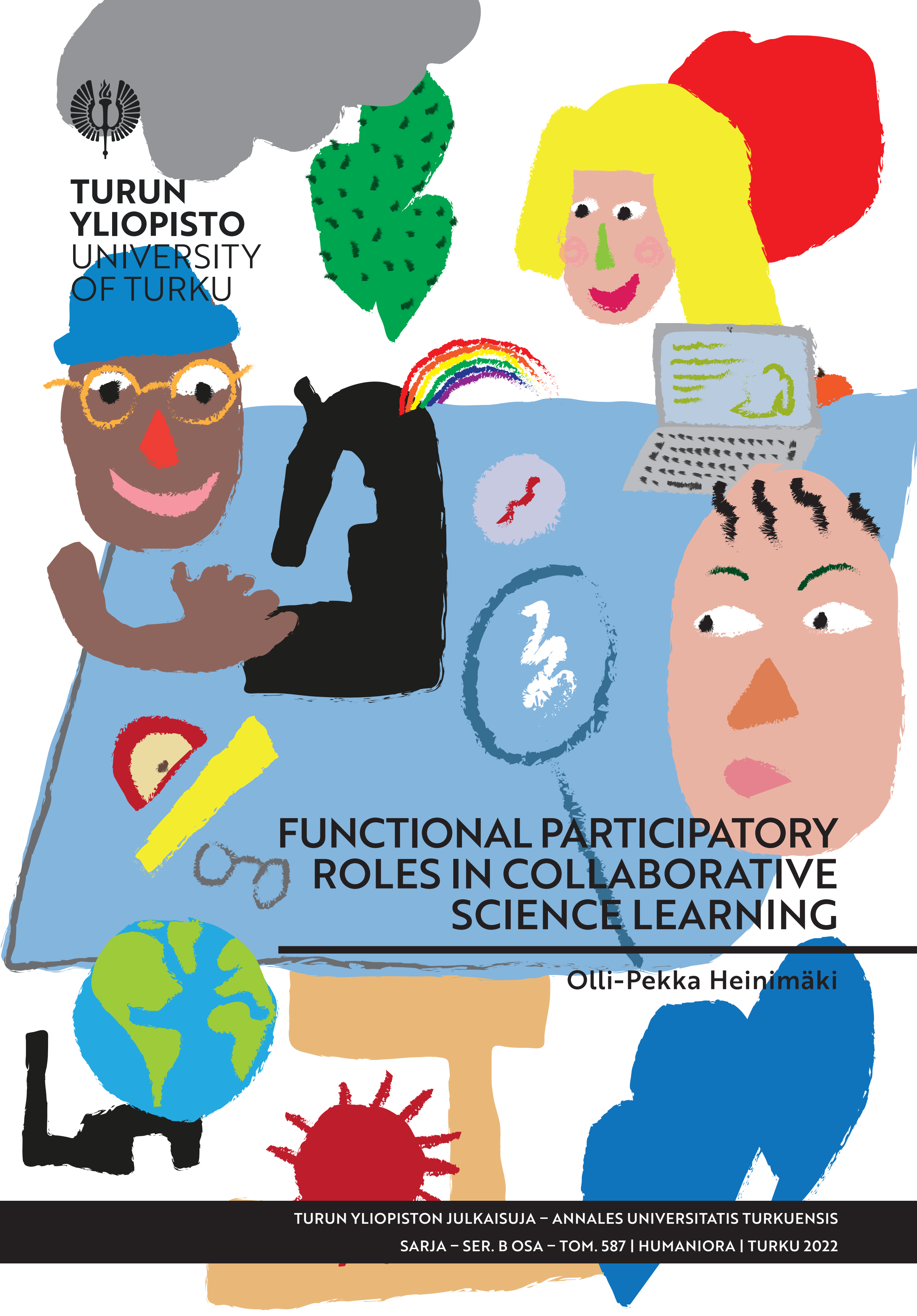

TURUN YLIOPISTO
UNIVERSITY OF TURKU

FUNCTIONAL PARTICIPATORY ROLES IN COLLABORATIVE SCIENCE LEARNING

Olli-Pekka Heinimäki

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA – SER. B OSA – TOM. 587 | HUMANIORA | TURKU 2022

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ABSTRACT

Research on roles in collaborative learning has concentrated mainly on roles that are prescribed for students while only limited attention has been devoted to roles that emerge naturally during collaboration. To address this gap, this thesis adopted a situative approach to study *the functional participatory roles* that emerge spontaneously and are self-enacted by students during collaborative learning and examined the significance of such roles in collaborative learning. Three datasets on students collaborating on inquiry-based science activities in small groups made up the data for the thesis. The role analyses were based on systematic video-observations, including a detailed analysis of emergent roles from videotaped group activities and a subsequent hierarchical cluster analysis to identify student role profiles. These analyses were consolidated further with an in-depth qualitative approach.

The thesis consists of three studies. Study I investigated the emergence of functional participatory roles in a computer-supported science inquiry and developed an analytical coding scheme for their analysis. Fine-grained analysis of the video data identified 17 distinct functional participatory roles self-enacted by the students and provided empirical support for the spontaneous, interactive, and dynamically evolving nature of roles in collaborative learning. Study II developed a scalable framework for analysing these emergent roles across a range of collaborative science learning environments. This flexible framework distinguishes between the *core roles* that resemble each other across different science learning settings and *activity-specific roles* that are unique to a particular context. Finally, Study III examined the relationships between group achievement and within-group configurations of role profiles. The results revealed striking differences in role configuration between higher- and lower-achieving groups. Taken together, this thesis extend existing understanding of spontaneously self-enacted roles and their significance in collaborative science learning and consolidate methodology in this area.

KEYWORDS: Roles, collaborative learning, role analysis, video observation

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TIIVISTELMÄ

Roolien tutkimus yhteisöllisessä oppimisessa on pääosin keskittynyt opiskelijoille ennalta määriteltyihin rooleihin, kun taas yhteistyön aikana luontaisesti esiintyviä rooleja on tutkittu vain vähän. Siten tämän väitöskirjan tarkoituksena oli tutkia spontaanisti esiintyviä, opiskelijoiden itsensä omaksumia *funktionaalisia osallistumisen rooleja* situatiivista näkökulmaa hyödyntäen ja tarkastella näiden roolien merkitystä yhteisöllisessä oppimisessa. Tutkimusaineisto koostui kolmesta luonnontieteiden tutkivan oppimisen aineistosta, joissa opiskelijat toimivat keskenään pienryhmissä. Systemaattiseen videohavainnointiin perustuva roolien tarkastelu sisälsi funktionaalisten osallistumisen roolien yksityiskohtaisen analysoinnin videoaineistosta ja tähän analyysiin pohjautuvan hierarkkisen klusterianalyysin opiskelijoiden rooliprofiilien tunnistamiseksi. Näitä analyyseja syvennettiin laadullisella tutkimusotteella.

Väitöskirja koostuu kolmesta osatutkimuksesta. Ensimmäinen tutkimus kohdistui tietokoneavusteisessa luonnontieteiden yhteisöllisessä oppimisessa esiintyvien funktionaalisten osallistumisen roolien tunnistamiseen tutkimuksessa kehitetyn analyysirungon avulla. Videoaineiston yksityiskohtaisella analysoinnilla tunnistettiin 17 erilaista opiskelijoiden omaksumaa roolia. Tutkimus vahvisti myös empiirisesti käsitystä roolien spontaanista, vuorovaikutteisesta ja dynaamisesti kehittyvästä luonteesta yhteisöllisessä oppimisessa. Toisessa osatutkimuksessa kehitettiin skaalautuva viitekehys tällaisten spontaanien roolien analysoimiseksi erilaisista luonnontieteiden yhteisöllisen oppimisen ympäristöistä. Tämä joustava viitekehys koostuu *ydinrooleista*, jotka ovat yhteneväisiä monien eri luonnontieteiden yhteisöllisen oppimisen ympäristöjen välillä, ja *aktiviteettispesifeistä* rooleista, jotka ovat omanlaisia tietylle kontekstille. Kolmannessa tutkimuksessa tutkittiin pienryhmien sisäisten rooliprofiilikokoonpanojen yhteyttä ryhmän suoritukseen. Tutkimuksessa havaittiin huomattavia eroja opiskelijoiden rooliprofiileissa paremmin ja heikommin suoriutuneiden ryhmien välillä. Väitöskirja laajentaa ymmärrystä opiskelijoiden spontaanisti omaksumista rooleista ja niiden merkityksestä luonnontieteiden yhteisöllisessä oppimisessa ja tarjoaa metodologisia edistysaskeleita tälle tutkimuskentälle.

ASIASANAT: Roolit, yhteisöllinen oppiminen, roolianalyysi, videohavainnointi

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First of all, I want to express my sincere gratitude to my supervisors, Professor Marja Vauras, Professor Simone Volet, and University Research Fellow Tuike Iiskala for guiding me along the doctoral thesis path. I am thankful to Marja for the invaluable opportunity to work on her research projects; this thesis would not exist without her support and trust. I admire Marja's keen eye for the wider picture, which was crucial at several points during my research when I was struggling to see the forest for the trees. Simone's deep knowledge of education psychology (and beyond) never ceases to amaze, and her commitment and constant innovation are truly inspiring. Working with Simone has also improved my academic writing skills. It has been a privilege to have Tuike on my team. She is always ready to offer help and guidance, and I have learned a great deal from her about the importance of attention to detail in research.

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I have learned that research is a resource-consuming job, and I am grateful to the Turku University Foundation, the Emil Aaltonen Foundation, and the OPPI doctoral programme for all their financial and other support for my research work and PhD studies. While I have also come to realise that the content is what really matters, I believe that no thesis is truly complete without a great cover. Thus, I thank Max Kanerva for the awesome cover picture, which really does capture the essence of the thesis. I am deeply grateful to Maikki Pouta for all the support within and beyond work. Maikki has an extraordinary talent for always encouraging me and cheering me up when I am doubting myself or struggling with my research, and I look forward to continuing our promising collaboration. Finally, I want to thank my parents and family for always being there for me; having people in your life that you can fully trust to have your back no matter what you are trying to achieve is a truly precious asset.

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List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Heinimäki, O-P., Salo, A-E., & Vauras, M. Luonnontieteiden yhteisöllisessä tietokoneavusteisessa oppimisessa omaksuttujen funktionaalisten osallistumisen roolien luokittelun kehittely [Development of a classification for functional participatory roles enacted during computer-supported collaborative science learning]. *Psykologia*, 2019; *54*(04): 236–254.

II Heinimäki, O-P., Volet, S., & Vauras, M. Core and activity-specific functional participatory roles in collaborative science learning. *Frontline Learning Research*, 2020; *8*(2): 65–89.

III Heinimäki, O-P., Volet., S., Jones, C., Laakkonen, E., & Vauras, M. Student participatory role profiles in collaborative science learning: Relation of within-group configurations of role profiles and achievement. *Learning, Culture and Social Interaction*, 2021; *30*, Article 100539.

In each publication, Heinimäki contributed to the conceptualization and designing of the study, and was responsible for the data analysis and writing of the manuscript.

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1 Introduction

Roles are fundamental in social activities, and they can be found almost anywhere people interact and work together (Biddle, 1986). Indeed, whether considering a work team undertaking a task, a group of students learning something together or a sports team competing against an opponent, roles are one of the key ingredients that structure productive group interactions and task performance (Forsyth, 2014; Katz & Kahn, 1978; Turner, 2002). Although humans have always relied on collaboration (Kozlowski & Ilgen, 2006; O'Madagain & Tomasello, 2022), the 21st century has brought growing requirements for the need to successfully collaborate and work together with others towards a collective aim (OECD; Organisation for Economic Co-operation and Development, 2019). For more meaningful and productive participation in different areas of society, individuals must learn how to act in meaningful roles when interacting and collaborating with others. Although studied extensively in other fields such as organisational sciences (Driskell et al., 2017; Lehmann-Willenbrock et al., 2016), there exists surprisingly little research on roles and their significance in collaborative learning. Furthermore, the existing research in this context has mainly focused on studying the impact of roles that are prescribed for learners prior to a collaborative activity, even though the practical reality in real-life classrooms is that collaborative activities are typically organised without any predefined individual responsibilities or roles (Kirschner & Erkens, 2013). This thesis addresses this gap by focusing on the roles that spontaneously emerge as a collaborative activity unfolds. The studied collaborative learning context in this thesis was science activities because science is a highly demanding and societally important discipline, making it a particularly fruitful context to examine emergent roles in relation to group processes and collaborative learning outcomes (cf. Songer & Kali, 2014).

To clarify the focus of this thesis further, I note that while the term 'role' originated as a dramaturgical analogy to paper rolls on which actors' lines were written, the term has become ubiquitous and taken on multiple different meanings (Driskell et al., 2017). Although the early phases of research that employed a dramaturgical approach to roles (e.g., Goffman, 1959), where 'parts' and 'scripts' played by the actors were believed to structure real-life social drama like in a theatre, were perhaps the most influential, soon, a number of competing theories emerged (Biddle, 1986). For instance, Linton (1936) claimed that roles are inseparable from status, position and norms, whereas Moreno (1934) highlighted the importance of role-playing as a mechanism to learn how to perform different roles in a society. Mead (1934) then made an important contribution to understanding how roles are shaped during interactions by suggesting that role taking is a dynamic process in which individuals select their own roles based on how they perceive the roles of the people with whom they are interacting. While the main focus of this early research was on society-based roles, today, roles are studied from multiple perspectives within different disciplines (Hare, 1994; Stets & Thai, 2010). Although roles can be broadly defined as a set of behaviour characteristics of an individual in a particular context, there exists no single universally agreed upon conceptualisation of what constitutes a role (Biddle, 1979; Driskell et al., 2017; Turner, 2002).

In general, rather than focusing on formal roles that relate to a certain position, status or contract, the present thesis's focus is on the informal roles that emerge spontaneously and evolve naturally during interactions as observable behaviours (Forsyth, 2014; Van Rossem & Vermande, 2004). Specifically, this thesis explores what *functional participatory roles* and role profiles are self-enacted by students during collaborative science learning, develops observation-based methods to capture the dynamic and interactive nature of roles and examines their significance for collaborative learning processes and achievement. Collaborative learning provides an intriguing context to study the roles that emerge spontaneously during social interaction because collaborative learning groups typically consist of peers who share basically the same opportunities to contribute to group activity, thus enabling them to self-adopt roles over the course of a learning activity without any notable formal constraints (Kirschner & Erkens, 2013).

