lack of challenges. In terms of SoRL, I found that SSRL was the most predominant form throughout the groups. Groups will benefit from having some scaffolding to support or encourage SoRL, but they equally need to have autonomy. This thesis highlighted how CoRL can sometimes have a negative effect on a group or can be used in a negative way. While unproductive CoRL itself is not unheard of, previous studies have not observed the form of aggressive CoRL or negative CoRL involving teachers that this thesis has.

This thesis has some implications for theory. While SoRL is a promising theoretical framework that can be used to understand group-based learning, documenting instances of SoRL remains a challenge. This thesis contributes significantly to this by testing an innovative method that documents group's SoRL over the course of a project. Our use of narratives allowed us to present episodes of SoRL as the project unfolded, showing how it was shaped by different events and choices made by the groups. It is a method that should be explored further as we need to learn more about how groups engage in SoRL over time in authentic project environments rather than focusing on groups brought together to solve a handful of tasks.

I believe that this thesis shows the advantages of both UREs and PjBL courses, but now I must draw attention to a rather uncomfortable fact. Both these forms of educational initiatives require quite some time to be effective. In the case of UREs it can be a year or more before students become proficient in "real" research (Linn et al., 2015) and six to nine months for groups in PjBL to truly begin to work in an interdisciplinary way (Taajamaa et al., 2014). Most courses in engineering education, including the UREs and Tracks courses observed in this thesis, do not run long enough to meet either of the given timeframes. However, I believe the strength in these programs lies in their ability to inspire students in terms of their academic and career paths. This is something we should not underestimate or forget as universities create courses chasing the goal of producing engineers that can walk into industry and work as seasoned professionals.

This thesis also has several implications for practice. First, my findings suggest that teachers implementing PjBL should create scaffolding which supports the students but also gives them adequate autonomy. An example from **paper 2** is weekly presentations of the student's work which forces them to consider monitoring their progress. Students should be reminded to look beyond the planning stages of a project and engage in effective regulation throughout the project. This will typically look like small weekly lifecycles as groups plan, monitor, and

evaluate tasks/work. However, these lifecycles will need to have the groups joint goals in mind. Teachers will also need to be aware of the make-up of the groups in terms of disciplines and the potential difference in procedural knowledge. Students from the same or a similar discipline to the course will need to be encouraged to take on more ambitious or difficult plans. Teachers should also strive to be facilitative, supportive and provide guidance when needed as opposed to directive or 'spoon feeding'. Achieving the necessary balance between scaffolding and autonomy for the groups might be difficult for teachers and they may require some level of support or training.

There are some limitations to this research. While the method of data collection in **paper 1**, reflective writing, gave the students the power to share their thoughts and opinions as they wanted, there were two issues. First, reflective writing is a skill, and one needs to practice it to become proficient. Engineering courses typically do not give students opportunities to write reflectively. Reflective writing is also limited in that neither the participant or researcher can ask clarifying questions, nor can the researcher explore answers in more detail with the participant.

The method of data collection in **paper 2**, interviews, does allow for clarification questions and for the researcher to "dig deeper" when needed. However, interviews rely on the participant remembering details after the fact, in this case weeks after the completion of the courses. There is the possibility then of participants misremembering or forgetting incidents. There is also the issue with identifying SoRL from interviews as the participant can sometimes give a broad explanation of an episode. As mentioned, episodes of regulation can be encapsulated within others or occur in a rapid sequence, the nuance of this can be lost if we are simply told "we discussed it, thought about it, and came to an agreement".

In terms of future research, my next paper will focus on a Tracks course that had groups containing students and professionals. It will explore how this group composition affected their learning and their regulation of learning. After that paper I will be exploring ways to stimulate and support SoRL within groups using artificial intelligence tools.

This thesis shows how interdisciplinary groups taking part in PjBL engage in collaborative learning and how they regulate their learning. These are important concepts that we need to be aware of when designing UREs or project-based courses. It is not enough to simply state that we wish to stimulate mode 2 knowledge production, as putting students into groups does not guarantee collaborative learning, true interdisciplinarity, or successful regulation of learning. The findings in both papers and this thesis highlight how important it is that we examine the students' experiences and processes of learning when taking part in UREs or project-based courses.

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Paper 1

CHALLENGE EPISODES AND COPING STRATEGIES IN UNDERGRADUATE ENGINEERING RESEARCH

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***Keywords**: undergraduate research, challenges, URE, coping strategies*

ABSTRACT

Higher education institutions are increasingly placing importance on engaging undergraduate students in genuine research, known as undergraduate research experiences (UREs). While the professional and personal benefits that result from UREs have been theorized and researched, the potential challenges students experience when engaging in genuine research remain relatively underexplored. Drawing on a sociocultural understanding of learning, this paper details challenge episodes and coping strategies that engineering students at master level reported while carrying out a research project in biomedical engineering. Data consisted of reflective writing collected at the beginning, middle, and end of the research project.

A thematic analysis of the data led to the identification of three overarching areas of challenges: (1) organizing, planning, and executing tasks; (2) managing the group and its members; and (3) receiving

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support from the teachers. We find that while groups often experienced similar challenges, the coping strategies they employed differed and were influenced by the groups' disciplinary composition and the students' previous project experiences. We nuance the discourse around the role of challenges in UREs by making the distinction between "desirable challenges" and "undesirable challenges", and we draw out implications for teachers wishing to involve students in realistic research.

1 INTRODUCTION

Across the globe, higher education institutions are increasingly experimenting with approaches for involving undergraduate students in realistic research, known as undergraduate research experiences (UREs). This surge of interest in UREs is also reflected in the rapidly growing body of research on UREs. The bulk of that research has relied on quantitative methodologies and focused on the professional and personal benefits of UREs [1]. While such studies can provide important insights, they tell us little to nothing about how students navigate their way through UREs, or how students experience being involved in realistic research [1]. Additionally, a quick perusal of three recent systematic reviews of research on UREs [2,3,4] reveals that there is a conspicuous lack of studies attending to the potential *challenges* that students experience while navigating their way through UREs — even though it is widely recognized that cognitive, affective, and social challenges have a significant impact on learning [5].

To redress this knowledge gap in the literature on UREs, this paper reports on a qualitative case study [6] driven by two research questions:

- What challenges do students experience during UREs?
- What coping strategies do students use in response to those challenges?

In examining these questions, we take our theoretical cue from the concept of "situated learning" in "communities of practice" [7], which emphasizes the importance of context — both social and material — for understanding how people learn to become members of a community of practice. Using this theoretical lens to study UREs means attending to how students engage in genuine scientific practices in a real laboratory environment, while interacting with experienced scientists as mentors and other students.

