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Social regulation of learning in interdisciplinary groupwork

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ABSTRACT

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 found indications of co- and socially shared regulation across all groups, with noteworthy differences in the project phases that led to varying student experiences. We discuss key factors that affected regulation along four themes we identified: (1) goal setting and planning, (2) implementation, monitoring, and evaluation, (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.

Introduction

In this 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, Strobel, and Lee 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), characterised by the integration of innovations such as artificial intelligence, robotics, the internet of things, and digitalisation in physical and digital domains (Boone 2023; Hadgraft and Kolmos 2020). The integration of these technologies requires engineering education to incorporate interdisciplinary collaboration across programmes while also instilling social responsibility and an awareness of societal contexts (Hadgraft and Kolmos 2020). This increasing interdisciplinarity in higher education institutions, particularly in science and engineering, reflects a shift in how knowledge is produced (Negretti and 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 and Henricson Briggs 2020).

While numerous studies have highlighted the benefits of group work (e.g. Johnson and Johnson 2009; O'Donnell 2006; Prince 2004), there remains a misconception that mere participation in group

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work guarantees collaborative learning (Summers and Volet 2010). For effective collaborative learning, groups must be willing to engage in co-construction of knowledge and regulate their strategies to succeed (Järvelä and Hadwin 2013; Summers and Volet 2010). Until relatively recently, research on the regulation of learning 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 collaborative learning where individuals' learning can be regulated by others. The concept of social regulation (Hadwin, Järvelä, and Miller 2017) was developed through 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, Järvelä, and Miller 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 and 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 and Bauer 2000). Further, previous studies have predominantly focused on regulated learning in mono-disciplinary groups (e.g. Järvelä et al. 2013; Malmberg et al. 2015; Panadero et al. 2015) with limited insights into the impact of interdisciplinarity on SoRL. Homogenous groups working on interdisciplinary projects (e.g. DiDonato 2013) differ significantly from interdisciplinary groups. Students taking part in interdisciplinary group work are introduced to new ways of thinking, communicating, and working in a way they would not usually do (Miles and Rainbird 2015). Interdisciplinary group work also allows students to become aware of different approaches to an issue which requires a comparison to identify the best solution. Although some research has examined SoRL in interdisciplinary groups throughout a project (e.g. Bakhtiar and Hadwin 2020), the majority of studies have focused on groups being physically put together to perform set tasks or a number of tasks within a short timeframe e.g. during a class (e.g. Malmberg et al. 2015). We argue that while this does allow for SoRL to be observed it is inherently artificial when compared to how a group works on a project over a longer period of time. Furthermore, few studies have employed interviews (e.g. Järvelä and Järvenoja 2011; Volet and Mansfield 2006), 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 group's 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, Järvelä, and Miller 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, behaviour, emotion, and motivation (Hadwin, Järvelä, and Miller 2017; Pintrich 2004; Zimmerman 2015). Most SRL models divide SRL strategies into different phases. For example, Winne and Hadwin's (1998), suggest four phases: generating a perception or definition of a task; forming a goal and plan to complete the task; the

implementation of the plan; reflection and adaption. However, Winne and Hadwin (1998) themselves concede that many students skip the first phase of their model entirely. The theoretical lens used for this study is based on Zimmerman's (2000) model of self-regulation consisting of three phases: the forethought phase where goals and plans are formed; the performance phase where the plans are enacted, and the work is monitored against the original goals and plan; the self-reflection phase where the completed work is evaluated against the goals and standards and changes are made for the next cycle if needed. This model's forethought phase can be seen as an equivalent to Winne & Hadwin's first two phases. However, while the number of phases varies across these and other 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, and learners moving between different phases.