2 Functional participatory roles in collaborative learning

This section starts by describing what 'collaborative learning' means and how collaborative learning activities are utilised in science classrooms with the aim of promoting learning outcomes. This is followed by a review of previous research on roles in task groups and collaborative learning. Furthermore, a case is built for the need to shift the focus from roles that are prescribed to students to functional participatory roles that emerge spontaneously and evolve dynamically throughout the course of collaborative learning. Then, methodological questions related to the research on emergent roles are discussed. Finally, the scarce empirical evidence on the significance of emergent roles in collaborative science learning is scrutinised.

2.1 Collaborative learning in science

In the simplest sense, collaborative learning can be understood as "a situation in which two or more people learn or attempt to learn something together" (Dillenbourg, 1999, p. 1). Learning activities grounded in students' collaboration in small groups are widely used in today's classrooms across different educational levels and disciplines (Sawyer, 2005). The popularity of collaborative learning stems from contemporary theories on learning highlighting that learning does not merely happen in the mind of the individual but fundamentally occurs as a result of social activity (Salomon & Perkins, 1998). However, not all group work is categorically conceived as 'collaborative' (Summers & Volet, 2010). According to Roschelle and Teasley's (1995) widely celebrated definition, collaborative learning refers to participants' mutual and active engagement in "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (p. 70). The term 'collaboration' in this definition highlights that the participants are expected to truly work *together* towards a common goal (Dillenbourg, 1999). This differs from 'cooperative' learning in which the group work is divided into separate sub-tasks, which the participants first undertake their duties individually and then finally put the separate parts together to construct the group product (e.g., the Jigsaw technique; Aronson et al., 1978). Following Baker

(2015), it can be summarised that "[c]ollaboration is a specific form of cooperation: cooperation works on the level of tasks and actions, collaboration works on the plane of ideas, understanding, representations" (p. 458).

In reference to the term 'learning', collaborative activities can cultivate students' collaboration skills as they learn how to work successfully together to accomplish a shared goal (O'Donnell & Hmelo-Silver 2013; Webb, 2008). Even more importantly, they offer a venue where students together can discuss their ideas, share information, exchange arguments and so forth (Dillenbourg, 1999; Summers & Volet, 2010). The opportunity for this co-construction process may, at its best, lead to new knowledge and understanding that cannot be traced back to any individual student (Weinberger et al., 2007). Indeed, ample evidence has demonstrated the positive effects of collaborative learning on knowledge gain, increased academic performance, process outcomes and favourable attitudes towards learning, to name a few (see Chen et al., 2018; Jeonga et al., 2019; Springer et al., 1999 for meta-analyses). However, this potential is not always realised due to pitfalls that may hinder productive collaboration, including a number of cognitive, socioemotional and regulatory issues (Cohen, 1994; Kirschner et al., 2018; Kreijns et al., 2003; Nokes-Malach et al., 2015; Näykki et al., 2021). Collaborative learning research has demonstrated the crucial role of interactions in explaining why some groups can function, perform and learn more efficiently than others (Baker, 2015; Howe, 2021; Nasir et al., 2022). For example, Barron (2003) found that groups more successful at problem-solving discussed correct proposals further and linked them to previous discussions more often in comparison to less successful groups. Successful collaboration was also characterised by group members' joint attention during the learning activity, which was achieved through the interplay of two complementary roles: the *speaker* and *listener*.

Particularly in science classrooms, collaborative learning is often organised around inquiry-based tasks (Anderson, 2007; Loyens & Rikes, 2010; Woods-McConneya et al., 2016), as in the present thesis. The notion of inquiry-based learning originates from John Dewey, who emphasised the important role of active inquiry in acquiring scientific knowledge as opposed to more passive and traditional strategies such as rote learning (Bell et al., 2009). The purpose of collaborative inquiry is to engage students in scientific practices that model what scientists actually do and how they think. This process consists of three broader aspects: *learning to do inquiry* (e.g., planning and conducting investigations, gathering and analysing data, drawing conclusions and communicating the findings), *learning about inquiry* (e.g., learning about the nature of science and how scientific knowledge is acquired) and *learning through inquiry* (e.g., co-construction of knowledge, conceptual understanding and hands-on skills) (Chen et al., 2021; Minner et al., 2010; Lehtinen, et al., 2017). Furthermore, learning environments and tasks authentic to the discipline are emphasised, as it is assumed that situating the inquiry within real-word contexts is important for meaningful learning (Joolingen et al., 2005). Inquiry activities can be more or less student led, but typically, the main role of the teacher is facilitative and guiding rather than directive (Dobber et al., 2017).

However, the effectiveness of inquiry-based learning has also been questioned (Jerrima et al., 2019). Critics have conceived inquiry activities as totally unstructured ‘discovery learning’ and claimed that these activities leave the learners with minimal guidance and instruction, resulting in too great of a cognitive load, particularly for students lacking sufficient prior knowledge and skills required to succeed in the task (e.g., Kirschner et al., 2006; Zhang et al., 2021). Hmelo-Silver et al. (2007; see also Schmidt et al., 2007) debunked this critique by claiming that inquiry-based learning does not equal a minimally guided approach “but rather provide extensive scaffolding and guidance to facilitate student learning” (p. 99). They delivered further evidence on how inquiry-based activities can foster learning when adequately designed and implemented.

Today, computer-supported collaborative learning (CSCL) environments aimed at facilitating meaningful collaborative science inquiry are constantly increasing (Gnesdilow & Puntambekar, 2021; van der Graaf et al., 2020). These environments can provide opportunities for authentic inquiry that goes beyond the possibilities of typical science classrooms and facilitate the learning process with automatic scaffolds that are incorporated in the design (Azevedo & Hadwin, 2005; de Jong et al., 2021; Duschl & Hamilton, 2011; Sinha et al., 2015). Engle and Conant (2002) also raised the importance of design in their conceptual framework of productive disciplinary engagement. To promote deeper science engagement and learning, Engle and Conant endorsed the use of science activities that allow to problematise learning content, provide adequate resources and authority for learners to solve those problems and keep the learners accountable to each other and discipline practices. Although productive disciplinary engagement was not directly studied in this thesis (e.g., Koretsky et al., 2019), it is contextually relevant because all three collaborative contexts involved were designed according to the aforementioned design principles (see, Iiskala et al., 2021; Vauras et al., 2019; Volet et al., 2019). In particular, granting authority and agency to the students in learning activities provides fertile soil for studying roles that are spontaneously emergent and self-adopted.

2.2 From prescribed roles to functional participatory roles: Theoretical underpinnings

For the research of roles in education and learning, research in organisational and small-group contexts has been particularly influential. Research in these contexts has traditionally focused on the exploration of roles during task-oriented phases of group work (Hare, 1994). This research has generated a plethora of different role typologies that describe different roles related to work teams and small groups (Driskell et al., 2017). For instance, Benne and Sheats' (1948/2007) oft-cited typology of 'functional roles of group members' described 27 distinct roles that were identified to emerge in group interactions during problem-solving activities (such as *the information seeker, the elaborator, the encourager, the follower, the dominator* and *the aggressor*). A few years later, Bales (1950) listed 12 categories of role behaviours, of which six were related to task aspects (e.g., giving and seeking information) and six were related to socioemotional aspects (e.g., showing tension or releasing tension). By aggregating observed individual behaviours based on these categories, Bales suggested two distinct role profiles, *task-specialist* and *socioemotional specialist,* that group members commonly exhibit in groups. Even though "an extraordinary range of roles have been suggested" (Moxnes, 1999, p. 110) since these early studies and a "universally accepted taxonomy of team member roles does not exist" (Stewart et al., 2005, p. 346), there is an agreement that most distinct roles in small task groups fall into being either *task* or *socioemotionally* focused (Driskell et al., 2017). Task roles contribute to task completion and content, whereas socioemotional roles contribute to positive group building, or alternatively, reflect individual needs or attitudes that might not align with the needs and goals of the group and thus can turn out to be dysfunctional (Benne & Sheats, 1948/2007; Lehmann-Willenbrock et al., 2016).

In the context of collaborative learning, two predominant approaches to roles can be distinguished: *prescribed* and *emergent* roles (Strijbos & Weinberger, 2010). As further elaborated in the following, prescribed roles refer to the kind of roles that are scripted and often assigned a priori for the students in the activity, whereas emergent roles are allowed to spontaneously emerge and be enacted without external interference (Pozzi, 2011).

Prescribed roles approach

Prescribed roles typically encompass a specific duty or task expected to be carried out by the role holder, the aim being to structure the collaborative effort and support productive interactions, such as argumentation and knowledge building, in which the learners do not always engage spontaneously (Strijbos & Weinberger, 2010). The value of prescribed roles in elevating the quality of group work and learning has long been recognised (e.g., Cohen, 1994; Dillenbourg et al., 1996; Johnson & Johnson, 1989; Slavin, 1996). For instance, Johnson and Johnson (1989) considered assigning roles, such as *reader*, *recorder* and *summariser*, for students as an effective way to strengthen positive interdependence between them. Prescribed roles have also been used successfully in peer tutoring in which learners working in pairs act in or alter between the roles of tutee or tutor during a shared learning task (e.g., Annis, 1983; King et al., 1998). More recently, the value of prescribed roles has been particularly acknowledged in the field of CSCL, where they have not only been found useful in structuring productive collaboration, but also in tackling thorny issues that the CSCL environment can be especially vulnerable to, such as unequal participation (e.g., Cesareni et al., 2016; Cheng et al., 2014; De Wever, Van Keer, Schellens, & Valcke, 2010; Farrow et al., 2021; Gu et al., 2015; Jiang, 2017; Morris et al., 2010; Pozzi, 2011). For instance, Cheng et al. (2014) used three prescribed roles (*metacognitive, cognitive* and *socioemotional leader*) that each had different foci towards collaboration to structure meaningful group activities during collaborative concept mapping. In turn, Gu et al. (2015) used six prescribed roles (*starter*, *arguer*, *questioner*, *supporter*, *challenger* and *timer*) that each had a specific task in group interaction to engage students in the co-construction of knowledge in an online environment. There is evidence that groups with prescribed roles can outperform nonprescribed groups in the quality of collaborative learning outcomes (Lazareva, 2021); however, not all studies have demonstrated such an effect (e.g., Strijbos et al., 2004; Zheng et al., 2014).

Although research on prescribed roles has obvious merits and has greatly expanded our understanding of how roles structure and influence productive collaborative learning, the prevailing focus on such roles has not come without challenges and limitations that need to be addressed. First, as noted by Oliveira et al. (2014), leaving each student to play only a specific prescribed role in an activity "oversimplifies the complexities of peer collaboration and overlooks the highly dynamic nature of group activity" (p. 281), which also contradicts the current theoretical view on collaborative learning as emergent, dynamic and complex (e.g., Bossche et al., 2022; Hadwin et al., 2018; Hilpert & Marchand, 2018; Zuiker et al., 2016). Second, prescribed roles can lead to potentially harmful 'over-scripting' of collaboration that can limit flexible and self-regulated participation (Dillenbourg, 2002), and this is likely to happen even if different roles are allowed to rotate between participants every now and then. Third, only roles that are considered a priori to promote collaborative learning processes and outcomes were considered in prescribed role studies, leaving unacknowledged all the other roles that can emerge and have relevance in a situation, including negative roles (Lehmann-Willenbrock et al., 2016). Finally, students are not guaranteed to stick to their prescribed roles, as those roles might conflict with emergent roles (Strijbos & Weinberger, 2010). These issues suggest that more research needs to be devoted to the roles that spontaneously emerge in collaborative learning.

Emergent roles approach

With a focus on how group members self-regulate and structure their collaborative learning process, the emergent role approach is interested in the kinds of roles that group members enact during this process and how those roles are reflected in collaborative learning outcomes (Strijbos & Weinberger, 2010). In other words, this approach is interested in how roles emerge and are negotiated in interactions among group members during group activity, when no explicit rules or restrictions on role taking have been provided in advance (Dowell & Poquet, 2021). Given that roles are a key aspect of group dynamics and productive group work (Forsyth, 2014), it is expected to be inevitable that roles emerge during a group activity, as learners interact with each other and the task content.

In contrast to prescribed roles, which serve as a method to facilitate collaborative interactions (Dillenbourg, 1999), emergent roles are at least partly a product of a particular collaboration context (Dowell et al., 2019). Therefore, there can be considerable divergence on what roles emerge in different collaboration settings (Driskell et al., 2017). For example, the nature of the activity (e.g., hands-on vs. virtual task) and the means of communication (e.g., asynchronous chat vs. synchronous face-to-face interaction) may give rise to different kinds of roles (Wang & Li, 2022).

Approaching the enactment of roles as an emergent phenomenon also opens up various possibilities for their conceptualisation (Strijbos & Laat, 2010). Therefore, there is typically considerable variation between studies in how roles are conceptualised and operationalised, leading to the issue that "much of this research has been carried out in isolation and the focus on roles lacks cohesion" (Strijbos & Laat, 2010, p. 495). Strijbos and Laat (2010) illustrated this issue further in their scoping review that identified three wider conceptual approaches to roles from previous research: role as *task* (i.e., micro level), role as *pattern* (i.e., meso level) and role as *stance* (i.e., macro level). At the finest-grained micro level, roles are understood as single tasks, behaviours or contributions undertaken by individuals during a group activity. Examples are the *starter* who kicks of the discussion whenever it is slacking (Gu et al., 2015) and the *challenger* who evaluates previous comments and actions with a critical eye (Benne & Sheats, 1948/2007; Volet et al., 2017). At the meso level, roles comprise multiple tasks, behaviours or contributions that pattern over the course of a group activity to form role profiles. One example of roles at this level is the *promoter of simple task completion* who is mainly interest to 'get the job done' without engaging to any deeper conceptual reasoning about the task content with other group members (Hogan, 1999). Also Bales' (1950) early dichotomy between the *task* and *socioemotional specialist* role profiles can be viewed as examples of roles at the meso level. The macro level reflects an individual's orientation towards collaboration and group task, and thus, according to

Strijbos and Laat (2010), can help to contextualize individual behaviour and role taking at the micro and meso levels. As an example, the *captain* has a strong orientation toward the group and is thus ready to invest a lot of effort to the group task; in contrast, the *freerider* attempts to benefit from the input of other group members by investing only little personal effort to the group endeavour (Strijbos & Laat, 2010). Two of these levels, namely micro and meso, are the foci of this study.

To advance towards a more coherent framework, Hoadley (2010) demanded that researchers in this field "make progress on ways to identify and communicate about not only their definitions of roles, but also their assumptions about where roles come from, and how they might emerge" (p. 554). Unfortunately, such attempts have remained few and far between. To address this issue, the construct of *functional participatory roles* was proposed as a part of the thesis to conceptualise roles that spontaneously emerge and are self-enacted during collaborative learning activities.