2 STUDY SETTING AND DESIGN

2.1 Empirical setting

The program this study is based on was designed to give undergraduate students an opportunity to participate in genuine research, for which they received payment. There were 14 participants, all of whom were about to begin their fourth year of a five-year master's program. Of the 14 participants, ten were female and four were male, and they came from a variety of different engineering disciplines. They were divided into four groups, with each group containing one male student. While only some groups were interdisciplinary, each project was designed to be interdisciplinary. The students were expected to work an average of 40 hours per week and each group had one to two scheduled weekly contact hours with their teachers. Each group were assigned their own project, all of which were actual research projects rather than projects with a course-based design. To give an example, one project was on the development of a gel to be used in the testing of medical applications of microwaves for cancer treatment. The students were given a list of criteria that the gel needed to fulfil. The project combined two disciplines: electrical engineering and chemistry.

To ensure the groups had a basic toolbox of skills to allow them to begin the project, one of two approaches was taken for each group. For some their project was based on their group bachelor's project, but at a higher level that took it further in a theoretical sense. The other groups were brought into the labs, trained on the relevant tools and theory, and worked on the same or similar research questions that they would work on in the project.

2.2 Data collection and analysis

As we sought to contextualize the groups' experiences, a qualitative case study design was deemed to be appropriate [6]. The project ran over eight weeks, each participant completed between four and five weeks, and not all participants worked full time on the project. This set up saw the participants finish at different times, which affected the data collection as some had finished before the final wave of collections. Said data was collected in the form or reflective writing, and the collections waves were in the initial stage (one or two weeks in), the middle stage (four to six weeks in), and the final stage (on the last week). Each wave consisted of between one and three questions addressing the participants' experiences and perceptions of the URE during the different phases. Eleven participants responded with their reflective writings in the first wave, three in the second wave, and seven responded in the final wave.

The data was analysed through inductive coding [8] identifying salient challenge episodes and their corresponding coping strategies. In a second step, the identified challenge episodes were grouped into larger themes based on their proximity.

3 FINDINGS

Three overarching themes of challenges were identified: (1) organizing, planning, and executing tasks; (2) managing the group and its members; and (3) receiving support from the teachers. This section describes challenge episodes within each theme and their corresponding coping strategies.

3.1 Organizing, planning, and executing tasks

The project required the students to plan and organise their own work, which raised several challenges. In the initial stages, *the project's unstructured nature* was a common challenge expressed by the groups. Some of those — but not all — felt that their issues stemmed from a lack of instruction. The coping strategies to face the lack of structure varied, from those that did not begin any work until they received what they felt were better instructions, to those that decided to work in the same vein as they had for their Bachelors project. Other solution strategies consisted of attempting to gain knowledge from examining previous data that was available to them, and simply making decisions under uncertainty on what tasks to perform, despite the lack of the scaffolding or structure they were used to.

Another challenge, *planning project work*, means having to decide which tasks to prioritize and which direction to take. A common strategy utilised by the groups for this was trial and error: they would try something, analyse the results, apply changes they think would lead to improvements and try again, or if needed they would change direction entirely. For one group this challenge led to the emergence of a de-facto leader who appeared to have naturally fit the role and who added structure. This same group would also allow for members to take on the role of an expert when tasks were in their area of study. In these instances, we were told that despite their expert status, the whole group would have to agree before making decisions. It is not known if this joint decision making also applied to the de facto leader.

The length of the project was also listed as a challenge as it was longer than any of the students' previous projects. However, no specific coping strategy for it was mentioned; they simply continued to work and seemed to adapt or became accustomed to it.

Further, the groups faced the challenge of *processing results*. Results needed to be analysed, conclusions drawn, and the reasons for wrong or unexpected results identified. Results could cause a change in strategy or the direction of a group's work. The groups predominantly used cooperative activities as a coping strategy for this challenge, working together to analyse results and try to identify potential improvements. The sharing of results among all group members was recognised as important, especially when obtained by a single individual or a sub-group working on a task. Group discussions were another cooperative activity used as a coping strategy for this challenge. The discussion of and sharing of results was not limited to individual groups as at least one group reported that they shared and discussed results with their teacher. Another strategy employed was the application of previous knowledge and knowledge gained from relevant research papers when analysing results to identify what would have a positive effect in future tasks.

Performing new or unfamiliar tasks was another listed challenge. One group's coping strategy was to seek out and read relevant literature on the topic. They remarked that the knowledge they gained from this coping strategy also proved useful later in the project. Some groups assigned tasks to individual participants and interdisciplinary groups would try to ensure said tasks fell within a participant's knowledge or discipline. This was not always possible, particularly in more homogeneous groups. For these participants, the only solution was for them to learn how to perform the task with the group providing support and help if needed.

An individual *becoming mired in a task*, which includes obtaining unexpected or unexplainable results, was a challenge some faced, regardless of whether it was in their discipline or not. The strategies employed were similar to those for previous challenges: the individual would present the issue to the group, and together they would try to provide help.

Further, *conducting academic tasks* — such as forming hypothesis, developing ideas, and being innovative — was reported as a challenge. Once again, the coping strategies were cooperative in nature as groups would hold brainstorming sessions and group discussions, where they would try to form hypothesis, ideas, plans, perform analyses and share ideas and thoughts.

The final challenge that was mentioned in this theme was when groups received *late task descriptions*, *goals*, *or last-minute project changes*. No specific coping strategies were provided; it appears that the groups simply worked to complete said goals and tasks.

3.2 Managing the group and its members

As mentioned previously, the groups had to organise and plan their own work, which led to the challenge of *assigning work within groups*. Groups would employ one of two coping strategies. The first strategy was to work on tasks together when physically possible, and if a group member had expertise or experience in the subject area then they would lead the group. The second strategy was to assign tasks to individuals or sub-groups. Groups tried to ensure that participants would be assigned tasks within their area of expertise or experience when possible. Interdisciplinary groups appeared to have an advantage over more homogeneous groups for both coping strategies.

Dealing with task dependencies, where groups were unable to proceed as planned due to unforeseen circumstances, was another challenge. Examples include delays in receiving vital data or being unable to begin a task until another was completed. These events were beyond students' control as they could not influence the person or task they were waiting on. Thus, they had no way

of applying coping strategies directly to ease these bottlenecks. Instead, they often ensured the time spent waiting was not wasted by reading relevant articles about their task or identifying and performing other tasks.

While participants in interdisciplinary groups were positive of their experiences, such groups would sometimes experience knowledge gaps which arose when reviewing literature, or performing a task, or analyse results that were outside of some members' discipline. The challenge then was *addressing knowledge gaps within the group*. One coping strategy was knowledge sharing, where one member would take on the role of an expert and explain concepts or material to the rest of the group. Another strategy was the use of cooperative activities, such as discussions, and the sharing of ideas or experiences. These coping strategies allowed group members to contribute with their own unique knowledge and skills, an experience they found fulfilling.