SoRL builds on SRL by incorporating the regulation of learning that occurs in social settings (Hadwin, Järvelä, and Miller 2017). This is how Zimmerman's (2000) model can be used to identify phases of SoRL as the primary difference between SRL and SoRL lies 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, Järvelä, and Järvenoja 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, 28). 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 and 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 and 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 and Hadwin 2020). The person initiating CoRL can be either the regulator or the person to be regulated (Hadwin, Järvelä, and Miller 2017), and the regulator can even be external to the group. However, CoRL does not account for a group's joint regulation, which is conceptualised 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, Järvelä, and Miller 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, Järvelä, and Miller 2017). It emerges over time through group interactions and exchanges and can therefore be seen as a transactive process (Hadwin, Järvelä, and Miller 2017). To engage in SSRL, group members need to ensure that they share similar perceptions of the group's requirements and are aware of the group's strengths and weaknesses (Miller and Hadwin 2015). Sharing the planning process, for example, can help develop a shared understanding (Ucan and Webb 2015).

What is the link then between SoRL and collaborative learning? Effective collaborative learning involves two components: content processing, and the regulation of content processing (Khosa and Volet 2014; Summers and Volet 2010; Volet, Summers, and Thurman 2009). Content processing involves the construction of knowledge, and the regulation of content processing refers to SoRL (Volet, Summers, and Thurman 2009). Thus, SoRL plays a crucial role in collaborative learning by enabling and supporting shared knowledge construction through collaboration (Miller and Hadwin 2015), so 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 and 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 and Spantidakis 2019; Ucan and 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 and 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 and Hadwin 2015).

Another important aspect of understanding social regulation of learning is linked to the role of the cultural and social environment in shaping CoRL and SSRL, in particular the development of the students' identity within and through interdisciplinary group projects. Interactions in project-based learning are expected to contribute the construction of a professional engineering identity (Paretti and McNair 2015), but also shaped by students' effort to find a balance between social identity and educational pursuits (McQuade et al. 2020). These dimensions become particularly crucial when considering the intersection of cultural and gender differences within diverse group compositions (Chen, Kolmos, and Du 2020; Du 2006)

Further, 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 and 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 and 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 and Hadwin 2020; Rogat and 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 and 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 and 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 and Guetterman 2021) allowing us to examine episodes of

SoRL through their perspectives. 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 presenting them as a narrative (Baron and McNeal 2019). The choice of narratives over alternatives was based on our focus on creating rich cumulative representations of how the groups navigated through their project, rather than emphasising variations of experiences within groups. Narratives also allow us to capture temporal dynamics as the groups' regulatory practices unfold over time, (Creswell and Guetterman 2021; Jovchelovitch and 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, Manion, and Morrison 2011). The narrative representation of key regulatory episodes in three cases of student groups, is our attempt to balance the wishes for situational detail and comparative insight in a limited space.

Research setting and participants

The study participants were enrolled in Tracks courses during the Autumn 2021 semester at Chalmers University of Technology. The courses were 'advanced', meaning they were limited to master's and PhD students, though all of the groups in this study consisted of master's students only. The courses were electives and open to students from different programmes. Course design and content was mainly driven by the teachers. This study did not collect data on their backgrounds, however, Kjellberg et al. (2023) found that while the majority of Tracks teachers had experience of smaller projects (e.g. masters theses) or mono-discipline project based-courses, there was little experience with supervising interdisciplinary project-based courses.

The three Tracks courses featured in this study included a total of 34 students, both Swedish and non-Swedish. All participants had a STEM background and were studying in different engineering fields. Each course ran for four months with the project work typically beginning after the first month and running until the end. Each course provided lectures before and/or during the project work to convey the theoretical and conceptual knowledge required to complete the projects. After several lectures, students were divided into groups of 2–4 for different projects based on interest.

Convenience sampling was used to select three courses and five participants for interviews. Two of the participants came from group 1, two were from group 2, and one was from group 3. Consent was obtained from all students. 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 by the main author after the courses were completed. None of the research team were involved in the teaching, examination or administration of any of the Tracks courses and this was communicated to the interviewees. 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, Manion, and Morrison 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. They ranged in duration from approximately 26–50 min. Pseudonyms were assigned to participants in the presentation of the empirical material. Recognising the potential constrains of interviewing in a digital environment in terms of rapport building, environmental control and privacy, Zoom was

chosen to ensure accessibility and let interviewees talk in a familiar and comfortable environment.