Emergent functional participatory roles

From a theoretical viewpoint, the conceptualisation of functional participatory roles draws from a *situative approach* (e.g., Greeno, 1998, 2006) to theorise how roles emerge and are enacted in situ as the students interact with each other, the group task and the learning environment during a social learning activity. Essentially, the situative approach aims to fuse together the cognitive and interactional aspects of learning by considering the intact activity systems "in which learners interact with each other and with material, informational and conceptual resources in their environment" (Greeno, 2006, p. 92). Research on such systems thus focuses on "learners-in-context" (Nolen et al., 2015, p. 237); that is, how individual cognitive agents act and interact with each other within a particular context, providing resources, affordances and constraints influencing group interactions and activities (Greeno & Engeström, 2014). Adopting a situative approach includes an observational analysis of group interactions, processes and dynamics that unfold and evolve in situ as learners engage in a shared activity in a certain context (Greeno, 2006; Summers & Volet, 2010).

In line with this approach, the first prefix *functional* in the conceptualisation highlights the contextual and situative nature of roles. It posits that roles do not emerge in a vacuum but that they are largely triggered by learners' attempts to respond to the functional demands of the situation and activity (Benne & Sheats 1948/2007; Forsyth, 2014; Oliveira, et al., 2014). For example, to successfully solve a problem arising during an ongoing activity in a particular learning setting, the enactment of a specific functional participatory role may be necessary. However, each group member can carry personal goals and preferences that are not necessarily aligned with the group's goals or the functional role's demands (Stempfle et al., 2001; Strijbos & Laat, 2010), which may arise as unproductive or even detrimental roles (Benne & Sheats, 1948/2007). The second prefix, *participatory,* makes it explicit that the focus is on the kind of roles that become manifested only through individual participation in the group activity (Marcos-García et al., 2015; Volet et al., 2017). This entails that roles come 'into flesh' in situ as observable behaviours only when they are actively and strategically taken up by individuals (Chiu, 2000). This highlights human agency, which is a key component of the situative approach (Greeno & Engeström, 2014), and which Spada (2010) desired to see as "the visionary goal of the pedagogic work on roles" (p. 549). The conceptualisation of functional participatory roles conceives of roles as spontaneously emerging, interactive and dynamically evolving in situ, thus relating to the micro level of roles (Strijbos & Laat, 2010). Additionally, the meso level of roles was touched upon in Study III, where students' role profiles were scrutinised based on the micro-level analysis of distinct functional participatory roles.

2.3 Methodological issues in analysing roles

Methodological solutions, such as analysis methods and units, are important because they reflect the theoretical assumptions of the researched phenomenon and have significant implications for the results (Säljö, 2021). Overall, a great deal of empirical research on roles in task groups has relied on self-reports and personality tests (Lehmann-Willenbrock et al., 2016; Wang & Li, 2022). With these methods, the purpose has been to predict what role each individual is likely to occupy in an upcoming group activity or to determine the most suitable role for the individual based on individual characteristics and preferences, the ultimate aim being to facilitate optimal group formation (Eubanks et al., 2016). One well-known instrument is Belbin's (e.g., 1993) team role questionnaire, which is a self-assessment tool originally developed for work teams but later also adapted to other contexts, such as collaborative learning (e.g., Meslec & Curşeu, 2015). In this questionnaire, individuals rate different statements by considering how well they describe their personal role preferences and behaviours, which are then used to assess individuals' team roles (such as *coordinator*, *resource-investigator* or *implementer*). Although individual characteristics and preferences are no doubt relevant, self-reports and personality tests assume a rather causal relationship between individual characteristics and roles, thus not giving much weight to how roles might emerge and evolve during interactions (Hare, 1994; Salazar, 1996; Lehmann-Willenbrock et al., 2016). Another issue addressed in the study by Mudrack and Farrel (1995) is that the other group members may perceive the role of an individual differently than the person themselves, which can hinder effective and coordinated collaboration. In their study that applied the peer assessment method, Mudrack and Farrel (1995) asked undergraduate students to select from provided options what roles their fellow group members played during a group project. Although the students appeared rather skilful in identifying each other's roles using this method, one limitation pointed out by the authors was that "… respondents made dichotomous judgments about role behaviours—that is, a given individual either did or did not play a particular role. Such a format fails to capture fine-grained distinctions in role adoption across group members" (Mudrack & Farrell, 1995, p. 568).

The abovementioned limitations suggest that more emphasis should be placed on the analysis of actual interactions to make sense of what roles are actually enacted by group members and how roles might fluctuate over the course of an activity (Jahnke, 2010; Oliveira et al., 2014). Such an approach necessitates process-oriented methods, such as a systematic analysis of observable behaviours (Lehmann-Willenbrock et al., 2016). In current state-of-the-art research, video observations are recommended over more traditional on-site observation because they enable in-depth analysis of process data, given that videos can be stopped at any time to capture all the desired nuances that can be discovered during analysis (Derry et al., 2010). Importantly, videos enable detailed temporal analysis of interactions and collaborative contributions (Ricca et al., 2019; Lämsä et al., 2021), which is particularly important for capturing fine-grained distinctions and transitions between roles at the micro level (Oliveira et al., 2014). Because modern video cameras are extremely compact and inconspicuous, they are expected to interfere only minimally with naturally occurring behaviours and interactions, thus increasing the validity of the research (Goldman et al., 2014).

However, one issue is that carrying out detailed observational analyses can be time-consuming and laborious, given the voluminous and rich nature of interaction data (Derry et al., 2010; Sawyer, 2005). Analysis of roles with observational methods typically means manually coding interactions with detailed coding schemes, limiting the amount of data possible to analyse within one study (Dowell et al., 2019). To overcome this constraint, quantitative methods, such as social network analysis, have been utilised in the learning analytics community to discern emergent roles automatically from online group interactions based on traces of participation, such as log files (Gašević et al., 2019; Marcos-Garcia et al., 2015). However, Strijbos and Weinberger (2010) have criticised such purely structural methods (see Gleave et al., 2009) for providing only a superficial understanding of roles compared to systematic content analysis of collaborative interactions. Recently, Dowell and Poquet (2021) aimed to address this deficit by combining social network analysis with computational linguistics techniques to identify self-enacted roles, including *socially detached, lurker, follower, influential actor* and *hyper poster*, in a massive open online course (MOOC). However, there seem to be no sophisticated automatic techniques that can reliably provide a meaningful, in-depth understanding of emergent roles from face-to-face collaborative learning processes, where systematic observational analysis of interactions and behaviours still appears as the most robust method.

Another issue is related to the fact that there exists a myriad of different role frameworks, typologies and coding schemes in the literature. This was illustrated in a literature review that identified 164 different roles in 23 unique team role typologies (Gregory et al., 2015, cited in Driskell et al., 2017). This diversity has made it difficult to compare and synthetise findings derived using different frameworks and coding schemes (Strijbos & Laat, 2010). As a result, there is only a limited understanding of what roles commonly emerge during collaborative (science) activities and what the primary structure of roles is in collaborative learning groups. However, the development of more generalisable frameworks has been challenging due to the earlier mentioned issue that emergent roles are influenced by the specific context in which they are enacted. As suggested by Volet and Summer (2011), there is thus an urgent need for analytical frameworks that are both driven by theory to address the scaling issue and sensitive to specifics of the particular context.

2.4 Empirical findings on roles and achievement

Any attempt to understand a group as a system, such as learners collaborating on a task, needs to consider how individual contributions amalgamate during an activity and influence individual- and group-level actions and outcomes (Greeno & Engeström, 2014; Kozlowski & Klein, 2000; Stahl, 2017). To that end, some scholars have argued that roles are one of the main mechanisms linking individual- and group-level phenomena (Hoadley, 2010; Katz & Kahn 1978; Stewart et al., 2005), making them a particularly useful construct for understanding group processes and outcomes (Mumford et al., 2008). In essence, roles are related to individuals, but in social interactions, they always become interwoven with the roles of other individuals. As explained by Mumford et al. (2008, p. 251), a role "carries with the notion of the individual playing a part within a larger drama and captures the 'embeddedness' notion that is viewed as essential for understanding individuals in teams". To follow this line of thought, roles, at the individual level, reflect engagement towards the task and collaboration (Volet et al., 2019); in turn, how roles configure within the group during an activity illuminates interaction and engagement at the group level (Meslec & Curşeu, 2015; Morris et al., 2010; Stewart et al., 2005).

Originally, the main interest of role research in the collaborative science learning context was on the specific role of the leader. One of the first to study this was Richmond and Striley (1996), who examined secondary school students' collaborative discourse during science experiments with the aim to understand how emerging roles are related to the engagement and development of scientific arguments during collaborative tasks. By observing six small groups, three different roles were identified: *leaders* (who actively generate plans and coordinate group activities), *helpers* (who assist the leaders in making and executing plans) and two types of *non-contributor*s (active: who follow others and sometimes engage in off-task activities, and passive: who rarely contribute). Further analysis of the leader role revealed three types of leadership: inclusive, persuasive and alienating. While inclusive and persuasive leadership are related to deeper and more socially shared engagement in scientific discourse at the group level, alienating leadership is related to increased off-task activities and lower levels scientific discourse. Oliveira et al. (2014) reported supporting evidence for these findings by examining the relationship between the nature of student leadership and group engagement in collaborative science inquiry within a small sample of university students. Higher levels of cognitive engagement were found in a group where the leadership role was decentralised among the group members compared to a group where the leadership role was centralised only to one group member. The most recent advancements in this line of research involve detailed interaction analysis of leadership moves and their influence on productive collaborative learning (Mercier et al., 2014; Leskinen et al., 2020).

The other main line of research, which is also the focus of this thesis, has attempted to understand the full spectrum of roles that emerge during science inquiry among peers and to explore how different roles or within-group role configurations are related to collaborative learning outcomes. In a seminal study, Hogan (1999) observed secondary school students' spontaneously enacted roles while they tried to make sense of science phenomena in small groups and examined the impact of different roles on the quality of co-construction and scientific reasoning. Hogan noticed that the role profiles of *modeller*, *mediator reasoning, promoter of reflection*, and *contributor of content knowledge* fostered the reasoning process, whereas *promoter of simple task completion or unreflective acceptance of ideas*, *reticent, promoter of acrimony* and *distractor* hindered it. An important merit of Hogan's study was that it also considered dysfunctional roles, which had largely remained unscrutinised in previous studies that focused on the positive impacts of prescribed roles.

In a similar vein, Maloney (2007) found an association between emergent role profiles and primary school student groups' ability to utilise scientific evidence in joint decision-making. Both positive (*chair, discussion manager, information manager, promoter of ideas* and *influential contributor*) and negative role profiles (*reticent participant*, *non-responsive contributor*, *distracter* and *non-influential contributor*) were identified with respect to how the group managed to utilise scientific evidence in their decision-making. Furthermore, groups in which diverse positive roles were played were found to be more successful in the task compared to groups where the students played similar roles. This finding reflected Belbin's (e.g., 1993) idea about the importance of *role balance* for successful group work, positing that it is useful to have a mix of different roles in a group rather than duplicate roles.

More recently, Volet et al. (2017) explored how emergent roles are related to the quality of concept maps co-constructed by veterinary students in small groups. Groups where roles focusing on knowledge co-construction (e.g., *knowledge seeker, information giver* and *challenger*) prevailed managed to construct scientifically more accurate concept maps compared to groups where cognitively lower-level roles prevailed (e.g., *opinion giver* and *follower*). An important strength of this study was the fine-grained coding carried out to identify roles from video data (cf. meso-level patterns analysis in Hogan [1999] and Maloney [2007]). This analysis revealed that in the higher outcome groups, the students enacted a wider range of different key roles, suggesting greater role flexibility in comparison to lower outcome groups. Role flexibility, an ability to adapt one's role according to situational demands and group needs (Benne & Sheats, 1948/2007), is considered a crucial skill, especially in small groups where high role specialisation is often not possible because each member is expected to participate in a variety of different tasks (e.g., brainstorming and implementing; Forsyth, 2014).

3 Aims and structure of the thesis

Research on roles in collaborative learning has tended to focus on roles that are prescribed for group members, downplaying the spontaneously emergent and dynamic nature of roles. Most empirical studies have also used different conceptualisations and operationalisations of roles and have studied them only in one setting, which offers limited generalisability (Hoadley, 2010; Strijbos & Laat, 2010; Volet et al., 2019). Moreover, thus far, only little research on emergent roles has been conducted in the context of science learning. With a focus on *functional participatory roles*, this thesis aimed to develop a deeper understanding of the nature and impact of spontaneously emergent roles in collaborative science learning contexts. This overarching aim consists of conceptual, methodological and empirical aims (Figure 1).

By adopting a situative approach (e.g., Greeno, 2006), the main *conceptual aim* was to contribute to research on emergent roles in collaborative science learning with a conceptualisation of *functional participatory roles*, which highlights the spontaneously emerging, dynamically evolving and interactive nature of roles. The main *methodological* aim was to advance the systematic observation-based research of such roles, with an analytical focus on micro (i.e., fine-grained analysis of distinct functional participatory as they unfold during collaborative learning processes) and meso (i.e., patterns of multiple self-enacted functional participatory roles constituting student role profiles) levels of roles. The main empirical aim was to identify what functional participatory roles and role profiles emerge in different collaborative science learning settings and examine their influence on collaborative learning processes and achievement.

Although all the main aims were touched upon in each of three studies, the main emphasis of the first two was on conceptual and methodological developments, while in the third, more emphasis was on making empirical contributions (Figure 1). During the research process, the studies become closely welded together, as each study always inspired and laid the foundation for the next one (see Section 5 for elaboration). Briefly, Study I aimed to explore the conceptual usefulness of functional participatory roles to better understand roles emerging spontaneously during computer-supported collaborative inquiry in science and develop a reliable coding scheme for their analysis in this yet unexplored context. Study II derived empirical data from three different collaborative science inquiry settings with an aim to develop a novel scalable framework of core and activity-specific roles for analysing functional participatory roles in and across diverse science learning settings. Finally, Study III examined how group members' functional participatory roles and within-group configurations of role profiles are related to the quality of group achievement in two different collaborative science learning settings (i.e., computer-supported and hands-on inquiry). Overall, the thesis' systematic analysis of emergent functional participatory roles in diverse inquiry-based science learning settings aimed at strengthening the validity and generalisability of the findings and thus expand the understanding of the nature and significance of functional participatory roles in collaborative science learning.