While most groups reported positive interactions and good social cohesion, one group reported negative interactions which led to *poor cohesion within the group*. These issues were due to the actions and attitude of one group member that worked independently off campus, did not coordinate with the others on task allocation, and communication was either negative or non-existent. As a result, the rest of the group did not know what work that member was doing or how the work was progressing. Ultimately this member left the project before its conclusion and failed to provide work or documentation of his/her work to the other members. Thus, *dealing with a negative member* was a challenge unique to this group. The group did not list any coping strategies employed to remedy the situation. Instead, they worked closely together as a separate group on campus, and after the troublesome member left the project, they worked to complete the outstanding tasks that remained.

3.3 Receiving support from the teachers

While participants generally praised the support provided by the teachers as the project progressed, several felt dissatisfied with the level of support and instruction provided to them at the beginning of the project. The perceived challenge then was *dealing with instructions that were unclear*, *few*, *non-existent*, *or late*. Various coping strategies were employed by different groups. One strategy was to learn more by questioning the teachers, with one group reporting that they did not begin any work until they received instructions that they considered adequate. Other groups were less specific about their strategies, with one group reporting that they did not start working until things became clearer, and another group simply reported that they "figured out" what they needed to do. Some groups did not provide any specific coping strategy that they employed for this challenge.

The project was run over the summer period, which resulted in limited access to teachers due to summer vacation. This, coupled with changes in the campus environment due to the Covid-19 pandemic, meant that groups were often unable to physically meet with their teachers. Adapting to this *lack of physical contact with teachers* was a challenge for the groups. A common coping strategy employed by the groups was to email their teachers. One group did mention having meaningful conversations with their teacher but did not specify if these conversations were in person or digitally, for example a phone call or Zoom. *Limited communication* between groups and teachers brought other issues to the fore; for example, when a group had more than one teacher for their project, who should they direct task specific questions to? Sometimes teachers would respond late or would reply that the group had asked the wrong person. One group employed the following coping strategy for these challenges: they would email as many people as possible that they think may know the correct answer to ensure a quicker reply. If possible, they would attempt to call teachers for an even faster response.

Another issue that arose was when a group received *conflicting facts or answers from different teachers* on the same topic or question. No coping strategy was provided for this issue, but the group reported that teachers tried to answer questions quickly, so we can speculate that their strategy may have been to send more emails to clarify previous answers. A particular issue highlighted by one student was knowing what questions to ask to ensure they received the information needed. As time progressed the student learned how to pose questions using previous experiences.

4 DISCUSSION AND CONCLUSIONS

This study set out to identify challenges students experience during UREs and the coping strategies they mobilise in the face of those challenges. In the remainder of this paper, we will discuss some of our most significant findings against the backdrop of prior work in the area and their implications for instructional design of UREs.

The first theme of challenges revolves around organizing, planning, and executing tasks. As suggested here and by others [9], students partaking in UREs tend to expect scientific research to be like their previous lab work and projects, with clear guidance and predictable outcomes. These expectations are inconsistent with the messy and iterative nature of doing research, resulting in the expressed challenges. Even though those challenges caused considerable frustration for some of the students, most students were able to develop effective collaborative coping strategies, leading to progress and learning.

The challenges allocated to the second theme relate to internal group interactions, project management, as well as knowledge gaps within the group. This theme is significant since the ability to work in groups has been signposted as a critical aspect of successful UREs [10]. Our findings reveal that coping strategies are largely based on students' previous project experiences, as well as groups' disciplinary make up. Members of interdisciplinary groups could in many cases contribute with their specific content knowledge, either in the role of an expert to share their specialised knowledge, group leader on a task, or specialist completing the task as an individual. This appears to have given interdisciplinary groups an advantage over more homogeneous groups that had to compensate for the lack of expert knowledge by reading articles and taking part in cooperative activities such as group discussions. Consequently, interdisciplinary groups were better equipped to develop coping strategies, which might be connected to the interdisciplinary nature of the projects. These findings suggest that (1) students partaking in UREs can benefit from relevant training in group work or project management prior to or as part of the UREs [10], and that (2) it is important to pay close attention to group composition.

Challenges allocated to the final theme relates to interactions between groups and teachers, including scaffolding, support, instructions, and communication. Students partaking in the URE viewed the teachers as a valuable source of information and guidance. This finding is consistent with prior research on UREs, stressing the importance of teachers as mentors, discussions between students and teachers, and scaffolding if needed [2,10]. The challenges in this theme were caused or exasperated by three factors: (1) the unstructured and open-ended nature of UREs, (2) the fact that the project ran during the summer when there was limited access to teachers due to summer vacation, and (3) that the project coincided with the pandemic, resulting in restricted campus access for both staff and students. Despite some contextual factors beyond the teachers' control, a lack of presence and interaction between teachers and students seemed to create significant challenges, such as late instructions, lack of physical contact with teachers in the labs, and difficulties to establish communication with teachers when needed. At the same time, we also find that students

developed valuable coping strategies in dealing with those challenges, such as learning how to correctly formulate a question, finding out who to ask said question, and working with what they might consider few or unclear initial instructions. These findings suggest that teachers in UREs should ensure that there is an adequate support structure available, and that instructions are clear, adequate, and delivered in a timely manner. Teachers also need to ensure that their students have access to expert performances to build a research identity as part of a community of practice [7,11].

Taken together, our findings point towards an understanding of challenges as a *double-edged sword*. That is, challenges are not inherently good or inherently bad in terms of learning. To nuance the discourse around the role of challenges in UREs, and engineering education more generally, we find it useful to borrow from the concept of "desirable difficulties" [12] and make the distinction between "desirable challenges" and "undesirable challenges". In terms of implications for teachers, we argue that teachers should strive to find the right amount and type of "desirable challenges" — together with support for appropriate coping strategies — while avoiding "undesirable challenges" resulting in a lack of progress, a loss of motivation, or inefficient use of resources (e.g. time). To be able to find this balance, future research on UREs would do well to suggest ways to better connect the research experiences to the students' prior experiences and beliefs, an argument that was brought forward in similar form by Linn et al. [2]. In the presented study, the overwhelming majority of students were overall very positive and enthusiastic about their experience of participating in the URE, despite - or because of - being confronted with the challenges of doing "real" research. Thus, we strongly encourage teachers and universities to offer UREs as part of their portfolio.

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Paper 2

Social Regulation of Learning in Interdisciplinary Groupwork

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Engineering education has seen a growing interest in how students regulate their learning as a group in interdisciplinary projects. This study adds to the current literature on social regulation of learning by conducting a comparative case study of three interdisciplinary group projects addressing real-world challenges. Semi-structured qualitative interviews were synthesised into narrative episodes representing key aspects of the groups' regulative behaviours. We observed indications of co- and shared regulation across all groups, with noteworthy differences in the project phases that led to varying perceptions of learning success. We discuss key factors that affected regulation along four themes we identified: (1) goal setting and planning, (2) the implementation phase, (3) the role of supervisors, and (4) the impact of disciplines. We offer insights for practitioners and provide a foundation for future research on social regulation in interdisciplinary group learning.