Data analysis

Using Zimmerman's (2000) model of regulation and Miller and 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 and 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 theoretical lens, 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 master's 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, they did not know each other prior to the course. 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, individual 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 SSRL relating to agreeing on a plan for the new project and descended into individuals attempting to engage in aggressive CoRL where an individual attempts to forcefully regulate others. In this case they would try to use the supervisor and their position of perceived power to enforce an idea/position over others in the group. This

had a negative socio-emotional effect on the group. 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 it. 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 their lack of knowledge of the topic, their disciplines, their personalities, and their different ways of doing things which he reflected may be due to differences in their cultural backgrounds. However, over time – as they got to know each other – they became friends and worked better together. 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 various differences between the group members as well as their unfamiliarity with both the topic and each other 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 individuals attempting to engage in aggressive CoRL by having the supervisor support and promote their idea over those of others in the group. 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 finalised 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. The group were happy overall with the course, however the lab work was cut short due to equipment issues. As a result, they felt somewhat satisfied with their work as they were successful in collecting data but felt they could have gotten more especially as their proficiency and knowledge had increased.

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 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, they did not know each other prior to the course.

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 not to 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 to 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 that they were continuously engaging in 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, however, this was not aggressive as the group were inviting this regulation as a form of support. 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 programme 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. Only Marjo and Toni knew each other prior to the course.

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. However, this episode of CoRL is not considered aggressive as the group initiated it seeking guidance as opposed to an individual seeking to impose their ideas on the rest of the group.

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 egalitarian 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 indicates 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 organised 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 recognised 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, Marjo felt that her motivations and personal goals were met.

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 found indications of SoRL in all groups, with noteworthy differences in the projects' phases that led to varying student experiences. From our results, we identified four major themes which we will now discuss in more detail: (1) goal setting and planning, (2) implementation, monitoring, and evaluation, (3) the role of supervisors, and (4) the impact of disciplines. The first two themes align with the regulation phases in Zimmerman's framework, while themes 3 and 4 reflect on critical factors that affected SoRL in our study.

Goal setting and planning

Our findings align with previous research (Hadwin, Järvelä, and Miller 2017; Iiskala et al. 2015; Miller and Hadwin 2015) emphasising 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 shown in Group 1. This reflects findings of Wallin, Adawi, and Gold (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, Adawi, and Gold 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 Järvelä 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 al. 2015).

Implementation, monitoring, and evaluation

Collaborative discussions were the primary form of SoRL during project implementation (see also Ucan and Webb 2015), though other methods, such as collaborating on a shared document were also reported. 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 and Linnenbrink-Garcia 2011), leading to an unsatisfying outcome for the students. This raises questions about the amount and form of 'desirable difficulties' (Bjork and 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 episodes of SSRL in the 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, Ingerman, and Svanström 2017), it reduces collaboration and may lead to misconceptions about effective learning among students (Summers and 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, 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. 2015). Our results also show that scaffolding through verbalisation helped the groups' metacognition, aligning with Negretti and 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, Adawi, and Gold's (2017a) advice to ensure that groups have the freedom to make their own decisions, we echo Negretti and 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. However, this requires a different set of pedagogical and communication skills among supervisors and while project-based courses are becoming more widespread in Engineering Education, it is not a given that teachers, in particular those without specialised training, can live up to these requirements (Kjellberg et al. 2023).