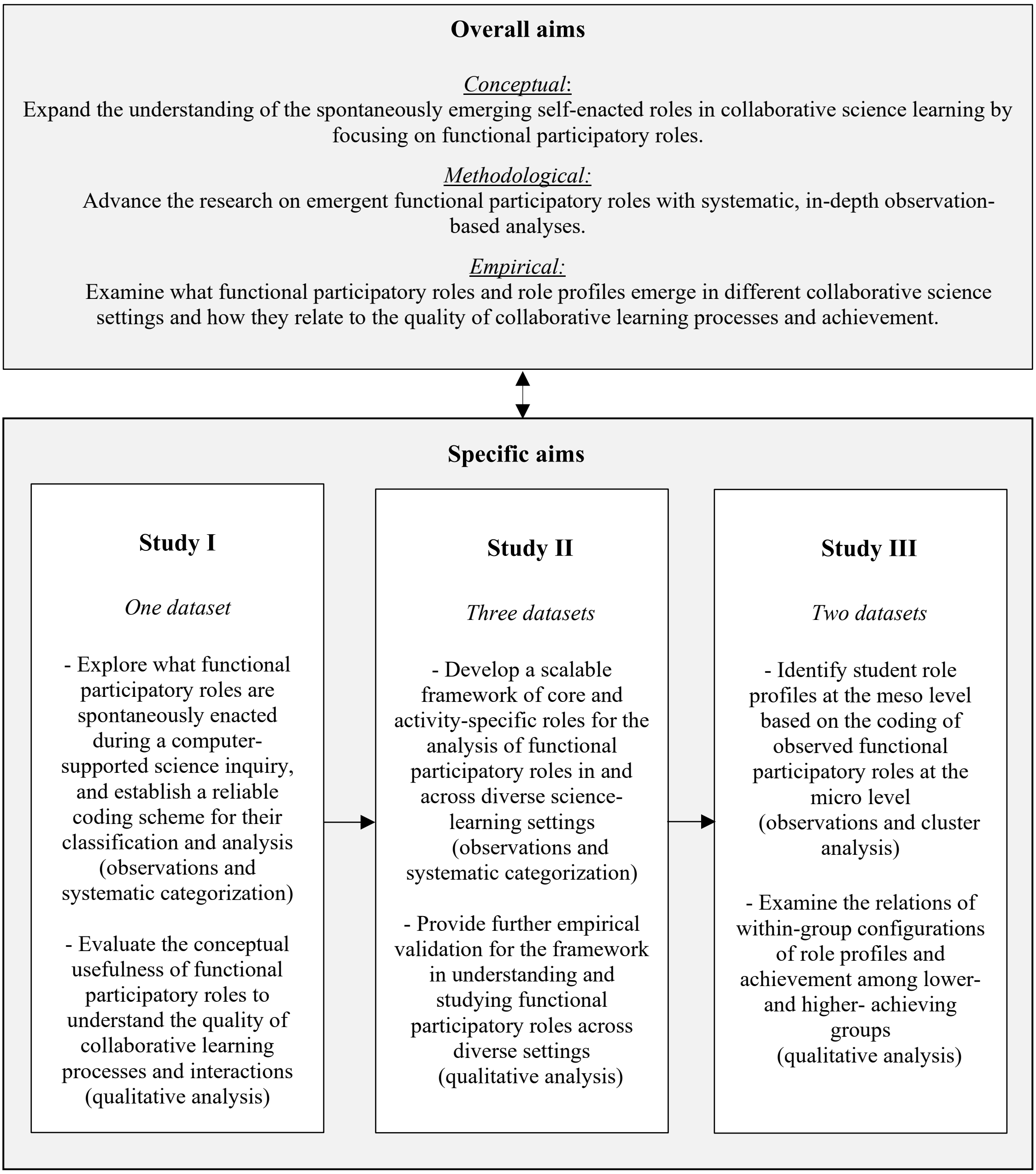


Figure 1. Overall and specific aims of the thesis.

4 Method

The data for this thesis originated from three larger research projects, one in Finland and two in Australia, each aiming to understand productive collaborative inquiry in science. The dataset from Finland (see Telenius et al., 2020; Vauras et al., 2019) is relevant to all three studies, the first dataset from Australia (see Pino-Pasternak & Volet, 2018; Volet et al., 2019) to the second and third studies and the second dataset from Australia (see Khosa & Volet, 2014; Volet et al., 2017) only to the second study. In this section, common information about the participants and the datasets is first provided. This is followed by an overview of each collaborative learning setting, with Table 1 summarising the datasets and samples. Finally, the role analyses are described.

4.1 Participants and collaborative learning settings

The three research contexts related to inquiry-based collaborative learning undertaken in real science classrooms as part of their regular curricula, thus maximising the ecological validity of the research (Abell & Lederman, 2007). In addition to two different countries (Finland and Australia), the research sites also differed regarding the nature of the group activity, science subject and academic level. The dataset from Finland involved high school students participating in a computer-supported task (referred to as high school students hereafter), the first dataset from Australia was made up of preservice student teachers participating in a hands-on activity (referred to as teacher education students hereafter) and the second dataset from Australia was made up of veterinary students participating in concept mapping (referred to as veterinary students hereafter; see the summary Table 1 on all contexts).

In each context, the collaborative inquiry was undertaken in small groups without prescribing any roles for the students. As mentioned at the end of Section 2.1, all the involved learning activities aimed to provide opportunities for the productive engagement in scientific concepts and practices (see Iiskala et al., 2021; Vauras et al., 2019; Volet et al., 2019). Moreover, the activities were designed to be rather challenging to make them 'group worthy' so that students would need to collaborate with each other to succeed in the joint task (Koretsky et al., 2019). The activities in the high school and teacher education contexts were partly student led, as they were guided and supported by the teachers, whereas the activity in the veterinary context was fully student led, as the teacher was not involved in the activity. The use of a uniform analytical approach and coding scheme across these three different datasets made it possible to examine similarities, differences and the significance of roles across variety of collaborative science learning settings, unlike in most prior empirical studies that studied roles only in one setting and with varying methods (Strijbos & Laat, 2010).

The role analysis focused on four to six small groups at each site that were chosen from a larger sample. As detailed in the following sections, the selection criteria differed between research sites and studies, but the main criteria was related to the quality of group *achievement*. As a general principle, the quality of group achievement was evaluated based on the group's collective outcome product or individual student outcomes—both of which have been used in prior research to evaluate the quality of collaborative learning (Enyedy & Stevens, 2014; Greeno & Engeström, 2014). Essentially, the aim of the sampling was to enable studying what functional participatory roles emerge in diverse groups (e.g., higher and lower achieving) and how roles possibly differ between them to gain insights into how roles might influence the quality of collaborative learning processes and outcomes.

At each research site, student participation was voluntary, and they could withdraw their participation anytime during the research without consequences. Informed consent was collected from the participants, including permission to videotape group activities and use the videos for research purposes. Universal and national ethical guidelines (Finland and Australia) for the responsible conduct of scientific research were followed. In publications, pseudonyms were used to protect the identities of the participants. Furthermore, only interaction excerpts whose contents did not pose a threat to revealing the identities of the participants were used in the publications.

High school students experimenting in a CSCL environment

The participants of this main dataset were senior high school students (general science) from Finland who participated in a collaborative inquiry in the CSCL environment Virtual Baltic Sea Explorer (ViBSE) environment (see Vauras et al., 2017; 2019). ViBSE is a web-based online learning environment capitalising on the affordances of digital tools to provide opportunities for learners to engage in authentic scientific practices and acquire interdisciplinary conceptual knowledge in biology and chemistry. In ViBSE, the participants join the crew of an actual research vessel for a virtual research mission to study the effects of pH on copepods in the Baltic Sea. In terms of resources, VIBSE includes a library that provides information about the Baltic Sea, a dictionary, videotaped interviews of the actual crewmembers of the vessel and a virtual laboratory for experiments. Students worked in the environment in small groups of two to four members over three lessons (75–90 min/lesson) in advanced-level chemistry and biology courses. The composition of the groups was decided by the teacher, as it was important to make sure that the groups were as balanced as possible regarding science knowledge and that there were group members proficient in English—that is, the dominant language of science and used in this environment. In each group, the students sat side by side at their own table, where they operated ViBSE using a laptop. The group task was to carry out a virtual science project by following authentic research practices, including planning the study and formulating hypotheses, running experiments in the virtual lab, analysing findings and drawing conclusions.

Finally, the groups prepared and delivered a PowerPoint presentation about their research project for their classmates and teacher. The PowerPoint, which was expected to include a research plan, results and conclusions, was each group's collective outcome. The quality of these outcomes was evaluated by two science experts on a six-point Likert scale (low = 1–2; average = 3–4; high = 5–6) based on the quality of a research plan, hypothesis, conclusions, scientific language and the extent the content presented reflected a deep understanding of the task (Telenius et al., 2020). In this thesis, 6 of 39 groups were chosen for the role analysis based on the quality of the collective outcome (two lower-, two averagely, and two higher-achieving groups; see Table 1). This selection focused on groups that were intact over the entire three-session-long research project. However, one higher outcome group with a student absent in the final session was selected as there were no intact groups with the highest group outcome mark.

Teacher education students conducting hands-on experiments

The participants were Australian first-year pre-service student teachers in an introductory science course that aimed to enrich students' conceptual knowledge in physics, chemistry and earth science and to promote their understanding and skills in how to conduct scientific investigations (Volet et al., 2019). Part of this course involved weekly hands-on lab sessions (about 2 hours/session) carried out in small groups of four members, including different experiments with everyday materials that the students were expected to utilise later on in their own classrooms as graduated teachers. The groups were self-selected by the students; however, this appeared to happen quite randomly, as the students did not yet know each other well, as this was a first-year course. Data for this thesis focused on students' interactions in two specific hands-on activities with varying scientific structures. In the first more structured activity called rocket lab (Studies II and III), the students planned and carried out an experiment with small rockets. This experiment aimed to foster their understanding of chemical reactions and conducting fair tests. The second activity, the squishy circuits lab (Study II), was more exploratory, the aim being to produce electronic circuits with playdough, batteries, wires and lights, to prompt group discussion on what happened and to demonstrate the 'why' in the experiment by using scientific reasoning. In terms of other resources, the students had textbooks that provided information about the activities, and they could utilise their notes from lectures that had preceded the lab activities.

Both Studies II and III comprised 4 groups selected out of 22 groups (Table 1). The groups scrutinised in Study II were derived from the study by Volet et al. (2019), which included groups of students with mixed attitudinal profiles towards science learning. The groups for Study III were selected based on the quality of group achievement operationalised as group members' aggregated mean marks on the final course exam, as the lab activity did not involve directly measurable learning outcomes. This final exam covered the science content of the entire course, thereby focusing on the content underpinning the lab activities and that presented in the lectures and textbook.

Veterinary students co-constructing mind maps of clinical cases

The participants were Australian second-year veterinary students in a mandatory physiology course (Volet et al., 2017). As part of the course, the students self-formed groups of six to seven members to complete a case-based clinical task. Each of the groups was randomly provided with a different authentic clinical case, which they investigated by themselves over multiple weeks. This collaborative task was designed with an aim to provide students with a chance to use their preclinical knowledge for the treatment of an authentic clinical case. Furthermore, the purpose of this open-ended task was to give insights into how these typically highly motivated and professionally oriented students engaged with a complex group task.

For research purposes, each group finally constructed a conceptual map of its clinical case (without any time limit). For this, each group was provided with cards describing the relevant concepts of their clinical case. Their task was to arrange the concept cards and to draw either one-way (representing causal relationship) or two-way (representing interrelated relationship) between the concepts in a meaningful way. The concept maps were the group's collective learning outcomes, and their quality was assessed by comparing the placement of the cards and the arrows with a corresponding expert map. The groups scrutinised in Study II were derived from Volet et al. (2017), comprising two groups with the highest and two with the lowest resembling maps in comparison to expert maps (out of 12 groups; Table 1).

Table 1. Summary of the datasets and samples.

Summary of the datasets				Group samples		
Country	***Educational level***	***Research site***	***Collaborative activity***	***Study I***	***Study II***	***Study III***
Finland	Senior high school general science (mostly 16–18 years old)	Advanced-level biology and chemistry courses	Research project in a virtual laboratory	Six triads; two lower-, averagely- and higher-achieving groups evaluated based on the group's research project	The same groups as in Study I	Four triads; two lower- and higher-achieving groups (a sub-sample from Study I)
Australia	First year teacher education (mostly 17–25 years old)	Introductory science course	Hands-on experiments with everyday materials	–	Four groups of four members; mixed groups in terms of their members' attitudes towards learning science (Volet et al., 2019)	Four groups of four members; two lower- and higher-achieving groups based on aggregated mean marks in the final course exam (all members of a group performed very well/very poorly in their individual course exam)
Australia	Second year veterinary education (mostly 19–25 years old)	Physiology unit	Concept mapping of authentic clinical case	–	Four groups of six members; two lower- and higher-outcome groups evaluated based on the quality of their concept maps (Volet et al., 2017)	–

4.2 Role analyses

Video/audio footage of the group activities made up the main data for the role analysis. Each group was video recorded separately with at least one camera placed near each group as they worked on their group task. In the high school dataset, video/audio footage was also collected with screen capture software that captured group actions in the CSCL environment via laptop screen, as this information was not directly captured with the main video camera but needed to achieve accurate role coding. Overall, the analysis focused on carefully chosen segments comprising key task phases, such as planning, experimenting and concluding. Shorter segments, instead of the entire collaborative activity, made the fine-grained analysis of rich interaction data more manageable (Sawyer, 2005). The analyses addressed both the micro- (as in detailed coding of functional participatory roles) and meso- (as in patterns/clusters of functional participatory roles constituting role profiles) level roles that were consolidated further with qualitative analysis.

The process of developing the coding scheme for video data coding

A coding scheme comprises a full set of individual codes, often arranged under broader categories and used for the systematic coding of particular data (Chen et al., 2019). Basically, a researcher can adopt an existing coding scheme as is after ensuring its validity for coding the data at hand, modify a prior scheme to tailor it for a particular data or generate a completely new scheme that is driven by data (Chen et al., 2019; Hennessy, 2020). In research on roles in collaborative learning, researchers have commonly used a specific scheme in each new context for analyse roles (Strijbos & Laat, 2010), which, according to Volet et al. (2019), "is problematic to advance this field of research since it offers limited generalisability" (p. 80). However, no prior studies have studied emergent roles in a similar context as in Study I, that is, face-to-face collaborative science inquiry in a CSCL environment. Therefore, the suitability of existing coding schemes from other types of collaborative (science) learning contexts and other relevant research fields (e.g., work teams) was first explored. Finally, after a rough preliminary examination of the data coupled with a careful scrutiny of available coding schemes in the literature, the one originally developed by Volet et al. (2017) was considered the most suitable 'starting point' for analysing roles from the data at hand. This Volet et al's (2017) original role coding scheme was developed in the context of collaborative concept mapping in veterinary education.