Keywords: social regulation of learning, co-regulation, socially shared regulation, interdisciplinary groupwork, collaborative learning, project-based learning

Introduction

In the rapidly evolving, knowledge-based society, engineering students must develop lifelong learning capabilities to be able to adapt to constantly changing problems, contexts, and technologies (Jonassen et al., 2006). Therefore, students do not only need to acquire discipline specific knowledge and skills, but also the ability to regulate their learning and to collaborate effectively (Wallin 2017). One of the major challenges for today's engineering graduates is the fourth industrial revolution (or industry 4.0), characterized by the integration of innovations such as artificial intelligence, robotics, the internet of things, and digitalization in physical and digital domains (Hadgraft & Kolmos, 2020; Boone, 2020). The integration of these technologies requires engineering education to incorporate interdisciplinary collaboration across programs while also instilling social responsibility and an awareness of societal contexts (Hadgraft & Kolmos, 2020). This increasing interdisciplinarity in higher education institutions,

particularly in science and engineering, reflects a shift in how knowledge is produced (Negretti & McGrath, 2022). In response to these challenges, Chalmers University of Technology launched a ten-year educational initiative titled *Tracks*, which fosters interdisciplinary group-projects across programme boundaries, grounded in real-world problems (Enelund & Henricson Briggs, 2020).

While numerous studies have highlighted the benefits of group work (e.g., O'Donnell, 2006; Prince, 2004; Johnson & Johnson, 2009), there remains a misconception that mere participation in group work guarantees collaborative learning (Summers & Volet, 2010). For effective collaborative learning, groups must be willing to engage in co-construction of knowledge and regulate their strategies to succeed (Summers & Volet, 2010; Järvelä & Hadwin, 2013). Until relatively recently, research has predominantly focused on self-regulated learning (SRL). SRL encompasses metacognitive, cognitive, and behavioural processes to achieve learning goals (Zimmerman, 2015), providing a lens into how individuals regulate and process their learning. However, SRL does not accurately address regulation processes within a group or the influence of individuals' regulations on one another. The concept of social regulation (Hadwin et al., 2017) emerged from the expansion of SRL theories and their application to social interactions. Social regulation of learning (SoRL) explores how an individual's or a group's learning is regulated by others or the group collectively (Hadwin et al., 2017). Thus, SoRL can illuminate the processes that occur during collaborative work.

As the field of social regulation is a relatively new research area, scholars are investigating various methods to observe and record instances of shared regulation. Although some studies have documented episodes of regulation by observing groups in specific situations (Panadero & Järvelä, 2015), there is a paucity of studies examining how social regulation evolves throughout a project. We contend that qualitative data such as interviews and narratives, offer a promising approach for tracing SoRL development over time without overly compromising data richness (Jovchelovitch & Bauer, 2000). Further, previous studies have predominantly focused on regulated learning in mono-disciplinary groups (e.g. Malmberg et al., 2015; Järvelä et al. 2013; Panadero et al., 2015) with very limited insights into the impact of interdisciplinarity on SoRL. Homogenous groups working on interdisciplinary projects (e.g. DiDonato, 2013) differ significantly from interdisciplinary groups. Although some research has examined SoRL in interdisciplinary groups throughout a project (e.g. Bakhtiar & Hadwin, 2020), the majority of studies have focused on groups performing set tasks or series of tasks (e.g. Malmberg et al., 2015). Furthermore, few studies have employed interviews (e.g. Volet & Mansfield, 2006; Järvelä & Järvenoja, 2011), despite their potential to yield rich data and enable students to retell their stories and experiences.

In light of these considerations, our study aims to investigate *how interdisciplinary groups regulate their learning during project-based courses*. By using narratives to illustrate their progress over time, we discuss, grounded in the qualitative analysis of the empirical material, *what factors can aid or hinder a groups regulation*. This exploration of SoRL in interdisciplinary group work will contribute to our understanding of the dynamics of collaborative learning, ultimately providing insights that can be applied to enhance educational initiatives and support students in their pursuit of lifelong learning.

Theoretical Background

Social regulation of learning (SoRL) theory builds upon the rich research and tradition of self-regulated learning (SRL) (Hadwin et al., 2017). SRL theory posits that learners regulate their learning through various strategies and construct goals and meaning from both external and internal sources (Pintrich, 2000, 2004). SRL involves the ability to take control of one's own learning through processes that involve metacognition, cognition, behavior, emotion, and

motivation (Pintrich, 2004; Zimmerman, 2015; Hadwin et al., 2017). Several models divide SRL strategies into phases (e.g. Winne & Hadwin, 1998; Pintrich, 2000; Zimmerman, 2000). While the number of phases varies across these models, they all share common attributes; goal setting and planning, working and monitoring, and evaluating and reflecting. These phases are typically iterative and recursive, with each phase influencing the others, with learners moving between different phases.

SoRL builds on SRL by incorporating the regulation of learning that occurs in social settings (Hadwin et al., 2017). Models of SRL (e.g. Zimmerman 2000) can be used to identify phases of SoRL with the primary difference between SRL and SoRL lying in the roles participants take in regulation. SRL is concerned with an individual's regulation, whereas SoRL examines direct regulation by or of others. In other words, SoRL acknowledges that group members affect each other's learning, as a group's ability to engage in SoRL depends on its members' ability to self-regulate. High quality SRL among members tends to lead to high quality SoRL within the group (Panadero et al., 2015). SRL can be hard to observe as it involves internal processes, but it is inherently ingrained in episodes of SoRL (Malmberg et al., 2017). The literature primarily identifies SoRL in two forms: co-regulation of learning (CoRL), and socially shared regulation of learning (SSRL).

CoRL is a relatively new concept with the potential to illuminate relatively unexplored facets of group work. It describes how individuals' regulation activities are "guided, supported, shaped, or constrained by and with others" (Järvelä and Hadwin, 2013, p28). CoRL is dynamic in nature and requires group members to monitor each other and step in when needed, while also being cognizant of each other's goals and contributions (Miller & Hadwin, 2015). CoRL can help or hinder the subject of the regulation depending on how it occurs – i.e., though directions/orders or through suggestions/support (Bakhtiar & Hadwin, 2020). CoRL can change during a project as participants become more skilled at regulating (Lajoie et al., 2015). CoRL as a process can be initiated by one or more participants, tools, or a task and can be applied to individual participants or the whole group (Bakhtiar & Hadwin, 2020). The person initiating CoRL can be either the regulator or the person to be regulated (Hadwin et al., 2017), and the regulator can even be external to the group. However, CoRL does not account for a group's joint regulation, which is conceptualized by Socially shared regulation of learning (SSRL).

SSRL describes how groups collectively regulate participants learning by jointly setting goals plans and standards and then monitoring and evaluating their work against them (Hadwin et al., 2017). SSRL involves the group exercising metacognitive control over tasks together, which may require negotiation of states and processes such as cognition, behaviour, motivation, and emotion (Hadwin et al., 2017). It emerges over time through group interactions and exchanges and can therefore be seen as a transactive process (Hadwin et al., 2017). In order to engage in SSRL, group members need to ensure that they perceive the group's requirements similarly, and be aware of the group's strengths and weaknesses (Miller & Hadwin 2015). Sharing the planning process, for example, can help develop a shared understanding (Ucan & Webb, 2015).