The impact of disciplines

From a disciplinarity perspective, both the projects' and the members' disciplinary contexts influenced the groups' perceptions of learning, organisation, and regulation. We found that the differences in disciplines extended beyond knowledge of subject matter, to include procedural knowledge or even discipline 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. While differences in disciplines and backgrounds did have some negative impact on the groups' SoRL in the initial stages of the projects, this changed as the students learned more about each other and the topic they were working on. Our findings therefore reinforce the notion that supervisors are advised to spend time at the beginning to let students get to know each other personally through icebreaker or similar activities, in order to create relatedness and promote awareness of potential differences in each other's knowledge, disciplinary, and cultural backgrounds (e.g. Wijnen et al. 2018).

To sum up our exploration of regulatory mechanisms and experiences of students in interdisciplinary groups during their learning processes, we conclude that all groups demonstrated elements of SoRL. Though the groups tended to make use of group internal and external expertise inviting co-regulation it was consistently backed by and embedded in episodes of SSRL, predominantly in form of discussions. Thus, in contrast to e.g. Malmberg, Järvelä, and Järvenoja (2017), SSRL was the most commonly reported form of SoRL in our study. Further, while most forms of SoRL were serving the individual and group wide learning goals, we also identified episodes of what we suggest be called 'aggressive co-regulation'. Other studies have observed instances of a member attempting to dominate a group (Grau and Whitebread 2012) or attempts of CoRL with damaging socio-emotional results (Rogat and Linnenbrink-Garcia 2011); however, we feel the term aggressive CoRL properly portrays the negative actions and impact of the regulator.

What factors influenced socially shared regulation? Apart from reinforcing the importance of planning, monitoring and evaluation, our findings stress the importance of iterative monitoring and evaluation against both the current and overall project and learning goals. While the planning phase was typically well developed, the abilities to monitor and evaluate varied substantially and might need extra scaffolding and support. The disciplinary backgrounds of group members, including their cultural and procedural knowledge, influenced collaboration dynamics. Thus, the interdisciplinary character of the courses and groups can create additional difficulties compared to mono-disciplinary contexts. Early familiarisation with peers' backgrounds can alleviate potential conflicts and misunderstandings. Supervisors play a pivotal role in supporting SSRL, with a changing role leaning towards guidance rather than control. Our results emphasise the value of a coaching approach that encourages desirable challenges for the student groups.

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. (2021) 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 an 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 recognise of the potential differences between disciplines that may extend beyond mere background knowledge.

As more institutions begin to implement interdisciplinary groupwork as part of project-based learning our study 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 and 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. Further, one has to consider that the views of the group members not interviewed are missing in the narratives. This is especially prevalent for the narrative of group 3 that only represented by person. Finally, when transferring the results both the unstructured approach to implementing project-based learning in Tracks as well as the advanced educational level of the students in the courses must be considered.

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References

Bakhtiar, A., and A. F. Hadwin. 2020. "Dynamic Interplay Between Modes of Regulation During Motivationally Challenging Episodes in Collaboration." *Frontline Learning Research* 8 (2): 1–34. https://doi.org/10.14786/flr.v8i2.561.

Baron, A., and K. McNeal, eds. 2019. *Case Study Methodology in Higher Education*. Hershey, PA: IGI Global.

Bjork, E. L., and R. A. Bjork. 2011. "Making Things Hard on Yourself, but in a Good way: Creating Desirable Difficulties to Enhance Learning." *Psychology and the Real World: Essays Illustrating Fundamental Contributions to Society* 2: 59–68.

Boone, L. 2023. *Industry 4.0 (Fourth Industrial Revolution)*. Salem Press Encyclopedia.

Cervin-Ellqvist, M., D. Larsson, T. Adawi, C. Stöhr, and R. Negretti. 2021. "Metacognitive Illusion or Self-Regulated Learning? Assessing Engineering Students' Learning Strategies Against the Backdrop of Recent Advances in Cognitive Science." *Higher Education* 82 (3): 477–498. https://doi.org/10.1007/s10734-020-00635-x.