Adapting a coding scheme to another context commonly requires certain adjustments to properly capture the behaviours and interactions shaped by the particular context being studied (Chen et al., 2019; Hennessy, 2020). The multi-phased adaptation process carried out in Study I, involving two researchers and one in a consulting role, commenced with a thorough trialling of the original scheme by Volet et al. (2017) to explore its functionality for analysing roles in the different type of science learning context at hand. For this purpose, test data was utilized, including groups from the same larger dataset as the groups systematically analysed in Study I to promote validity and enable reliable inter-rating coding of the six selected groups later in the process. This development process included an iterative process of going back and forth with the data at hand and the original coding scheme until reaching a saturation point, combined with several conceptual discussions within the research team along the way. Although Volet et al's (2017) coding scheme served as the basis for this inquiry, the emergence of possible data-driven roles were also taken into consideration when scrutinizing the video data. Generally, Volet et al's (2017) coding scheme turned out suitable as all its distinct role codes were identifiable from the data. Nevertheless, some of the original coding indicators, boundaries between them (e.g., distinctions between 'information giver' from 'knowledge provider' roles) and broader coding categories were adapted to achieve optimal resemblance with the data at hand. Moreover, some data-specific roles largely stemming from contextual factors were discovered, leading to the development of descriptive labels and indicators for them (see Section 5 and Appendix A). Additionally, one new coding category accommodating roles related to experimenting activities in the CSCL environment was generated into the coding scheme under construction. The functionality and reliability of the established coding scheme was ensured with a final test coding resulting a high inter-rating agreement between two researchers.

A similar overall procedure of developing the coding scheme was followed regarding the teacher education context used as a part of this thesis, including validating and adapting Volet et al's (2017) original coding scheme for the particular context and adding a few activity-specific roles on a data-driven basis (see Volet et al., 2019).

The role coding scheme

The final coding scheme comprised distinct functional participatory roles categorised under four different foci. Appendix A provides more detailed information on all the distinct roles and their coding indicators, while an overview of different types of roles is presented below.

Science content-focused roles are related to science-based discussions and contributions. For instance, the role of the *knowledge provider* under this category provides scientific explanations for the group; the *information seeker* seeks factual information related to the task; and the *challenger* is keen to consider other alternatives during task completion. *The opinion sharing roles* category includes two roles, *opinion giver* and *opinion seeker*, based on contributions on personal viewpoints rather than offering science-based input. For instance, a student playing an *opinion giver* role can make a suggestion related to a group's science experiment without linking the suggestion to science or any factual evidence. *Experiment- and process-focused roles* encompass roles that offer procedural rather than content-related contributions. For instance, the *navigator* uses the group's laptop to move the group through different phases of the activity in the CSCL environment; the *technology contributor* instructs others on the use of the technology to improve task performance; and the *reader* reads materials and instructions aloud for the group from a lab book. Unlike the three categories described above, the last category, *socioemotional roles*, comprises socioemotional rather than task-focused contributions. Here, the *harmoniser*, who promotes a good atmosphere and provides positive feedback, is considered to play a positive group-building function role when thinking about the purpose of the activity (i.e., collaboration on a science learning task). In turn, the *off-tasker*, who attempts to shift the focus away from the task, and *negativity*, who makes negative comments in reference to the task or collaboration, are considered to have negative functions in this sense.

Coding of observed functional participatory roles

To capture the spontaneously emerging, interactive and dynamically evolving nature of functional participatory roles, their coding was carried out at the interaction turn level from the video footage (Volet et al., 2017). Turn was considered the most optimal unit of analysis, as it provides both detailed and rather unambiguous units to analyse "what the participants actually do and say" (Hennessy, 2020, p. 105). Turn level analysis thus enabled systematic, reliable and fine-grained analysis of distinct functional participatory roles from the unfolding interactions. The actual coding of functional participatory roles was undertaken with the professional behavioural coding software Observer XT (Noldus, 2017). This software enables segmentation of the video data into discrete codes and assigning codes directly to them, thus facilitating rigorous and detailed video data coding (Lehmann-Willenbrock & Allen, 2018). By producing a sequential record of timestamped turns (Koschmann, 2013), the coding preserved the temporality and order of distinct functional participatory enacted by group members over the course of a collaborative activity (cf. Lehmann-Willenbrock & Allen, 2018).

The coding focused on the individual student level on both verbal and non-contributions. For each group member, all verbal turns from longer intact monologues to briefly passing utterances (e.g., 'ymm', 'okay' and 'yeah') were exhaustively coded as distinct functional participatory roles; in contrast, only non-verbal behaviours that could be unambiguously identified as explicit contributions by means of observation were coded (e.g., operating a computer, nodding to indicate agreement or pointing something with a finger for demonstration). Each coded turn was temporally bound, demarcated by the start and end points of the contribution. In most turns, only one distinct functional participatory role was identified, reflecting the quick tempo of turn-taking during group activities. However, sometimes, a secondary role was identified to emerge, for example, during rarer lengthier turns consisting of multiple utterances or both verbal and non-verbal contributions. To code these turns, the decision adopted by Volet et al. (2017) was to code only the role that was more dominant in the turn. For example, if a student discussed something related to science content while making a brief procedural contribution, this turn was coded as a science content-focused rather than an experiment and process-focused role.

Moreover, the coding was carried out conservatively (see Volet et al., 2017) so that roles with a science content focus were assigned over other task-related roles (opinion and procedural based) only when the contribution was explicitly based on factual information or reflected scientific thinking, understanding or knowledge. For example, giving a suggestion to a task-related problem at hand without any reference to science or facts was considered a mere personal opinion about the matter and was thus coded as an opinion giver. Alternatively, using prior information or scientific evidence to justify that suggestion would have been coded as part of a knowledge provider or information giver role (Appendix A). Furthermore, socioemotional role codes were applied only when the predominant content of the contribution in the given turn was identified as off-tasking, harmonising or negativity. This means that the main coding criteria was related to the input contribution rather than, for example, the tone of the voice. As an example, a student stating enthusiastically ‘we were totally right!’ after an experiment in the virtual lab was coded as information giver rather than harmoniser despite carrying an affective undertone because the statement conveyed the factual information that the results of the experiment were as the group had expected.

Inter-rater reliability coding

Inter-rating coding is a vital practice to enhance the reliability of observations and interpretations drawn from video data (Hennessy, 2020). The basic idea in the kind of inter-rating coding in question here is that the same video data are coded with the same coding scheme by more than one independent investigator, and finally, the outcomes between the coders are compared to check their (in)consistency (Vogel & Weinberger, 2018). In each dataset, the coding was carried out by two coders, who had also taken part in developing the coding scheme(s). A portion of the same coders participated in the coding of the different datasets, ensuring that the role coding was carried out consistently across the settings. The main coder (i.e., the author of this thesis for the high school dataset and for the teacher education data used in Study III) coded all the turns in the selected data segments. To ensure sufficient coverage, a minimum of 20% of turns from each group within each task phase was randomly selected for inter-rating (e.g., planning, experimenting and concluding phases in Study I). It was considered important to include inter-rated data from each group in every task phase to ensure the representativeness of the inter-rating.

The coding was undertaken in such a way that both coders worked independently with the same coding file, selecting the most suitable functional participatory role for each turn from the coding scheme (e.g., knowledge provider or information giver). Then, the agreement between the two coders was evaluated statistically on a turn-by-turn basis. In addition to relying simply on percentage agreement, the agreement was also evaluated with Cohen's Kappa statistics, as it is more sensitive to disagreements related to specific codes, thus further corroborating reliability. Across datasets, "substantial" to "almost perfect" inter-rating results were achieved (see Landis & Koch, 1977, p. 165). The disagreements concerned mostly lower-level roles, such as one coder coding a procedural contribution as navigator and the other as recorder role. Additionally, a brief non-verbal contribution, such as a student quickly pointing to the computer screen with a finger, could occasionally have been unnoticed by another coder, which was considered a disagreement. Finally, the disagreements were solved collaboratively by the coders who reviewed and discussed the video material together.

Identification of student role profiles

A turn was not only a useful unit of analysis because it allowed the capturing of the emergent and constantly fluctuating nature of functional participatory roles but also because it enabled the quantification of video data, as turns are countable and hence can be analysed further statistically (Vogel & Weinberger, 2018). In Study III, this important feature was applied for the statistically driven identification of student role profiles at the meso level based on the coding of distinct functional participatory roles at the micro level. The identification of student role profiles, operationalised as patterns/clusters of self-enacted functional participatory roles, was undertaken with a hierarchical cluster analysis, which is a data mining method that reveals internally homogenous clusters that differ significantly from other clusters (Antonenko et al., 2012; Everitt et al., 2012). In the behavioural sciences, cluster analysis has been used successfully to identify patterns from observational data (Lehmann-Willenbrock & Allen, 2018). However, in the identification of emergent roles and role profiles, the method has been applied only recently. These studies have also been conducted in different kinds of contexts than the present thesis, namely, online learning (e.g., Dowell et al., 2019; Saqr & López-Pernas, 2021) and workgroup meetings (Lehmann-Willenbrock et al., 2016).

In the clustering, rather than frequencies, percentage values of enacted functional participatory roles were used to make the data comparable across students and groups (Lehmann-Willenbrock et al., 2016). Furthermore, broader role categories (i.e., aggregated values of distinct functional participatory roles within each category) were used as analytical units instead of using each distinct role individually. These categories included the three task-focused categories described earlier (i.e., science content-focused roles, opinion-focused roles and experiment- and process-focused roles). Since the original socioemotional role category included roles considered positive (*harmoniser*) and negative (*off-task initiation*, *negativity*) for the group's joint science effort, this category was divided into two for the purpose of the cluster analysis (i.e., categories of positive and negative socioemotional roles). In this way, each category used as a variable in the clustering included roles with a similar nature and basic function. This also enhanced the reliability and robustness of the clustering, as it made the number of variables more manageable for the analysis (see Everitt et al., 2012). The final cluster solution, arrived at after careful qualitative scrutiny of several different cluster solutions (Lehmann-Willenbrock et al., 2016), was chosen by considering the conceptual validity of the clusters, the inner consistency of individual clusters and between-cluster differences (Antonenko et al., 2012).

Qualitative in-depth analysis

Video analysis methods relying solely on the 'coding and counting' approach can offer only limited empirical insights into the dynamics of collaborative learning interactions as they unfold in real time (Kapur, 2011; Pöysä-Tarhonen et al., 2021; Sawyer, 2005). Therefore, the outcomes obtained by the systematic coding of functional participatory roles and the statistically driven identification of student role profiles were deepened qualitatively in this thesis. In Studies I and II, brief exemplary data excerpts were selected and analysed with a fine-grained qualitative lens to illuminate further the emergent, dynamic and interactive nature of functional participatory roles and their different situated functions in diverse groups and science learning settings. In Study III, four diverse cases (two lower- and two higher-achieving groups) were selected for in-depth qualitative analysis to provide a deeper understanding of how the interplay of different role profiles impacted the quality of group achievement. As in Studies I and II, these findings were also discussed through brief interaction excerpts and analytical comments to maintain analytical rigour while keeping the amount of data manageable for the requirements of in-depth qualitative analysis (Hennessy et al., 2020).

5 Overview and main findings of the studies

This thesis comprises three studies that together deepen the understanding of spontaneously self-enacted roles and their significance in collaborative science learning. Furthermore, it provides conceptual and methodological advancements. The first study explored what functional participatory roles spontaneously emerge during a computer-supported science inquiry, the second proposed a novel framework for the analysis of functional participatory roles across different collaborative science learning settings, and the third investigated the relations between student role profiles and group achievement. A summary of each study is provided as follows.

Study I

Heinimäki, O-P., Salo, A-E., & Vauras, M. Luonnontieteiden yhteisöllisessä tietokoneavusteisessa oppimisessa omaksuttujen funktionaalisten osallistumisen roolien kehittely [Development of a classification for functional participatory roles enacted during computer-supported collaborative science learning]. *Psykologia*, 2019; *54*(04): 236–254.

The use of technology and CSCL environments have been consistently increasing in science classrooms (van der Graaf et al., 2020), leading to a need to gain a better understanding of collaborative learning and what roles spontaneously emerge during the process when the learning activity involves such tools. To that end, the aims of this exploratory study were to unravel what functional participatory roles students spontaneously enacted during a computer-supported science inquiry, establish a detailed and reliable coding scheme for their classification and analysis and evaluate the usefulness of the fine-grained analysis of functional participatory roles to understand collaborative learning processes and interactions. For this, the systematic coding of observed emerging functional participatory roles and qualitative analysis of interaction excerpts were utilised.

The study focused on Finnish high school students engaged in face-to-face collaboration in a CSCL environment called ViBSE, where they carried out a virtual research project that included planning, experimenting and concluding research phases. The role analysis focused on six triads differing in the quality of their research project, as evaluated on a six-point scale. This sample ensured that the observations and established coding scheme represented a sufficient cross-section of more and less successful groups. Systematic coding of observed functional participatory roles was carried out from video footage at the turn level, yielding a fine-grained analysis of 3461 turns, including both on- and off-task interactions. The building of the coding scheme was driven by both theory and data, as it was expected that some of the emerging roles would resemble the ones found in the previous literature, but it was also considered possible that some roles would be distinctive for the particular context.

Seventeen distinctive functional participatory roles were identified from the data. Most resembled the roles found in the study by Volet et al. (2017), upon which the development of the coding scheme for this study was mainly grounded. However, seven roles specific to the data also emerged. All roles included the following (the seven specific roles are in italics): knowledge provider, knowledge seeker, information giver, information seeker, challenger and supporter (science content-focused roles); opinion giver and opinion seeker (opinion-sharing roles); *recorder*, *dictator, technology contributor, navigator, attention focuser* and follower (experiment and process focused roles); and harmoniser, *negativity* and *off-tasker* (socioemotional roles). As shown above, most of the roles specific to this data were related to the experimentation and procedural aspects of the task and reflected the computer-supported nature of the activity; two new types of socioemotional roles (cf. Volet et al., 2017) were also identified (see also Section 4.2 and Appendix A).

Brief data excerpts that were qualitatively analysed were provided in Study I to concretise the detailed turn-level analysis of functional participatory roles and demonstrate the different functions of roles and their significance for group processes and interaction. For illustration purposes, one of these original excerpts can be found below, as translated from Finnish. This excerpt was taken from a higher-achieving group in a situation where they discussed their experimental arrangements and decisions.