What is the link then between SoRL and collaborative learning? Effective collaborative learning involves two components: content processing (subject knowledge that students are expected to learn), and its regulation (how the students manage their learning) (Khosa & Volet, 2014; Summers & Volet, 2010; Volet et al., 2009). Content processing involves the co-construction of knowledge, and the regulation of content processing refers to SoRL (Volet et al., 2009). Thus, SoRL plays a crucial role in collaborative learning by enabling and supporting shared knowledge construction through collaboration (Miller & Hadwin, 2015), and a group's ability to regulate themselves will affect their collaborative learning, as will their method of knowledge construction. For instance, a group that splits tasks among its members can still

engage in SoRL, even though the group is not working collaboratively on the content. In such cases, group members may perceive that they are learning when they convene to review and discuss each other's work, but the learning experience is not as profound as it would be if the group members were working together on tasks (Summers & Volet, 2010).

When do groups engage in SoRL? Triggers for SSRL often include task-related problems illustrated through the voicing of doubt, the expression of conflicting ideas, and when seeking consensus for a change in a joint strategy or plan (Seiradakis & Spantidakis 2019; Ucan & Webb 2015). Iiskala et al. (2015) suggests that ill-defined questions and multidimensional tasks during collaborative groupwork provide opportunities for SSRL - particularly metacognitive regulation. The level of task difficulty can determine the number of instances of SSRL a group engages in. For example, a task or problem that appears to be relatively straightforward tends to trigger less regulation than one that is perceived to be more complex or difficult (Iiskala et al., 2011, 2015). CoRL, on the other hand, is often triggered by a misunderstanding or lack of knowledge of domain content communicated by a group member (Ucan & Webb, 2015). CoRL can also be initiated by a group member that observes another is having difficulty in achieving a learning goal, or when a group member takes a lead role and directs other group members (Miller & Hadwin 2015).

Socioemotional interactions within the group also influence how SSRL and CoRL unfold. Groups experiencing positive socioemotional interactions engage more in regulatory processes than groups with negative socioemotional interactions (Rogat & Linnenbrink-Garcia, 2011). A positive social environment within a group contributes to their use of SoRL, as members feel more comfortable monitoring, providing help, and receiving help from fellow members (Ucan & Webb, 2015). Positive socioemotional interactions include valuing and seeking each other's opinions, recognising contributions, including group members (e.g. in meetings), being attentive, and actions supporting group cohesion (Bakhtiar & Hadwin, 2020; Rogat & Linnenbrink-Garcia, 2011). Conversely, negative socioemotional interactions involve actions that damage the group's cohesion, disrespecting fellow members, excluding or discouraging participation and disrupting group harmony (Rogat & Linnenbrink-Garcia, 2011). Such negative socioemotional interactions can result in fewer instances of SSRL as group members may engage in CoRL in an attempt to dominate the rest of the group (Grau & Whitebread, 2012). In sum, these considerations show that examining groups' SoRL is essential for understanding the dynamics and effectiveness of collaborative learning in higher education settings that aim to promote interdisciplinary, project-based learning.

Methodology

Research context and design

In this study, we employed a qualitative case study approach to explore how interdisciplinary groups regulate their learning as a group in project-based courses and discuss the factors that can aid or hinder a groups regulation. This enables us to explore the phenomenon through the experiences of the course participants (Creswell & Guetterman, 2021). We chose a comparative narrative case study design, which involves gathering data from one or more individuals about a particular event or events via qualitative interviews, then interpreting and analysing the results and present them as a narrative (Baron & McNeal, 2019). Narratives allow for events to be told chronologically to tell the participants' story and share their experiences (Creswell & Guetterman 2021, Jovchelovitch & Bauer 2000), so that a series of events and their consequences are documented and brought to life in an authentic and realistic way for the reader (Cohen et. al., 2011).

Research setting and participants

The study participants were enrolled in *Tracks* courses during the Autumn 2021 semester at a Swedish University of Technology. All the courses were "advanced", meaning they were limited to master's and PhD students. The three Tracks courses featured in this study included a total of 34 students from a variety of engineering disciplines. The courses had students with both Swedish and non-Swedish backgrounds. All three courses divided students into groups of 2-4 for their project work. The courses were electives and open to students from different programs. Each course provided lectures before and/or during the project work to convey the theoretical and conceptual knowledge required to complete the projects. The student groups were formed after several lectures. Convenience sampling was used to select three courses and five participants for interviews. The participants were all volunteers and provided written informed consent. In compliance with Swedish policy, formal ethical approval was not obtained as the collected data are anonymous and contain no sensitive information.

Data collection

The individual, in-depth interviews were conducted after the courses were completed. The interviews followed a semi-structured guide with general themes and open-ended questions, allowing the interviewer to explore the interviewee's responses more deeply, clarify the questions if necessary, and let the interviewee explain or elaborate their responses if needed (Cohen et al., 2011). The questions were primarily based on the three phases of Zimmerman's SRL framework (Zimmerman 2000), a common approach in the SoRL literature, with additional questions regarding the participants reflections on the course and their backgrounds. The participants came from varying engineering disciplines and national backgrounds. The interviews were all held in English over Zoom, recorded, and later transcribed for data analysis. Pseudonyms were assigned to participants in the presentation of the empirical material.

Data Analysis

Using Miller & Hadwin (2015)'s table of definitions for SRL, CoRL, and SSRL as an analytical framework, the first author identified and coded regulation episodes. The co-authors compared these episodes with the original transcripts to ensure reliability. The first author then grouped the episodes into clusters related to similar events. These clusters were formed into readable episodes, combining events of interviewees from the same working group where applicable. A narrative plot was then formed for each group, which facilitated the decision-making process for selecting episodes to include and determining the beginning and end of the narrative (Jovchelovitch & Bauer, 2000). The narratives were then developed from these plots. The co-authors reviewed the narratives in comparison with the episodes and clusters to ensure they accurately reflected the participants' stories. Lastly, the narratives were collectively interpreted according to our framework, with the interpretations embedded after each episode to highlight instances of social regulation for the reader.

Results

The results are presented as a series of episodes which form an overall narrative for each group. The episodes are interspersed with interpretations through a lens of SoRL.

Narrative 1

Group 1 participated in a Tracks course on battery development. The group consisted of three masters students: Hans, Saoirse, and John. All three members had bachelor's degrees in different disciplines and were pursuing master's degrees in different fields. They each came from different countries and cultures. The topic of the Tracks course was outside of each student's primary disciplines, though Hans had better foundations from a previous class.