Chen, J., A. Kolmos, and X. Du. 2020. "The Role of Teamwork on Students' Engineering Professional Identity Development in the AAU PBL Model: From the Perspectives of International EngineeringStudents." In *8th International Research Symposium on PBL* (pp. 405-413). Aalborg Universitetsforlag.

Cohen, L., L. Manion, and K. Morrison. 2011. *Research Methods in Education*. (Depending on RTAC solution; 7th ed.). London: Routledge.

Creswell, J. W., and T. C. Guetterman. 2021. *Educational Research: Planning, Conducting and Evaluating Quantitative and Qualitative Research*. (Depending on RTAC solution; 6th ed.). Harlow, Essex: Pearson; Chalmers Library Print Collection.

DiDonato, N. C. 2013. "Effective Self- and co-Regulation in Collaborative Learning Groups: An Analysis of how Students Regulate Problem Solving of Authentic Interdisciplinary Tasks." *Instructional Science* 41 (1): 25–47. https://doi.org/10.1007/s11251-012-9206-9.

Du, X.-Y. 2006. "Gendered Practices of Constructing an Engineering Identity in a Problem-Based Learning Environment." *European Journal of Engineering Education* 31 (1): 35–42. https://doi.org/10.1080/03043790500430185.

Enelund, M., and K. Henricson Briggs. 2020. "Tracks for Change, Flexibility." *Interdisciplinarity and Creativity in Engineering Education, Proceedings of the 16th International CDIO Conference*, 37–47.

Grau, V., and D. Whitebread. 2012. "Self and Social Regulation of Learning During Collaborative Activities in the Classroom: The Interplay of Individual and Group Cognition." *Learning and Instruction* 22 (6): 401–412. https://doi.org/10.1016/j.learninstruc.2012.03.003.

Hadgraft, R. G., and A. Kolmos. 2020. "Emerging Learning Environments in Engineering Education." *Australasian Journal of Engineering Education* 25 (1): 3–16. https://doi.org/10.1080/22054952.2020.1713522.

Hadwin, A. F., S. Järvelä, and M. Miller. 2017. "Self-Regulation, Co-Regulation, and Shared Regulation in Collaborative Learning Environments." In *Handbook of Self-Regulation of Learning and Performance*, edited by Dale H. Schunk and Jeffrey A. Greene, 83–106. New York: Routledge. https://doi.org/10.4324/9781315697048-6.

Iiskala, T., M. Vauras, E. Lehtinen, and P. Salonen. 2011. "Socially Shared Metacognition of Dyads of Pupils in Collaborative Mathematical Problem-Solving Processes." *Learning and Instruction* 21 (3): 379–393. https://doi.org/10.1016/j.learninstruc.2010.05.002.

Iiskala, T., S. Volet, E. Lehtinen, and M. Vauras. 2015. "Socially Shared Metacognitive Regulation in Asynchronous CSCL in Science: Functions, Evolution and Participation." *Frontline Learning Research* 3 (1): 78–111. https://doi.org/10.14786/flr.v3i1.159.

Järvelä, S., and A. F. Hadwin. 2013. "New Frontiers: Regulating Learning in CSCL." *Educational Psychologist* 48 (1): 25–39. https://doi.org/10.1080/00461520.2012.748006.

Järvelä, S., and H. Järvenoja. 2011. "Socially Constructed Self-Regulated Learning and Motivation Regulation in Collaborative Learning Groups." *Teachers College Record: The Voice of Scholarship in Education* 113 (2): 350–374. https://doi.org/10.1177/016146811111300205.

Järvelä, S., H. Järvenoja, J. Malmberg, and A. F. Hadwin. 2013. "Exploring Socially Shared Regulation in the Context of Collaboration." *Journal of Cognitive Education and Psychology* 12 (3): 267–286. https://doi.org/10.1891/1945-8959.12.3.267.