Paula: How many from that acid one, for example? (Knowledge seeker)
Ellen: Two, I don't know. (Opinion giver)
Sofia: Two is the absolute limit. (Challenger)
Ellen: Well, they [copepods] don't decease to that extent. (Challenger)
Paula: Yup, but there can be like wrong…. (Knowledge provider)
[2:54–3:10]
Sofia: Maybe like three. (Opinion giver)

Paula: Three is the minimum. (Challenger)
Sofia: If we would be real researchers, then five …. (Knowledge provider)
Ellen: Yes, they experiment with large [samples]. (Supporter)
Paula: Yes, they can have like a dozen. (Supporter)
[3:17–4:44]
Sofia: [writes with the computer] (Recorder)
Paula: But like in 'real life', five is very little. (Challenger)

The above excerpt illustrates the emergent, temporal and dynamic nature of functional participatory roles and shows how even during a brief interaction segment, group members could change flexibly between different roles. For instance, although Sofia had the primary responsibility here in carrying out group activities in the CSCL environment as visible in the enacted recorder role, she also actively participated in discussions about the content and task decisions (*challenger*, *knowledge provider* and *opinion giver* roles). The excerpt further illustrates how functional participatory roles are related to different aspects of joint task completion and understanding. By providing knowledge and challenging and supporting previous statements, the group gradually built an understanding that helped them to consider their choices from the viewpoint of scientific research. It is also noteworthy how opinions not supported by science or facts were immediately challenged, helping the group eventually come up with arrangements and agree on decisions that were more grounded in science.

Study II

Heinimäki, O.-P., Volet, S., & Vauras, M. Core and activity-specific functional participatory roles in collaborative science learning. *Frontline Learning Research*, 2020; *8*(2): 65–89.

Study II provided further conceptual and methodological contributions to the research on functional participatory roles in collaborative science learning. The main concrete contribution of this study was the development of a conceptual framework of core and activity-specific functional participatory roles. This framework was designed with the aim of providing a common framework for the analysis of emergent (task-related) functional participatory roles across diverse science learning settings, as prior role frameworks and coding schemes have been typically designed with only one particular data setting in mind. Although a data-driven approach is necessary to consider the influence of the particular context on emergent roles in which they are studied (as illuminated in the findings of Study I), such a focus has made it tricky to compare findings derived with different frameworks and coding schemes and complicated the development of more scalable frameworks (Strijbos & Laat, 2010). Therefore, the proposed framework aimed to address the demand for frameworks that are both generalisable to address the scaling issue and flexible to data specificity (Volet & Summers, 2013).

Figure 2 summarises all the components and underlying claims of this framework. Reading from the bottom up, the figure illustrates two types of functional participatory roles, *core* and *activity-specific*, that can be spontaneously enacted by group members during collaborative science learning activities. Core roles were assumed to be commonly found across different collaborative science learning settings, whereas activity-specific roles only in some settings. Given their close resemblance across activities, *core* roles are inherently related to the nature of science learning, whereas *activity-specific* roles are depended on the characteristics, affordances and demands of the specific science environment and activity.

Empirical evidence regarding the assumption of *core* and *activity-specific* roles was derived from three prior studies (Heinimäki et al., 2020/Study I; Volet et al., 2017, 2019), including three different science learning datasets and four different activities (see Section 4.1 and Table 1). Despite the contextual differences (e.g., group task, science discipline, student characteristics and educational level), similar roles were identified across the datasets (for descriptions, see Appendix A). Most of these *core roles* (*knowledge provider, knowledge seeker, information giver, information seeker, supporter, challenger, follower, opinion giver* and *opinion seeker*) are related to the processing of the science content underpinning the activities. In turn, some roles were found only in one activity or context. These *activity-specific roles* (*recorder, dictator, technology contributor, navigator, attention focuser, reader, procedural contributor* and *observation maker*) are related to the procedural aspect of task completion and reflected the specific characteristics of the environment and involving artefacts. For example, the technology contributor role identified in the high school context stemmed from the involvement of technology in the group activity.

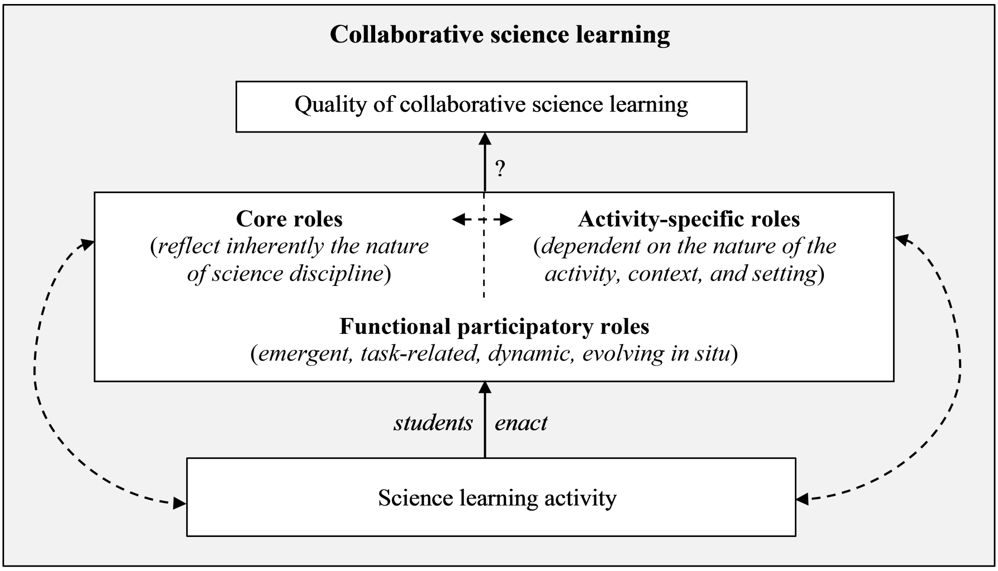


Figure 2. A conceptual framework of the core and activity-specific functional participatory roles in collaborative science learning (reprinted from Heinimäki et al., 2020).

Study III

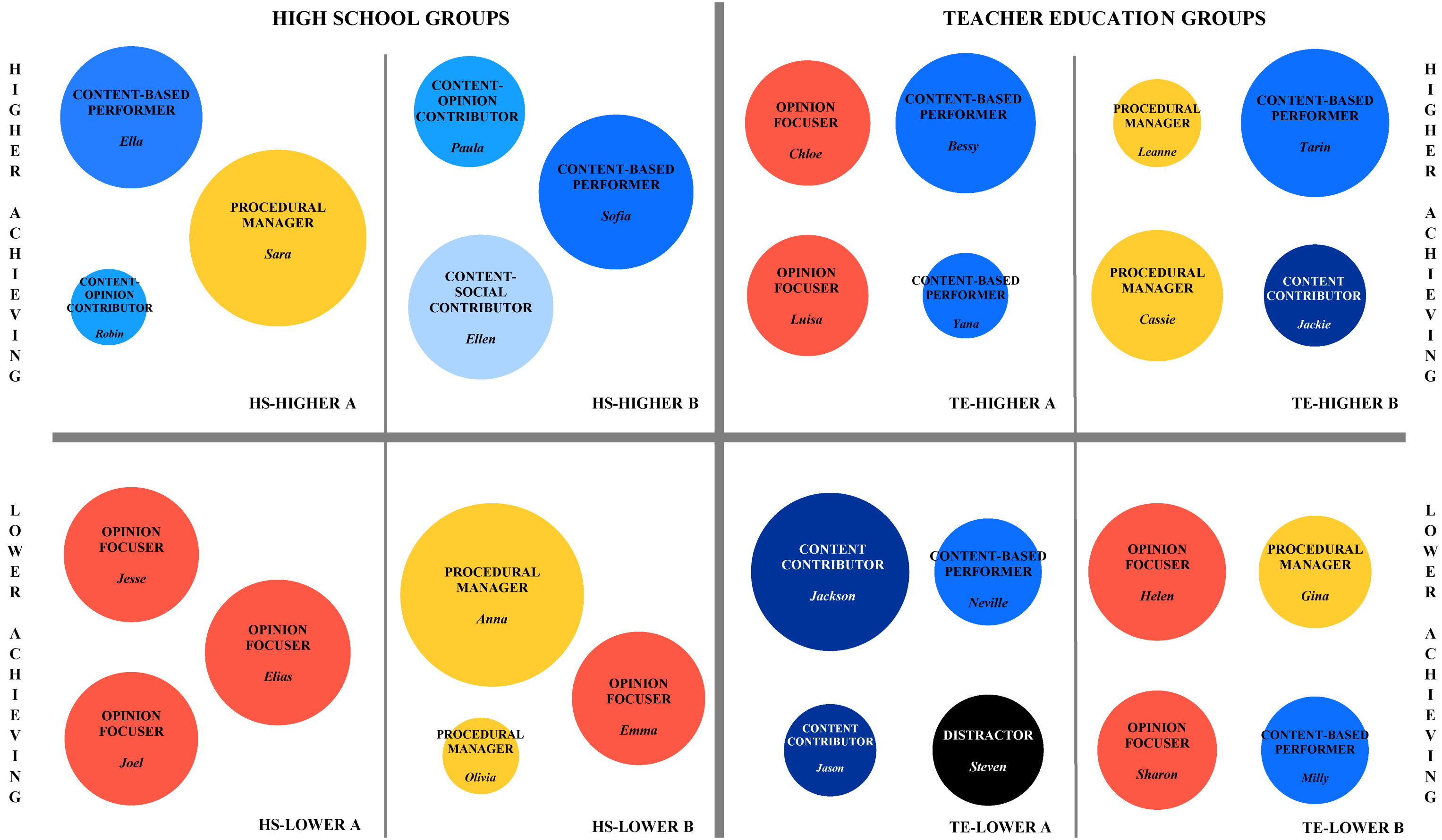
Heinimäki, O-P., Volet., S., Jones, C., Laakkonen, E., & Vauras, M. Student participatory role profiles in collaborative science learning: Relation of within-group configurations of role profiles and achievement. *Learning, Culture and Social Interaction*, 2021; *30,* Article 100539.

The purpose of Study III was to examine the association between self-enacted functional participatory roles and the quality of collaborative science learning (as assumed in Study II; see the arrow with a question mark at the top of Figure 2). More specifically, the first aim was to identify *student role profiles*, following the aim of investigating how within-group configurations of role profiles are related to lower and higher group achievement. Student role profiles capturing multiple roles self-enacted by group members were studied because their impact on overall group achievement was expected to be greater than mere discrete functional participatory roles.

The relationships between role profiles and achievement were investigated in two different settings, that is, high school students experimenting in a CSCL environment and teacher education students doing hands-on experiments. The analysis focused on two lower- and two higher-achieving groups from both sites ($N^{groups} = 8$; $N^{students} = 28$) and in two task phases: i) planning of the experiment and hypothesising and ii) analysing the results and concluding. Student role profiles were identified by hierarchical cluster analysis based on turn-level coding ($N^{turns} = 2815$) of the observed discrete functional participatory roles. The main focus of the analysis in this study was on-task interaction segments; therefore, longer off-task episodes lacking reference to the learning situation at hand were omitted from this analysis. However, those turns that initiated or attempted to initiate off-task behaviour were still included in the analysis to get important insights into contributions that aimed to shift the discussion from on- to off-task. Regarding high school students' science background and competence in relation to achievement, the number of science courses completed, scores on chemistry/biology pre-tests and their grades in science (and English language) did not significantly correlate with the quality of group achievement. Teacher education participants' science backgrounds were known to be rather limited throughout, given that the introductory science course they participated in did not comprise any students who had successfully completed post-secondary science courses before the beginning of their university study.

The results provided new insights into students' role profiles and their relations to the quality of achievement in collaborative science learning. Seven distinct student role profiles were found—three, all task-focused, were common for both the high school and teacher education students, whereas the rest were specific only for one setting and also involved socioemotionally-laden profiles (see Appendix B for descriptions). Figure 3 sums up the within-group configurations of role profiles among groups with contrasting achievements. Although none of the groups displayed identical role profile configurations, the most significant differences were found between the lower- and higher-achieving groups. Overall, science content-focused role profiles were more predominant in the higher-achieving groups, whereas opinion-based role profiles were more common in the lower-achieving groups, in which one student with a distractor profile was also identified. Furthermore, the role profile configurations were more versatile in the higher-achieving groups compared to those in the lower-achieving groups.

In-depth qualitative analysis of four selected groups further unpacked the relationships between within-group configurations of role profiles and achievement. In one group with a dominantly science-focused role profile configuration (group HS-Higher B in Fig. 3), this analysis revealed rich and reciprocal task interactions that promoted high-level knowledge co-construction and task performance. This was in clear contrast to the unproductive and low-level dialogue found in the group that was predominantly focused on opinion (HS-Lower A). In the group where science and opinion profiles were equally distributed (TE-Higher A), lower opinion-based contributions were elevated and reframed to something more science-based by content focused roles, increasing the scientific quality of the group's dialogue and task completion. The final case revealed how only the distracting profile had a major influence on derailing the group from productive task engagement, despite the fact that all the other group members displayed a positive science-oriented profile (TE-Lower A).



Note. Circles represent the students, while the size of each circle shows the frequency of that student's enacted functional participatory roles in relation to other students' in the group, thereby illustrating the distribution of contributions in each group.

Figure 3. Student role profiles in higher- and lower-achieving high school and teacher education groups (reprinted from Heinimäki et al., 2021).

6 Main contributions and general discussion

The overall aim of this doctoral thesis was to gain further insight into spontaneously emerging functional participatory roles and their significance in collaborative science learning, as well as to provide conceptual and methodological contributions to advance research in this area. Study I provided a new understanding of the variety of different functional participatory roles spontaneously self-enacted by students during a computer-supported inquiry and demonstrated how these roles were interactive and dynamically evolving, highlighting the benefits of using fine-grained analytical lenses for properly capturing such roles from collaborative learning interactions. With empirical evidence gathered from three different science learning settings, Study II developed a scalable analytical framework for identifying both functional participatory roles that are common across different science learning settings and roles that are specific to only a particular setting. Study III built on these contributions and examined how student role profiles are related to achievement in two different science learning environments, revealing strikingly different within-group role profile configurations between higher- and lower-achieving groups. This last section elaborates on this thesis' contributions from conceptual, methodological and empirical perspectives, considers the implications for practice and provides suggestions for future research.

6.1 Conceptual contributions

Recently, there have been calls for greater attention to theory building and conceptual developments in educational psychology research (e.g., Nasir et al., 2021; Wentzel, 2021). This need also concerns research on roles in collaborative learning (De Wever & Strijbos, 2021; Hoadley, 2020). In collaborative learning contexts, prior research has mainly focused on fixed roles prescribed to collaborating students, whereas research on emergent roles has been far scarcer (Oliveira et al., 2014). To address the identified conceptual gap in explaining "where roles come from, and how they might emerge" (Hoadley, 2010, p. 554), this thesis proposed the construct of functional participatory roles to characterise the roles that are spontaneously emergent and self-adopted by students during collaborative science activities. Grounding this conceptualisation in a situative approach (e.g., Greeno, 2006) provided a new theory-driven lens to explain how functional participatory roles emerge in situ through ongoing interaction between group members and the characteristics and functional demands of the activity and the environment. By highlighting the functional participatory roles that naturally emerge and evolve during collaboration rather than focusing on roles that are predetermined for group members, this conceptualisation aligns with a contemporary view of collaborative learning as a highly dynamic and complex activity (e.g., Hilpert & Marchand, 2018; Zuiker et al., 2016). As such, this thesis makes an important conceptual contribution to expanding our understanding of the nature of emergent roles in collaborative learning.