Episode 1: Hans, Saoirse and John met to discuss the goals and plan for the project, which proved challenging due to their limited background knowledge. There were disagreements as Hans proposed ideas that Saoirse and John considered overly ambitious. Eventually they agreed on project goals and a plan, which they presented to their supervisor. However, the supervisor rejected it, replacing it with a new topic, which required the group to meet and compose a new plan. Unable to reach a new agreement, students tried to convince the supervisor to impose their idea on the group.

> "*At that point, we were really pulling in different directions, and it sort of felt like everybody was just trying to get the support of the supervisor on their idea.*" – Hans

Hans felt demotivated by the process. However, after several additional meetings, he felt that the group's dynamic improved and, in the end, they reached an agreement on their own.

Interpretation: This episode showcases several attempts for SSRL in the form of aligning goal and plan perceptions. After successfully determining their own project through SSRL, the supervisor's rejection and substitution with a new goal indicates 'directive' CoRL. Following this interference, the group initially failed in SSLR relating to agreeing on a plan for the new project and descended into attempts of 'aggressive' co-regulation via the supervisor with negative socio-emotional effects. However, over time ongoing negotiations led to an agreement.

Episode 2: The main part of the project involved considerable lab work that the group initially conducted together. However, scheduling issues due to their different timetables made it difficult to arrange times to meet and work together as the project progressed. Work tasks were divided between group members based on their knowledge and expertise, as well as their schedules and availability.

> "*[The assignment of tasks] was based on timing, also the method of working. So, I was working on something that was easier for me."* – Saoirse

During lab work they sometimes called on the supervisor to check their work and discuss. Due to their previous experiences, they had different expectations on how to conduct lab work, which caused some tension in the beginning. There were ongoing disagreements - in particular between Hans and Saoirse, who did most of the work - for example on what should be done next, or how to complete a task. They would first try to resolve issues though discussion, which often was successful. When they could not resolve issues, both would seek the supervisor's support for their ideas.

> "*Whoever got the supervisor to say 'yeah, that's a good idea', then that idea won.*" – Hans

Hans attributed the group's early disagreements to differences in their cultural backgrounds, personality, disciplines, and their unfamiliarity with each other. However, over time - as they got to know each other – they became friends. John's lack of effort was not considered to be an issue as the group was very understanding and sympathetic to each other since they all recognised the difference in their prospective workloads.

Interpretation: The diverse backgrounds of the group members caused many disagreements. The group found it challenging to find an effective or consistent approach to establishing social regulation and identifying joint goals, standards and plans to guide collective task completion, which was partly caused by their time management approach. They often invited CoRL from the supervisor in the form of support and advice, but as in the previous episode, failed attempts of SSRL resulted in 'aggressive' CoRL via the supervisor. The group's diversity, initially seen as a problem, became less of an issue over time.

Episode 3: The project supervisors held weekly class meetings where each group would present; their work for that week and their progress against their Gantt chart. These meetings also provided an opportunity to seek feedback and advice from both supervisors and peers.

> "*We met in a classroom. Just to discuss our progress for all projects…. every group would come down and show what they have done so far, and we would discuss.*" – Saoirse

Most of the time, the primary interaction between Hans, Saoirse and John occurred in the hallway after the class meetings, where they would briefly discuss the plan for the coming week. Towards the end of the project, the group jointly finalized the data and prepared the final presentation, seeking support from the supervisor and lab technicians on some details. While Hans delivered the presentation, Saoirse and John created a poster, incorporating audience feedback from the presentation.

Interpretation: The course was highly structured, regularly scaffolding the groups by supporting SSRL in the form of monitoring their progress against their original goals. These weekly meetings also gave the group opportunities to invite co-regulation from their peers and supervisors through support or guidance. Although the group also had planning meetings, indicating SSRL, they were usually brief and only a supplement to the class meetings. The final tasks saw the group engage in SSRL and CoRL, the latter in the form of support and guidance from experts and peers.

Narrative 2

Group 2 participated in a Tracks course on infrastructure and sustainability. The group originally consisted of four master's students; however, one dropped out due to scheduling issues, leaving Sophia, Abdul, and Tadgh to complete the project. Sophia and Abdul had bachelor's degrees in the same discipline, but from different universities and were in similar yet distinct master's degree programmes. Tadgh's bachelor's degree and master's programme were in a different discipline than the others. While the Tracks course was within or related to Sophia and Abdul's discipline, Tadgh's master's had only a loose connection to it. All three were from different countries and cultures.

Episode 1: Initially, Sophia, Abdul, and Tadgh had agreed on a project, but during further

planning found that the scope was too large. Instead, they decided to repeat a failed project of a real estate company. They were familiar with the topic because of their backgrounds, and the prospect of a real project made them enthusiastic after the 'mundane' lectures at the beginning of the course.

> "*Once we thought it was visible and [company] was planning to build it, we thought, OK, maybe this is something that we can really bring into reality. So, we were quite excited about it*." – Abdul

All three members had big ideas on what to include. After some discussion, they formed a project plan, though they decided to not have a specific timeline other than the few course submission deadlines.

Interpretation: The group's ability to jointly agree on, re-evaluate and adjust their goals and plan according to their perceived abilities indicates successful SSRL. Working on an authentic project increased the group's motivation.

Episode 2: The group worked on most tasks separately since they were rarely on campus, providing them with flexibility.

> "*The work was distributed, we worked on our own time because each one of us were from different programs and had our own schedule.*" – Abdul

They held regular meetings but made them short or over lunch and sometimes hybrid or online to overcome scheduling issues and accommodate everyone. The meetings were used to review, discuss, plan, and assign work. They would also help each other clarify concepts.

> "*We discussed if something came up that someone didn't understand, we talked about it*." – Sophia

Everyone's contribution was shared before each meeting to allow for review beforehand. The group was conscious of each other's workloads and understanding if someone was late completing work. Typically, only Sophia would point out mistakes and ask questions for the group to discuss. Occasionally, the group would reach out to their supervisor for advice or help. Abdul repeatedly asked for more of a specific topic to be included. The group discussed it but always refused. Sophia felt Abdul's questions and points were good but also a distraction for the group.

> *"…but it's something he still tried to carry to the project, which, like it was a good thing, but it pulled focus from the main project.*" – Sophia

Interpretation: In addition to planning, the group engaged in monitoring and evaluating work at each meeting, indicating continuous SSRL. A group member voicing a misunderstanding or lack of knowledge triggered CoRL, with the group helping the member. The group showed awareness of each other's workloads and schedules, demonstrating that they monitored each other as individuals. Like the previous group, they sometimes initiated CoRL from their supervisor. The group engaged in SSRL through discussions and negotiations when a change was proposed. Repeated requests of the same change indicate unsuccessful SSRL as Abdul clearly did not agree with the rest of the group.

Episode 3: Sophia, Abdul, and Tadgh worked together on their final presentation and report. At this point, they compared their early draft with their original planning report and realised there were significant deviations. They adapted it accordingly, made their presentation, and incorporated feedback from the audience (supervisors and peers). After a final round of supervisor feedback, they successfully submitted their final report. However, on an individual level, all members were disappointed with their work.