Järvelä, S., P. A. Kirschner, E. Panadero, J. Malmberg, C. Phielix, J. Jaspers, M. Koivuniemi, and H. Järvenoja. 2015. "Enhancing Socially Shared Regulation in Collaborative Learning Groups: Designing for CSCL Regulation Tools." *Educational Technology Research and Development* 63 (1): 125–142. https://doi.org/10.1007/s11423-014-9358-1.

Johnson, D. W., and R. T. Johnson. 2009. "An Educational Psychology Success Story: Social Interdependence Theory and Cooperative Learning." *Educational Researcher* 38 (5): 365–379. https://doi.org/10.3102/0013189X09339057.

Jonassen, D., J. Strobel, and C. B. Lee. 2006. "Everyday Problem Solving in Engineering: Lessons for Engineering Educators." *Journal of Engineering Education* 95 (2): 139–151. https://doi.org/10.1002/j.2168-9830.2006.tb00885.x.

Jovchelovitch, S., and M. W. Bauer. 2000. "Narrative Interviewing." In *Qualitative Researching With Text, Image and Sound: A Practical Handbook*, edited by M. W. Bauer, and G. Gaskell, 57–74. London: Sage.

Khosa, D. K., and S. E. Volet. 2014. "Productive Group Engagement in Cognitive Activity and Metacognitive Regulation During Collaborative Learning: Can it Explain Differences in Students' Conceptual Understanding?" *Metacognition and Learning* 9 (3): 287–307. https://doi.org/10.1007/s11409-014-9117-z.

Kjellberg, M., M. T. O'Connell, B. Bergman, C. Stöhr, and J. Larsson. 2023. *Teachers' Reflections on Their Experiences Teaching Interdisciplinary Project-Based Courses*. 51st SEFI conference: Engineering Education for Sustainability.

Lajoie, S. P., L. Lee, E. Poitras, M. Bassiri, M. Kazemitabar, L. Cruz-Panesso, C. Hmelo-Silver, J. Wiseman, L. K. Chan, and J. Lu. 2015. "The Role of Regulation in Medical Student Learning in Small Groups: Regulating Oneself and Others' Learning and Emotions." *Computers in Human Behavior* 52: 601–616. https://doi.org/10.1016/j.chb.2014.11.073.

Lönngren, J., Å Ingerman, and M. Svanström. 2017. "Avoid, Control, Succumb, or Balance: Engineering Students' Approaches to a Wicked Sustainability Problem." *Research in Science Education* 47 (4): 805–831. https://doi.org/10.1007/s11165-016-9529-7.

Malmberg, J., S. Järvelä, and H. Järvenoja. 2017. "Capturing Temporal and Sequential Patterns of Self-, co-, and Socially Shared Regulation in the Context of Collaborative Learning." *Contemporary Educational Psychology* 49: 160–174. https://doi.org/10.1016/j.cedpsych.2017.01.009.

Malmberg, J., S. Järvelä, H. Järvenoja, and E. Panadero. 2015. "Promoting Socially Shared Regulation of Learning in CSCL: Progress of Socially Shared Regulation among High- and low-Performing Groups." *Computers in Human Behavior* 52: 562–572. https://doi.org/10.1016/j.chb.2015.03.082.

McQuade, R., E. Ventura-Medina, S. Wiggins, and T. Anderson. 2020. "Examining Self-Managed Problem-Based Learning Interactions in Engineering Education." *European Journal of Engineering Education* 45 (2): 232–248. https://doi.org/10.1080/03043797.2019.1649366.

Miles, M., and S. Rainbird. 2015. "Evaluating Interdisciplinary Collaborative Learning and Assessment in the Creative Arts and Humanities." *Arts and Humanities in Higher Education* 14 (4): 409–425. https://doi.org/10.1177/1474022214561759.

Miller, M., and A. Hadwin. 2015. "Scripting and Awareness Tools for Regulating Collaborative Learning: Changing the Landscape of Support in CSCL." *Computers in Human Behavior* 52: 573–588. https://doi.org/10.1016/j.chb.2015.01.050.