Furthermore, referring to Strijbos and Laat's (2010) conceptualisation, this thesis focused on two of the role levels proposed by them: the micro and meso levels. The conceptualisation of functional participatory roles as dynamically emerging and fluctuating in interaction contributes to enriching the micro-level conceptualisation of roles. Research at the micro-level has often treated roles as something "essentially made up of single tasks" (Strijbos & Laat, 2010, p. 496), which, as supported by the empirical evidence gathered in this thesis, may be limited to fully appreciating the constantly changing and evolving nature of roles during collaborative learning activities (Oliveira et al., 2014; Volet et al., 2017; 2019). Consequently, the conceptualisation of meso-level roles was also enriched to contain micro-level patterns/clusters of distinct emergent functional participatory roles, forming student role profiles (see Section 6.2 for an elaboration on the methodological contributions of analysing these two levels).

The macro level of roles (i.e., role stance) was, however, out of the scope of this thesis. According to Strijbos and Laat (2010), the macro level can provide further insights on role taking at micro- and meso-levels as it reveals an individual's "emotional and intellectual attitude" toward collaboration and task (p. 497). Thus, one important direction for future would be a stronger integration of the macro level with micro- and meso-level research. For instance, students may enter the collaborative learning situation with a variety of expectations, attitudes, achievement goals, motivation, personality characteristics or role preferences, which may all have an impact to the roles they enact during a group activity (Hare, 1994; Hogan, 1999; Stewart et al., 2005). In this way, exploring spontaneously self-enacted roles in conjunction with a variety of background factors, revealing important information about individual stance toward collaboration and task, could expand the understanding of the factors influencing role enactment and shed light on why the roles enacted by peers can differ significantly from each other during collaborative activities. Future research aiming to integrate all these dimensions meaningfully into a single framework could consider drawing from a systems theory approach, such as ecological system (e.g., Bronfenbrenner & Morris, 2006) or complex dynamic systems theory (e.g., Hilpert & Marchand, 2018). Such an approach could not only help to expand the understanding of how roles unfolding in a collaborative learning situation are potentially influenced by a number of students' background factors but also cast the net even further by considering the influence of cultural aspects, interpersonal relationships and changes that happen over time (see Section 6.5).

6.2 Methodological contributions

Regarding methodological contributions, this thesis, first and foremost, advances observation-based research on emergent roles in collaborative learning. Much prior related research has used broad-brush observations or self-reports that bear limitations, as described in Section 2.3 (see also Lehmann-Willenbrock et al., 2016). The moment-by-moment, micro-discursive analysis of discrete functional participatory roles applied in this thesis enabled the capturing of the emergent, dynamic and temporal nature of roles as they unfolded in real time during group activities. Moreover, the multi-layered nature of roles was acknowledged in this thesis through diverse analytical lenses. Although the micro-level analysis was crucial in revealing the emergence and evolution of functional participatory roles as they unfolded in real time in social interactions, the meso-level as a more general analytical unit capturing student role profiles was useful in understanding the relations of within-group role profiles and the quality of group achievement.

Furthermore, how the micro- and meso-level analyses were methodologically combined in this thesis to inform each other makes a novel contribution to this research field. As noted by De Wever and Strijbos (2021), most studies on roles in collaborative learning "have predominantly focused on one level only", and "future research could investigate whether roles on different levels can be combined" (p. 324). For instance, in one previous case, Maloney (2007) explained that students' role profiles in collaborative science learning were identified based on "clusters' of similar actions" (pp. 385–386). However, no fine-grained observations were carried out at the micro level, and the clusters at the meso level were qualitatively rather than statistically generated. In another case, Hogan (1999) identified role profiles by observing "consistent patterns of participation in group practices" (p. 861). This approach may be insufficient when considering that self-enacted roles are not always consistent or stable over time, as they can be in a state of constant flux (Oliveira et al., 2014). To address these issues, this thesis adopted a 'bottom up' approach in which the identification of student role profiles at the meso level with cluster analysis was based on countable contributions produced by systematic micro-level coding of distinct functional participatory roles. Therefore, this approach is expected to offer a more data-driven, rigorous and transparent approach for any future exploration of emergent roles and role profiles in collaborative (science) learning. Finally, micro- and meso-level analyses were deepened with an in-depth qualitative approach for the group interactions (Pöysä-Tarhonen et al., 2021), which proved valuable since it further illuminated the rich interplay of different roles and role profiles, as well as exemplified the diversity of roles between differently achieving groups.

Since learning activities are increasingly taking place in diverse environments and contexts, there has been a demand for analytical frameworks that help reveal the similar and unique features of those activities (Ludvigsen et al., 2011). Until now, and because empirical work has typically involved single studies, research on roles has not really considered commonalities and differences in spontaneously enacted roles across learning settings and thus has not differentiated common roles from roles that are more or less unique or specific to a collaborative learning setting and activity. To contribute to addressing this issue, a framework of core and activity-specific functional participatory roles was developed as a part of this thesis. This framework considers both the functional participatory roles that are common across different collaborative science learning settings (core roles) and those that are more specific to a certain setting and activity (activity-specific roles; see Appendix A). As such, this framework addresses the demand for flexible frameworks that can concurrently provide cross-dataset generalisability and high sensitivity to data specificity (Volet & Summers, 2013). In this framework, the first is achieved through core roles, while the latter is achieved through activity-specific roles. As this is the first attempt to provide a common framework for studying roles in collaborative science learning, the framework of core and activity-specific functional participatory roles is expected to provide a valuable contribution to future research aimed at understanding spontaneously self-enacted roles in and across diverse collaborative science learning settings.

However, as the framework of core and activity-specific roles was based on the scrutiny of three collaborative science learning datasets that included four different inquiry-based activities, more empirical research in different science learning settings and contexts is required for further validation. Importantly, future attempts to validate the framework and its derived coding schemes in new settings will show whether the core roles identified in this thesis can be actually found in various diverse collaborative science learning settings, as claimed. When this work continues to cumulate in the future, it is acknowledged possible to eventually lead to reconsiderations of what counts as core and activity-specific roles; for instance, in the case that some roles identified as activity-specific in this thesis will be widely identified across multiple diverse datasets. Another interesting aspect for future research could be to examine the possibility of expanding the framework to include socioemotional roles, given that the focus of the present framework was only on task-related roles.

6.3 Empirical insights

The empirical evidence gathered in this thesis supports the notion that certain task-related functional participatory roles are similar across diverse science learning settings (i.e., core roles), whereas some are more specific to particular settings and activities (i.e., activity-specific roles; see Appendix A). Findings resembling core roles across datasets despite differences related to academic level, discipline, nature of activity and learning materials suggest that these roles are closely related to the nature of the science discipline and that they are at the crux of collaborative science learning (nature of science, see Anderson, 2007; Duschl & Hamilton, 2011). This is supported by the finding that the common function of core roles involves discussing and understanding the science content of the learning task (cognitively, both higher and lower levels). In turn, activity-specific roles were found to be related to the procedural aspects and demands of task completion. The emergence of these roles reflects the specific affordances and constraints of carrying out an activity in a particular environment and context. For example, roles like navigator and technology contributor reflected the characteristics of a computer-supported activity, whereas roles like observation maker and procedural contributor were related to the characteristics of a hands-on activity. Despite their different functions, this thesis's findings suggest that both core and activity-specific roles have an important, and often a complementary, role in productive collaborative science learning.

However, the types of functional participatory roles that turned out to be especially influential for productive collaboration were the science-content focused roles, including roles providing, seeking and advocating for science-based evidence. This finding is line with prior evidence regarding the positive influence of roles demanding deeper content processing on the quality of collaborative learning outcomes (Hogan, 1999; Maloney, 2007; Oliveira et al., 2014; Saleh et al., 2021; Volet et al., 2017), as well as with research describing types of interactions that play a key role in contributing to the high-level co-construction of knowledge (e.g., Cress & Kimmerle, 2018; King, 2002, Volet et al., 2009; Völlinger et al., 2022). As such, science-content roles were unfortunately rarely enacted by the students; for example, in Study III, these roles were found to make up under a quarter of all enacted roles. This result aligns with previous research that reported frequencies of self-adopted roles in collaborative science learning (see Volet et al., 2017; 2019). This finding indicates that exhibiting science content-focused roles, especially the kinds of roles that relate to producing new knowledge rather than just passing on existing information or facts, can be rather challenging for students. Given the importance of these roles in productive collaborative learning, an essential challenge for future research will be to examine how their successful enactment could be promoted among collaborating students. One useful way to pursue the achievement of this aim could be to use the stimulated recall method (e.g., Hogan, 1999; Näykki et al., 2014), in which video clips of their completed collaborative activities would be shown to students in a follow-up interview to reveal what they thought and experienced in different situations. These video clips could focus on 'critical' moments where a clear opportunity for the enactment of high-level science content roles and collaborative knowledge building existed, but was not optimally taken up by the students for some reason. A better understanding of what inhibited students from seizing those opportunities at the time could help promote more meaningful enactment of roles that focus on science content and knowledge construction.

In contrast, roles focusing on *opinion sharing* without any scientific evidence were found to be related to superficial engagement of the learning content and lower achievement, which reflects some prior findings on the influence of opinion-based roles and resembling role profiles (Hogan, 1999; Volet et al., 2017). Interestingly, students favouring opinions contributed relatively actively to their groups (see Figure 3). This finding provides support for the earlier claim that mere active participation of individual group members does not necessarily lead to productive collaborative learning in science, but that the content and focus of contributions is also vital (Lombardi et al., 2021). However, it should be noted that there was some evidence that cognitively lower-level roles, such as opinions, occasionally reflected a real interest in engaging with the task and science. This suggests that students' apparent tendency to prefer the enactment of opinion-based roles may be because they experienced the demands of the task as overly challenging, which prevented them from adopting more science-based roles. These students could therefore have benefitted from stronger scaffolding and guidance prior to and during the collaborative activity (see Section 6.4).

The *process- and experiment-focused roles*, which are related to procedural aspects of the task, such as filling out and manipulating materials, navigating in the CSCL environment and other largely context-dependent 'jobs' needed to complete the task, were found to be the most commonly enacted types of roles. Their prevalence may be partially explained by the nature of the observed activities, which demanded tangible contributions along with conceptual discussions, but also by the fine-grained analysis protocol in which each distinct student action was coded as a distinct role (e.g., providing a brief procedural remark or using the keyboard to write something). However, it is also possible that some students favoured such procedural roles, as they can occupy a meaningful position in the group without needing to expose themselves to cognitively more demanding inputs or opinion sharing. For example, in the high school dataset, each small group worked with one laptop that could only be operated by one student at a time. In some groups, this appeared to lead to a situation where mainly only one particular student operated the computer, and while doing so, contributed only minimally to the group's science content-related discussions. This observation, which also illustrates how constraints and affordances related to contextual factors such as involving technological tools can have an influence on role taking, suggests that it is important to remind group members to prevent roles from becoming too fixed among them to promote equal opportunities for everyone to gain access to a wide range of different types of roles.

In the present research, roles with a *socioemotional* focus were relatively uncommon in comparison to task-related roles. However, it should be noted that the main interest in this thesis was on-task interactions, which influenced, for example, the selection of analysed video segments. Therefore, socioemotional roles could have turned out more prominent if all the available video data had been role analysed—additionally, other functional participatory roles in addition to *harmoniser*, *negativity* and *off-tasker* could have also emerged. Moreover, the conceptualisation of the *off-tasker* role captured various aspects of off-task talk. Recent research has demonstrated that off-task interactions can have multiple different functions in collaborative learning, sometimes even positive ones (Langer-Osuna et al., 2020). Therefore, future research should consider exploring whether meaningful, finer-grained distinctions in off-task roles can be identified. Although relatively infrequent, the present research still demonstrates the importance of *socioemotional* roles for collaborative learning processes and achievement. As illustrated in the qualitative analyses, there was some evidence of the positive impact of the *harmoniser* role in maintaining positive spirit and overcoming emotional challenges when the group faced challenges during task completion. In contrast, there was evidence that the *negativity* and *off-tasker* roles impeded productive engagement and motivation during group tasks. These findings are consistent with prior research highlighting the importance of socioemotional interactions and regulation in productive collaborative learning (e.g., Isohätälä et al., 2018; Jones et al., 2022; Järvenoja, et al., 2020; Näykki et al., 2014) and point to the need for more focused research on the nature, origin and significance of such roles in collaborative learning.

It can be expected that research at the macro-level, providing insights into individuals' attitudes and motivation towards collaboration and task completion, could be particularly illuminating to explain why some students assume maladaptive or even socioemotionally negative roles while collaborating with their peers instead of favouring more positive and productive roles. A better understanding of the influence of such antecedents and background factors could help educators to be better prepared to assist students toward more productive roles (Strijbos & Laat, 2010). This understanding might also help the students' to better regulate their own actions in group situations by possibly providing them with new insights into factors influencing the roles they tend to enact during collaborative activities (see Section 6.4).

This thesis's findings also provide new insights into the interplay of different roles and role profiles in relation to the quality of collaborative learning processes and achievement. The empirical findings support earlier claims (Meslec & Curşeu, 2015; Stewart et al., 2005) that roles should be perceived as a configurational property of the group rather than a mere sum of individual roles. This was particularly highlighted in Study III, which explored relations between within-group configurations of role profiles and achievement. A bit surprisingly, all higher-achieving groups were not found to be science-oriented; for example, one group was mixed between science- and opinion-based role profiles (Figure 3). Here, qualitative in-depth analysis revealed interesting interaction patterns in which lower-level contributions were enriched and expanded towards science by content-focused roles. These patterns illustrated how opinion sharing and other lower-level contributions, when meaningfully supported by science-based roles, can, in fact, act as a positive engine for richer learning interactions and high achievement (Pozzi, 2011). One reason for this is that lower-level contributions might elicit elaborating questions, deeper explanations and different perspectives on the topic from other group members (Kafai & Chang, 2001). This productive interplay reflects Strijbos and Laat's (2010) notion that researchers should avoid too hesitant and over-simplified judgements regarding whether to deem a particular role as positive or negative before first carefully studying how that particular role interacts with the roles of other group members in relation to group goals. However, the influence of one particular role profile, the *distractor*, on group achievement was no doubt negative. A group with three group members engaging in the activity with a science-oriented role profile still not managed to attain high achievement because only one distractor profile was found to shift the group's focus away from productive task engagement. Rather than just considering the composition of individual roles and role profiles, these empirical findings demonstrate the importance of studying the dynamic interplay of different roles and role profiles and how they combine to influence group-level outcomes.