> "*We were also not quite satisfied with the final result…. We personally thought - like each of us personally thought - that we could do much better than this*." – Abdul

They felt their goals could have been more ambitious and challenging. They were also unhappy with the data collection which Abdul felt was hampered by covid restrictions. Although all three had fun and enjoyed working together, Sophia felt the project would have benefitted from having more diverse disciplines in the group.

Interpretation: Even though the group continued to show multiple instances of regular SSRL and invited CoRL from the supervisors and others, they showed a lack of monitoring against their original goals. Despite their dissatisfaction with the final result, their ability to reflect upon their work and identify potential improvements also shows an ability to regulate.

Narrative 3

Group 3 participated in a Tracks course on quantum computing. The group consisted of four master's students: Marjo, Toni, Oskar, and Kerry. Marjo, Toni, and Oskar had bachelor's degrees in the same discipline, but from different Universities. Marjo and Toni were doing the same master's program and were from the same country. Oskar's master's degree was in the same discipline but in a different programme than the others. Kerry, the final member, had a bachelor's degree in a different discipline to the rest of the group, his master's was in the same discipline as the others but in a different programme to them. Oskar and Kerry were also from the same country.

Episode 1: Marjo, Toni, Oskar, and Kerry met multiple times to become acquainted and decide on a project. The course supervisors offered project ideas, but before deciding, the group sought additional information from a professor responsible for one particular lab experiment. The professor supplied papers to read, leading the group to select a project topic. They started planning by creating a Gantt chart for the work. Early disagreements arose primarily due to their limited knowledge, prompting discussions. Everyone's opinion was considered, but whenever a decision could not be reached, they asked the supervisor for help or relied on a particularly knowledgeable member for direction.

> "*We all had solid arguments I would say. We're like 'OK then maybe we have to take this into account' or the one that knew more about [the topic], like, of course, we listened to him. We asked him [Kerry] for some opinions because we just didn't have the knowledge*." – Marjo

Interpretation: The negotiations and careful formation of joint goals and a plan indicate SSRL. They also initiated CoRL by seeking advice and guidance from outside experts or knowledgeable group members when necessary.

Episode 2: The group split into smaller sub-groups as the project contained two distinct parts. Marjo and Toni tackled one part, because it aligned with their backgrounds and they had previously worked together. Kerry's prior experience suited the other part, and he partnered with Oskar, whose background did not fit either part. Consequently, Kerry assumed a leadership role in their sub-group, while Marjo and Toni shared similar knowledge levels. Kerry's expertise proved valuable, as he continuously taught and provided suggestions to the entire group. The four students enjoyed working together, but the sub-groups often had to work in separate labs. Still, they tried to work simultaneously, walking between labs to keep each other informed, ensuring everyone generally knew what was happening.

> "*As we had that continuous feedback between each other, we kind of built up our knowledge in the two things. So, in the end, we all knew about what was going on.*" – Marjo

Interpretation: The students divided the work into smaller parts and formed sub-groups. One sub-group appeared to work in a fairly equalitarian manner, indicating primarily SSRL-based activities. The second group on the other hand, had a clear leader/mentor, suggesting predominantly CoRL-related activities. The deliberate and continuous communication between the sub-groups to keep everyone informed shows effective monitoring of everyone's progress and learning. Kerry's teaching and guidance of the entire group indicate successful CoRL.

Episode 3: All four group members attended joint weekly meetings with their supervisor and the supervisor's team. Each sub-group reported their progress and received feedback, using these meetings to seek help or advice. Additionally, the group organized their own meetings, during which sub-groups updated each other on their work to increase everyone's knowledge of both sub-parts. Occasionally, they used these meetings to work on something together, but the meetings primarily ensured their work remained on track.

> "*We need to force ourselves to focus on the project. Because if not - it's parallel to other courses - you can easily forget about it. [...] It was just also to put ourselves on track of what goals we wanted to achieve throughout the project*." – Marjo

The group valued the importance of listening to and considering everyone's thoughts. This approach led them to get to know each other well. The group's motivation increased throughout the project, and they found they learned a lot.

Interpretation: The supervisor meetings provided the group with opportunities to engage in CoRL through support and guidance. Their own meetings saw monitoring and evaluation of progress against their joint goals, content monitoring (each other's knowledge), and regulation of behaviour (staying focused) - all of which indicates strong SSRL and CoRL. The environment was perceived as positive, with everyone's voice heard and considered, positively affecting motivation and learning.

Episode 4: When a member encountered a problem or struggled to understand something, they informed the whole group. Typically, other members then explained their understanding, also taking into account the level of detail needed for the project's progress.

> "*Sometimes it's just, 'OK, this is a very theoretical thing that maybe I don't need now and I should focus myself to understand another thing in order to deliver*

> *something.' So, you just go for that one and you're happy with some basic explanation."* – Marjo

Regarding specific lab work issues, Marjo and Toni would try to help each other first, then ask the supervisor (team) for assistance. In some cases, Marjo sought help directly from an expert for convenience or if she thought Toni could not help. Throughout the project, disagreements within the group were rare and generally resolved through discussion between the members presenting their arguments to the group for a decision. The group explicitly recognized the importance of compromise and leveraging the members' strengths. They noticed the number of disagreements decreased as they learned more.

Interpretation: The episode contains several instances of CoRL following the expression of unresolved issues or lack of understanding. The sub-group also enacted CoRL for issues, first internally, then externally. The awareness of the importance of negotiation and consensus for resolving disagreements indicates strong SSRL.

Episode 5: During the final meetings, the group determined the content for the final report and presentation, assigned tasks, and practiced the presentation.

> "*We kind of distributed the work, so for the presentation I would say that the one of us that had more time by then or that we just tried to organize the slide.*" – Marjo

For the final report, members worked independently with feedback from the supervisor before adding their parts to a shared document. The group thereby relied on each other's strengths to shape the document; for example, Marjo was more experienced in the project's theoretical aspects, while Kerry was more technical. To ensure clarity, they reviewed each other's sections to see for comprehensibility by a non-expert and provided feedback through comments. Finally, Marjo read the entire report to ensure it was readable, cohesive, and not just a patchwork of contributions. Overall, they got along very well and continued to meet occasionally after the course. They enjoyed the course as it was project-based and involved real research.

Interpretation**:** The negotiation of the presentation and report content and the co-construction of a strategy to complete them indicate the continued application of SSRL. The feedback from the supervisor and peers demonstrates CoRL. Jointly monitoring and evaluating the report against the original joint goals and standards shows SSRL, even when leveraging individual strengths.

Discussion

This study aimed to investigate how interdisciplinary groups regulate their learning, using interviews from three group projects and the resulting narrative episodes. We observed indications of SoRL in all groups, with noteworthy differences in the projects' phases that led to varying perceptions of learning success. Four major themes emerged from our results that we discuss in more detail: (1) goal setting and planning, (2) the implementation phase, (3) the role of supervisors, and (4) the impact of disciplines.