Negretti, R., and L. McGrath. 2022. "Setting the Stage (s) for English for Research and Publication Purposes: Authors, Audiences, and Learning the Craft." *Ibérica* 43: 7–26. https://doi.org/10.17398/2340-2784.43.13.7.

Negretti, R., and Š Mežek. 2019. "Participatory Appropriation as a Pathway to Self-Regulation in Academic Writing: The Case of Three BA Essay Writers in Literature." *Journal of Writing Research* 11 (1): 1–40. https://doi.org/10.17239/jowr-2019.11.01.01.

O'Connell, M., T. Adawi, H. Trefna, A. Ström, and C. Stöhr. 2021. "Challenge Episodes and Coping Strategies in Undergraduate Engineering Research." 49th SEFI Conference: Blended Learning in Engineering Education: challenging, enlightening–and lasting?

O'Donnell, A. M. 2006. "The Role of Peers and Group Learning." In *Handbook of Educational Psychology*, edited by P. A. Alexander, and P. H. Winne, 781–802. New York: Lawrence Erlbaum Associates Publishers.

Panadero, E., and S. Järvelä. 2015. "Socially Shared Regulation of Learning: A Review." *European Psychologist* 20 (3): 190–203. https://doi.org/10.1027/1016-9040/a000226.

Panadero, E., P. A. Kirschner, S. Järvelä, J. Malmberg, and H. Järvenoja. 2015. "How Individual Self-Regulation Affects Group Regulation and Performance: A Shared Regulation Intervention." *Small Group Research* 46 (4): 431–454. https://doi.org/10.1177/1046496415591219.

Paretti, M. C., and L. D. McNair. 2015. "Analyzing the Intersections of Institutional and Discourse Identities in Engineering Work at the Local Level." In *Sociotechnical Communication in Engineering*, edited by Jon Leydens, 55–78. London: Routledge.

Pintrich, P. R. 2000. "Chapter 14—The Role of Goal Orientation in Self-Regulated Learning." In *Handbook of Self-Regulation*, edited by M. Boekaerts, P. R. Pintrich, and M. Zeidner, 451–502. San Diego, CA: Academic Press. https://doi.org/10.1016/B978-012109890-2/50043-3.

Pintrich, P. R. 2004. "A Conceptual Framework for Assessing Motivation and Self-Regulated Learning in College Students." *Educational Psychology Review* 16 (4): 385–407. https://doi.org/10.1007/s10648-004-0006-x.

Prince, M. 2004. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education* 93 (3): 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x.

Rogat, T. K., and L. Linnenbrink-Garcia. 2011. "Socially Shared Regulation in Collaborative Groups: An Analysis of the Interplay Between Quality of Social Regulation and Group Processes." *Cognition and Instruction* 29 (4): 375–415. https://doi.org/10.1080/07370008.2011.607930.

Seiradakis, E., and I. Spantidakis. 2019. "Socially-Shared Metacognitive Regulation Episodes Between Undergraduate Engineering Students During a Collaborative Genre Analysis Task in an English for Academic Purposes Course." *English Language Teaching* 12 (6): 217–225. https://doi.org/10.5539/elt.v12n6p217.

Summers, M., and S. Volet. 2010. "Group Work Does Not Necessarily Equal Collaborative Learning: Evidence from Observations And Self-Reports." *European Journal of Psychology of Education* 25 (4): 473–492. https://doi.org/10.1007/s10212-010-0026-5.

Taajamaa, V., T. Westerlund, Guo Xing, M. Hupli, S. Salanterä, and T. Salakoski. 2014. "Interdisciplinary Engineering Education—Practice Based Case." *Fourth Interdisciplinary Engineering Design Education Conference*, 31–37. https://doi.org/10.1109/IEDEC.2014.6784677.

Ucan, S., and M. Webb. 2015. "Social Regulation of Learning During Collaborative Inquiry Learning in Science: How Does it Emerge and What are its Functions?" *International Journal of Science Education* 37 (15): 2503–2532. https://doi.org/10.1080/09500693.2015.1083634.