One more empirical insight arising here relates to role flexibility. The analysis outcomes illustrated how the participants could play multiple different roles over the course of the group activity, how roles often naturally followed the ebbs and flows of the interaction and task completion and how at least some students managed to adapt successfully to their roles based on the demands of the situation (e.g., the data excerpt in the overview of Study I in Section 5). This observed flexibility reflects earlier concerns that prescribing too narrowly defined roles for students can be problematic, as these prescriptions can limit the different ways of participation (Dillenbourg, 1999; 2002; Vauras et al., 2003). There was also evidence concerning the positive influence of role flexibility on collaborative learning processes and achievement. For example, the kind of role profiles that encompassed versatile foci, such as the content-based performer who contributed actively to both 'thinking' and 'doing' aspects of science, were found to be much more common in higher- than lower-achieving groups. This finding suggests that the flexibility of such profiles in adapting their roles based on situational demands had a positive impact on group performance and success. It also aligns with the research reporting the benefits of having a diverse set of roles in a group to make the group more flexible and resilient in addressing different issues arising during task completion (Belbin, 1993; Maloney, 2015; Meslec & Curşeu, 2015). However, the need to fulfil a large number of different roles in an activity can turn out to be problematic for a single individual, since it is likely that there is some limit to how many different roles an individual can successfully master at once. To support and facilitate optimal role flexibility, future research could thus explore whether such a limit actually exists and whether there is a variation in the degree of role flexibility among students.

To sum up, the empirical findings of this thesis unveiled how a variety of emergent functional participatory roles and role profiles were spontaneously and dynamically self-enacted by students during collaborative science activities and how these roles influenced the quality of collaborative learning processes and achievement. In general, these findings support earlier notions regarding the conceptual usefulness of roles in understanding the quality of group work and collaborative learning (e.g., Hoadley, 2010; Stewart et al., 2005), bolstering the case further that in future collaborative learning research, more attention should be devoted to the nature and significance of naturally emerging roles. Furthermore, the findings provided evidence of the usefulness of spontaneously self-enacted roles and their interactions as indicators of individual and group engagement. Although not yet common in research (cf. Volet et al., 2017; 2019), future research aimed at contributing to resolving the perpetual "challenges of defining and measuring student engagement in science" (Sinatra et al., 2015, p. 1) could benefit from considering the functional participatory roles that are self-enacted by students during collaborative learning processes.

6.4 Practical implications

This thesis carries practical implications for teachers and other practitioners applying collaborative learning in their curricula. First and foremost, it draws attention to the importance of paying more attention to the roles that are spontaneously enacted by students during collaborative learning activities. This understanding is needed even if the teacher is utilising prescribed roles to structure peer collaboration because, optimally, those roles should be tailored based on naturally emerging roles (Lazareva, 2021; Spada, 2010). Importantly, being aware of different emergent functional participatory roles and their impact on collaborative learning processes may help teachers tune their support and guidance to the needs of different groups.

With such an understanding, teachers could react quickly and meaningfully if maladaptive or negative role patterns start developing, avoid their escalation and taking the opportunity to strengthen existing positive patterns further. Functional participatory roles can also have new value in advancing teachers' in situ guidance because they might be more familiar and easily observable indicators of collaborating students' behaviours and engagement compared to many other facets, such as social regulatory processes, and thus help them also adapt their own 'instructor participatory roles' based on students' needs (Ouyang & Xu, 2021). The actual data examples illustrated in the three studies show what different functional participatory roles and their interplay looks like in real life and hence can help teachers to be more sensitive to different roles.

A lot can also be done upfront to facilitate more successful role enactment and collaboration. As one new potential way to help students be more prepared for collaborative learning (see Mende et al., 2021 for a review), teachers could provide information to students about the characteristics and the learning value of different functional participatory roles. Combined with teachers modelling what different roles actually look like, this information could not only help students understand the nature and characteristics of different roles, but also help them to spontaneously enact more favourable roles during their collaboration efforts and avoid those that are less so.

This thesis' findings on the impact and interplay of different roles certainly contribute to the discussion of how to optimise productive collaborative learning through group formation (see Cohen, 1994; Hämäläinen & Vähäsantanen, 2011; O'Donnell & Hmelo-Silver, 2013). Particularly, the findings concerning productive within-group role profile configurations can provide new insights into how to mix students together for collaborative learning activities. Since it is unlikely that only the most productive roles and role profiles are enacted by students in collaborative activities (cf. Stempfle et al., 2001), teachers could capitalise on their understanding of the learning value of different roles by balancing groups so that the most productive roles would have the opportunity to support and scaffold other roles in the joint learning effort or even mitigate the influence of counterproductive roles. However, there was evidence that even one dysfunctional role profile could distract the entire group from productive task engagement. This finding reminds us of the crucial role of teacher scaffolding and support during collaborative learning activities, particularly for lower achievers (Dobber et al., 2017).

Empirical research on emergent roles could also have value in designing productive collaborative learning environments. This is because "roles-as-intended" can differ significantly from "roles-as-enacted" (Hoadley, 2010, p. 553); hence, roles might have the potential to help identify the discrepancy between design and practice. For example, if technology-related roles turn out to be predominant at the cost of other more content-related roles during CSCL, this might be an indicator that the students are struggling to use the technology in the way intended, which may hinder their learning efforts as a group (Gu et al., 2015). Therefore, research on roles has the potential to provide insights into how desired collaborative learning interactions can be more effectively promoted through design.

6.5 Limitations and future directions

The empirical work presented in this thesis was undertaken in ecologically valid science learning environments, including systematic analyses of observational data. Due to the demanding and laborious nature of these analyses, the findings were, therefore, based on relatively small datasets derived from only a few different collaborative learning settings. To address this limitation, future research could gather further evidence in different kinds of settings and use larger datasets to determine the extent to which the findings are generalisable to other contexts. At least to some extent, the findings can be expected to resonate with other science, technology, engineering and mathematics (STEM) disciplines given their close resemblance in terms of the nature of collaborative learning (Johri & Olds, 2011). Although already a previously increasing trend, the COVID-19 pandemic has pushed collaborative learning to online and hybrid platforms (Dowell & Poquet, 2021). Therefore, future research could also explore whether the functional participatory roles and role profiles identified in the face-to-face learning situations in this thesis can be also identified in hybrid or purely online collaborative science learning contexts and whether the interplay of different roles is similar compared to the findings here.

Research with younger children is needed, too, given that this thesis focused only on high school and university students. For instance, it is possible that the most cognitively demanding roles, such as those that are knowledge based, may turn out to be too demanding for young children to be spontaneously self-enacted; alternatively, new types of roles might emerge among younger children that were not observed in this thesis (cf. Maloney, 2015).

Larger datasets would also provide the opportunity for more sophisticated statistical analyses. Here, cluster analysis of student role profiles was done at the broader, categorical level of enacted roles (e.g., science content-focused roles). Larger datasets with more observations could enable the identification of student role profiles at the discrete role level, thus potentially revealing more detailed profiles and finer distinctions between them. Although it is crucial to study roles in authentic learning settings (Morris et al., 2010), future research could also study how the relationships found between achievement and within-group role profiles might replicate in more controlled circumstances that would allow more causal interpretations. This is because there might have been factors influencing the quality of achievement that were undetectable with observations (Study III), especially in the teacher education sample in which the achievement measure (aggregated individual final exam marks) was not directly related to the observed activity, as in the high school sample (group's joint presentation).

In this thesis, roles were observed in a rather limited time over one to three sessions, which calls for the need for a more longitudinal approach in the future. Shifting the focus from ad hoc groups to groups undertaking longer collaborative learning projects would also be important in understanding how roles develop and mature within a group over time. This line of research could deepen our understanding of how different stages of group formation (e.g., newly formed or long-established group), task phase (e.g., planning or executing) or transitions may influence roles and their emergence (Benne & Sheats, 1948/2007; Forsyth, 2014). At the individual level, this could lead to new insights about students' role trajectories, such as whether students' roles and role profiles remain rather constant or if they change over time, or whether they change from one activity to another or not.

Regarding future directions, greater attention should also be dedicated to exploring how the atmosphere and interpersonal relations within a group and classroom might affect roles. For example, when students feel there is a safe and encouraging atmosphere (Brummernhenrich et al., 2021; Newman et al., 2017), they might feel comfortable and confident striving towards more demanding roles instead of just adhering to roles that are already familiar to them. Ultimately, a better understanding of the prerequisites and conditions affecting role enactment could facilitate interventions that promote flexible adoption of key roles and make them more accessible for all students.

Another important aspect that definitely needs more emphasis in future research is cultural issues. Gu et al. (2017) explored what roles students from the USA and China enacted during distance collaboration and found that the self-enacted roles differed notably between the students from these two different cultures. This interesting finding reminds us that the influence of cultural dimensions on roles cannot be underestimated. It also reminds us that much more research still needs to be done outside the Western, educated, industrialised, rich and democratic (WEIRD) countries (see Muthukrishna et al., 2020) to get a more comprehensive picture of the nature of spontaneously self-enacted roles in different cultural settings. Moreover, a better understanding of emergent roles in multicultural settings could help facilitate more productive collaboration in such diverse groups, which would be important given that groups and teams comprising members from diverse cultural backgrounds are more and more common in education, in the workplace and in society at large.

Future research should also explore the possibilities of bringing in new modern data modalities and technologies (e.g., eye tracking, facial recognition, and heart rate monitoring) to research roles in collaborative learning (De Wever & Strijbos, 2021). In addition to the fact that their analysis is often less labour-intensive compared to the comprehensive coding of observation data, another prospect of these modalities is that they are not solely dependable on explicit contributions, such as verbal communication, making them particularly useful when dealing with younger children or students who take a passive role in group activities. For instance, one recent study identified leadership and follower roles in collaborative learning based on emotional mimicry captured with facial recognition technology (Dindar et al., 2020).

To conclude, this thesis expands the understanding of spontaneously self-enacted roles and their significance in collaborative learning and provides a useful compass for further research in this area.

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Appendices

Appendix A. An overview of the functional participatory roles identified in the thesis (adopted from Heinimäki et al., 2020; see also Heinimäki et al., 2019; Volet et al., 2017, 2019).

Functional participatory roles	Summary of descriptions and indicators
Task-related	
Core roles	
Knowledge seeker (KS)	KS attempts to foster a deeper understanding of science content without being critical of previous contributions. KS is especially interested in scientific explanations, interrelations, cause and effects.
Knowledge provider (KP)	KP provides scientific explanations, effects, interrelations, causes and other deeper science knowledge. KP can provide new solutions or initiate something new and meaningful for the group by shaping existing facts and information and introducing how they would work if adopted by the group.
Information seeker (IS)	IS seeks facts and information related to science content without being critical of previous contributions. When seeking deeper science understanding, effects or interrelations, code KS is used.
Information giver (IG)	IG offers facts and information related to the task content. For contributions that go deeper than just offering factual information, the code KP is used.
Challenger (CH)	CH questions previous contributions and ideas and is interested in exploring other, science-based alternatives. CH can offer alternative solutions or invite others to evaluate solutions, suggestions or actions.
Supporter (SU)	SU supports previous ideas, suggestions or solutions by, for example, rephrasing or adding clarity to previous statements, but clearly in a supportive way. In doing so, a new type of information or deeper science content is added, and codes IG or KP are used.
Follower (FO)	FO shows agreement verbally or non-verbally (e.g., by nodding) without offering additional science-related input. FO may also just repeat previous statements and express readiness to go along with what others decide.
Opinion seeker (OS)	OS wants others to express their opinions about the task content or performance. In doing so, OS is not interested in factual information or science-based justifications.
Opinion giver (OG)	OG expresses opinions related to task content or performance, without backing up the suggestions and comments with science.

Activity-specific roles	
Navigator (NV)[1]	NV operates a laptop to navigate the group in the virtual environment.
Attention focuser (AF)[1]	AF attempts to focus other students' attention to some aspect of the task either verbally (e.g., reading aloud) or non-verbally (e.g., pointing at computer screen with a finger).
Recorder (RE)[1]	RE is responsible for keeping record of group decisions and activities, for example, by taking notes or writing-up the group's presentation. While doing so, RE does not challenge the suggestions of other group members (cf., CH role).
Dictator (DI)[1]	DI dictates and summarises what to record (e.g., write) or how to proceed (e.g., which option to choose) based on joint group discussions or decisions without offering new information. When a more general and personal comment is in question, the code OG is used.
Technological contributor (TC)[1]	TC gives instructions, as well as raises and solves problems related to technology in task performance.
Reader (RD)[2]	RD reads aloud instructions or information relating to the experiment from materials.
Procedural contributor (PC)[2]	PC focuses on task processes/procedures, such as writing answers, recording notes and giving generic comments about materials. If new facts or information are given, code IG or KP is used.
Observation maker (OM)[2]	OM draws other students' attention in situ to some aspect of the hands-on experiment and materials by, for example, verbalising simple observations or something unfolding in the experiment.
Socioemotional-related	
Harmoniser (HR)	HR attempts to create a positive atmosphere with praises, task-related jokes, conflict resolution strategies and tension alleviation techniques.
Negativity (NE)	NE expresses frustration and negativity towards other students, the learning situation or the task.
Off-tasker (OF)	OF derails the group from the task by discussing issues that are not related to the learning situation and task. If the off-task contribution has a negative focus, code NE is used.

Note. [1] indicates the activity-specific roles for high school students and [2] for teacher education students.

Appendix B. Student role profiles: High school and teacher education students (adopted from Heinimäki et al., 2021).

Profiles	Descriptions
Common	
Opinion focusers	Had relatively predominant focus on opinion sharing
Content-based performers	Favoured both science content and experiment- and process-focused roles, indicating a tendency to use scientific evidence for task performance
Procedural managers	Contributed mainly to procedural aspects of the task.
Specific to high school students	
Content-opinion contributors	Enacted both science content and opinion sharing-focused roles, with relatively few procedural contributions.
Content-social contributor	Favoured science-based roles when on-task but also occasionally enacted positive (harmonising) and negative (off tasking) socioemotional roles
Specific to teacher education students	
Content contributors	Predominantly science-oriented, with only minimal enactment of other types of roles
Distractor	Showed clear task avoidance by contributing minimally to the group effort and making negative social contributions (off-tasking)

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