Goal setting and planning

Our findings align with previous research (Iiskala et al., 2015; Hadwin et al., 2017; Miller & Hadwin, 2015) emphasizing the importance of student autonomy in goal setting and planning for SoRL. All three groups displayed considerable dedication during the forethought phase, though their approaches varied. Clear goal setting and active monitoring were crucial, as illustrated by the challenges faced by Group 2, which lacked an overall plan with a set timeline and sub-goals/checkpoints (e.g. a Gantt chart). The student groups' autonomy for choosing their projects stimulated SSRL and encouraged students to devise their own learning goals. Even though early stages of an unstructured project can cause considerable frustration, students are often able to overcome these difficulties and develop effective coping strategies fostering learning (O'Connell et al., 2021). Directive external CoRL during this phase can have negative effects on the students' motivation and socio-emotional state as observed in Group 1. This reflects findings of Wallin et al., (2017a) who noted the importance of allowing student groups to choose the direction of their own project and that formulating goals and plans give groups a sense of ownership (Wallin et al., 2020). Another important factor for student learning emerged through the focus on learning or project completion. This is illustrated through Group 2 that shifted their initial focus from learning to project completion, ultimately resulting in an unsatisfactory learning result. It resonates with similar findings from Zheng et al. (2020) and Järvela et al (2015) stressing the importance of ensuring student groups' focus on learning and collaboration rather than end results as better task performance may not indicate better learning. A suggestion is to focus on assessing the learning process rather than a polished project result, e.g. through reflective writing (e.g. Wedelin et a., 2015).

The implementation phase

Collaborative discussions were the primary form of SoRL during project implementation (see also Ucan and Webb, 2015), though we also observed other methods, such as collaborating on a shared document. SSRL in this phase was often triggered by disagreements or suggested changes to the group's plans and strategies. In line with other research, we found that the group that experienced less difficulty in their project tended to highlight fewer SSRL episodes (Iiskala et al., 2011) and their SSRL in general had a more limited scope, in particular with regard to monitoring (Rogat & Linnenbrink-Garcia 2011), leading to an unsatisfying outcome for the students. This raises questions about the amount and form of 'desirable difficulties' (Bjork & Bjork, 2011) or 'desirable challenges' (O'Connell et al., 2021) that supervisors can post to promote collaboration and SSRL. We also found numerous episodes of internal and external CoRL in this phase. Interestingly, CoRL was often initiated by or embedded into by episodes of SSRL in form of discussions, highlighting the importance of discussions for SoRL and collaborative work in general that emerges from the empirical material, as well as from the research literature (Ucan and Webb, 2015; Wallin 2020). All groups faced scheduling challenges as the courses were electives with a need to align different timetables and workloads, particularly in interdisciplinary groups (see also Taajamaa et al., 2014). Consequently, groups tended to regulate their learning through task-splitting and independent work. While this approach can be effective for project completion (e.g. Lönngren et al., 2017), it reduces collaboration and may lead to misconceptions about effective learning among students (Summer & Volet, 2010).

The role of supervisors

Supervisors played a crucial role in facilitating SoRL for all three groups, mirroring previous work on interdisciplinary project-based learning (O'Connell et al., 2021). Scaffolding, in particular encouraging monitoring and evaluation, benefitted regulation (see also Järvelä et al., 2015), which supports the assertion that supervisors should have some involvement in a group's monitoring and evaluation processes to help the group's SSRL (Järvelä et al.'s,,2015). Our results also show that scaffolding through verbalization helped the groups' metacognition, aligning with Negretti & Mežek's (2019) findings. The scaffolding in question saw groups describe their progress, problems and plans which required them to actively monitor and evaluate their progress and spurred them to think about and ask for advice on current and future strategies. Keeping in mind Wallin et al.'s, (2017a) advice to ensure that groups have the freedom to make their own decisions, we echo Negretti & Mežek's (2019) suggestion that supervisors should take a coaching approach when interacting with groups. That is to say, we recommend that supervisors provide support and guidance where needed but avoid being over-involved. Supervisors should facilitate rather than dictate.

The impact of disciplines

From a disciplinarity perspective, both the projects' and the members' disciplinary contexts influenced the groups' perceptions of learning, organization, and regulation. We observed that the differences in disciplines extended beyond knowledge of subject matter, to include procedural knowledge or even culture. A similar observation was made by Wallin et al., (2017b): different disciplines can have different cultures which in turn will affect interdisciplinary groups, and supervisors themselves bring their own discipline's culture to their course. An example of differences in procedural knowledge or culture are group 1's different experiences of lab work. All three members had lab experience, but for some members lab work was akin to following a set recipe and reporting the results while others expected to work with less direction. Supervisors might be aware of or expect differences in content knowledge in interdisciplinary groups, however they may not be aware of the procedural and cultural differences between disciplines. As with group work in general, simply having interdisciplinary groups work together will not necessarily result in quality collaborative learning.

We conclude this paper with some final reflections about implications for practitioners and further research. Our study builds on works such as Cervin-Ellqvist et al. (2020) highlighting that students often have difficulties in effectively implementing self-regulation strategies for their learning. Our research extends this notion to the challenges of regulating learning as a group. We reiterate our initial statement that instructors should not just assume that students - even on advanced level - will automatically engage in effective regulation or collaborative learning. As such, our findings have important practical implications for educators and learners alike. Our study suggests that educators should be mindful of the difficulties associated with group self-regulation and should consider incorporating explicit instruction on group regulation strategies into their curricula. Students ought to be encouraged to extend their focus beyond the planning phase of a project and engage in micro-lifecycles of planning, monitoring and evaluation throughout the project, while keeping their collective goals in mind. Furthermore, supervisors in interdisciplinary courses must be aware of the groups' composition in terms of disciplines and the potential disparities in procedural knowledge. Students originating from disciplines closely aligned with the course should be urged to undertake more ambitious or challenging plans. Supervisors should strive to adopt a

facilitative, supportive, and guiding role rather than being too directive or prescriptive. A general 'hands-off' approach is preferable once the necessary scaffolding has been established. Moreover, they need to recognize of the potential differences between disciplines that may extend beyond mere background knowledge.

Our study also highlights the need for further research into the effectiveness of such instructional approaches and the factors that influence successful group self-regulation. As previously noted, there is a scarcity of empirical studies that examine SoRL in interdisciplinary groups over a period of time. The interviews and its narrative representation enabled us to present rich data, though the loss of detail and the potential disconnect between the interviewees memories and the actual phenomena are a limitation to be considered (Creswell & Guetterman, 2021). While we encourage the further development of this methodological approach, future studies should experiment with a wider spectrum of data collection methods to balance the analysis of sequences of regulation events with the degree of detail in observing such instances of regulation.

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