Volet, S., and C. Mansfield. 2006. "Group Work at University: Significance of Personal Goals in the Regulation Strategies of Students with Positive and Negative Appraisals." *Higher Education Research & Development* 25 (4): 341–356. https://doi.org/10.1080/07294360600947301.

Volet, S., M. Summers, and J. Thurman. 2009. "High-level co-Regulation in Collaborative Learning: How Does it Emerge and how is it Sustained?" *Learning and Instruction* 19 (2): 128–143. https://doi.org/10.1016/j.learninstruc.2008.03.001.

Wallin, P. 2017. "The Potential of Complex Challenges in Undergraduate Research to Stimulate Transformative Learning." *Nordic Journal of STEM Education* 1 (1): 307–318. https://doi.org/10.5324/njsteme.v1i1.2339.

Wallin, P. 2020. "Student Perspectives on co-Creating Timescapes in Interdisciplinary Projects." *Teaching in Higher Education* 25 (6): 766–781. https://doi.org/10.1080/13562517.2020.1777962.

Wallin, P., T. Adawi, and J. Gold. 2017a. "Linking Teaching and Research in an Undergraduate Course and Exploring Student Learning Experiences." *European Journal of Engineering Education* 42 (1): 58–74. https://doi.org/10.1080/03043797.2016.1193125.

Wallin, P., T. Adawi, and J. Gold. 2020. "Involving Undergraduate Students in Research: Practices, Promises and Pointers." *International Journal of Engineering Education* 36 (3): 1–12.

Wallin, P., R. Lyng, B. Sortland, and S. Veine. 2017b. "Experts in Teamwork-A Large Scale Course for Interdisciplinary Learning and Collaboration." In *13th International CDIO Conference*, edited by Robert Brennan, Kristina Edström, Ron Hugo, Janne Roslöf, Robert Songer, and Daniel Spooner, 1–11. Calgary, Canada: University of Calgary.

Wedelin, D., T. Adawi, T. Jahan, and S. Andersson. 2015. "Investigating and Developing Engineering Students' Mathematical Modelling and Problem-Solving Skills." *European Journal of Engineering Education* 40 (5): 557–572. https://doi.org/10.1080/03043797.2014.987648.

Wijnen, M., S. M. M. Loyens, L. Wijnia, G. Smeets, M. J. Kroeze, and H. T. Van der Molen. 2018. "Is Problem-Based Learning Associated with Students' Motivation? A Quantitative and Qualitative Study." *Learning Environments Research* 21 (2): 173–193. https://doi.org/10.1007/s10984-017-9246-9.

Winne, P. H., and A. F. Hadwin. 1998. "Studying as Self-Regulated Learning." In *Metacognition in Educational Theory and Practice*, edited by Douglas J. Hacker, John Dunlosky, and Arthur C. Graesser, 277–304. New York: Lawrence Erlbaum Associates Publishers.

Zheng, J., W. Xing, G. Zhu, G. Chen, H. Zhao, and C. Xie. 2020. "Profiling Self-Regulation Behaviors in STEM Learning of Engineering Design." *Computers & Education* 143: 103669. https://doi.org/10.1016/j.compedu.2019.103669.

Zimmerman, B. J. 2000. "Attaining Self-Regulation: A Social Cognitive Perspective." In *Handbook of Self-Regulation*, edited by Monique Boekaerts, Paul Pintrich, and Moshe Zeidner, 13–39. San Diego, CA, US: Academic Press. https://doi.org/10.1016/B978-012109890-2/50031-7.

Zimmerman, B. J. 2015. "Self-Regulated Learning: Theories, Measures, and Outcomes." *International Encyclopedia of the Social & Behavioral Sciences* 21: 541–546. https://doi.org/10.1016/B978-0-08-097086-8.26060-1.