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Towards a micro-ecological approach to CSCL

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Abstract
In this paper, we argue that how we use theories may be preventing us from developing a deeper understanding of computer supported collaborative learning (CSCL) contexts. We focus the argument on our understanding of orchestration processes and draw on common theories to show how they prioritize a mono-ecological approach: the examination of collaborative processes at a single level of an ecological system. We argue that doing so prevents us from seeing the full complexity of the types of decisions that teachers and learners make when implementing collaborative learning activities in technologically enhanced, real-world contexts. To address this problem, we propose a micro-ecological framework that recognizes collaborative learning as a complex, cognitively nested, ecological phenomenon and analyzes interactions in a way that aligns with this view. Our approach focuses on the microanalysis of interactions between individuals, learning objects, the small group, and the classroom community. The purpose of this analysis is to identify critical points in the learning process where actions at one level of cognitive activity propagate to influence other levels of individual and joint activity. We call these events transecological disruptions. We argue that these disruptions can provide opportunities to understand how the learning ecology develops over time through teacher orchestration and learner engagement. To illustrate our framework, we pursue the following research question: "How can a micro-ecological framework help us better understand the CSCL ecology?"

Keywords Theoretical frameworks · Ecological systems · Orchestration · Evaluation · And methods Q2

Towards a micro-ecological approach to analyzing orchestration in CSCL

In their article, Wise and Schwarz (2017) synthesize the perspectives of the Computer Supported Collaborative Learning (CSCL) community through a conversational narrative that debates eight themes as provocations that currently engage our field. The purpose of the paper

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was to serve as a point of reflection, to provoke discussion around problems that may interfere with the larger goals of our community. One of these provocations, the fourth provocation, was titled "The co-habitation of analytical and interpretative approaches in CSCL is actually a situation of co-alienation that cannot be surmounted" (Wise and Schwarz 2017, pg. 436). Within this section the two fictional speakers, the Provocateur and Conciliator, discuss the diverse theoretical and methodological approaches that exist in our field as both points of strength and weakness. The strength resides in the diversity of ideas and approaches our community has as a means to innovate, create, problem solve, and inform. The weakness resides in the epistemological biases that our theoretical predispositions create. Wise and Schwarz emphasized how these biases can lead to polarization within a community, but we want to discuss how these biases can interfere with how we examine collaborative activity.

Our theoretical leanings can influence what we choose to study, at what level we examine it, and how we examine it. Our community has a history of prioritizing the study of cognitive learning processes at the individual level of analysis and of rigorously analyzing smaller pieces of a larger ecological system. We do this even when examining complex nested phenomenon like teacher orchestration practices. We argue that these common methodological practices can prevent us from fully understanding how a CSCL ecology develops and therefore prevent us from better understanding how different orchestration processes can impact a community.

In this paper, we extend the discussion started by Wise and Schwarz to examine problems associated with how we currently use theory to guide analysis of CSCL contexts. We focus on teacher orchestration processes because understanding and supporting these processes is gaining increasing attention in CSCL. We propose a micro-ecological approach for analyzing CSCL contexts and the embedded orchestration processes. We then analyze a case to show how such analyses can help us to see CSCL activities in a more robust and ecologically meaningful way, and finally discuss the implications of a micro-ecological approach for teacher professional development.

The importance of CSCL orchestration

Collaboration entails that a group of people share, collectively think about, expand on, and negotiate their ideas for the purpose of creating something new: new ideas, new ways of thinking, novel solutions to problems, or collective artifacts that did not exist in the head of any participating individual or in the cultural artifacts the group had access to prior to collaboration (Roschelle and Teasley 1995; Stahl 2006). Collaboration is a collective cognitive endeavor that is hard, requires sustained effort from participants to work well, and is prone to breakdowns caused by different socio-emotional, cognitive, metacognitive, and socio-metacognitive problems (Barron 2003; Borge et al. 2018; Kerr and Tindale 2004; Kozlowski and Ilgen 2006). Thus, it is not surprising there are many known issues that arise during collaborative interactions. For example, students can fight over materials or dominate conversations; they can fail to negotiate ideas or regulate activity (Hogan 1999; Zurita and Nussbaum 2004); or they might not feel psychologically safe (Edmondson 1999) to share their ideas and mistakes with the community.

Collaborative issues can lead to off-task behavior, negative social interactions, and the disintegration of a group, especially in classrooms with a high number of students with little collaborative experience (Borge and White 2016). When adding technology, this difficulty can and usually does increase as problems emerging from technology use are added to existing social issues, such as inability to use a program, connectivity issues, system crashes, or fights over who controls the technology. Effective orchestration can increase the likelihood of positive learning outcomes, but requires adaptability and flexibility on the part of the teacher, who is largely responsible for the orchestration (Dillenbourg et al. 2009). For this reason, the orchestration of CSCL activities has been getting increasing attention (Dillenbourg et al. 2009; Dimitriadis 2012; Roschelle et al. 2013).

Dillenbourg et al. (2009) explain that orchestrating learning in CSCL contexts is a complex process requiring the coordination of multiple activities at multiple levels of interaction. For example, there is a need to orchestrate learning activities, use of scaffolds, regulatory activities, and motivation at the level of the individual, small group, and classroom community. As such, different elements of a classroom system can interact with each other in real-time in a variety of complex ways.

Dillenbourg et al. (2009) discuss the practical and methodological challenges posed by orchestration. Practical challenges include determining how to best orchestrate collaborative activities, how and when to scaffold or support different types of processes (cognitive, social, and metacognitive) across different social planes (individual, group, and community). Dillenbourg et al. also point out that the diversity of methodological practices that exist in our field make the accumulation of knowledge on CSCL orchestration difficult. There is a question of how to conduct basic research on orchestration, when the phenomenon is so complex and has so many interacting factors. Dillenbourg et al. explain that there is a tension between real-world, design-based studies and controlled studies. We argue that the problem is even more complex than that.

Common CSCL theories and methods can help us to understand how learning can occur at one level of interaction within a larger ecological system, at the mono-ecological level. This is because we focus our methodological and analytical lens on the examination of one level of interaction within a larger, more complex system, e.g., the individual as they move through different interactional levls. As such, even when our research includes data from multiple levels of interaction, we primarily investigate these levels independently of each other by examining how one level may impact another, i.e., how community values impact group learning processes. We do not examine interactions across levels, i.e. how community values, group learning processes, and individual activity impact each other over time. Investigating these different levels of interaction independently from each other may interfere with our ability to understand, or even observe, how actions at one level of activity can propagate accross levels to influence trans-level activity: activity across levels in an ecological system. A better understanding of trans-level interactions may be necessary in order for teachers and students to learn how to manage their interactions so as to promote more positive collaborative learning contexts.

Methodological challenges posed by common theoretical frameworks

The Learning Sciences, including CSCL, emerged from multiple disciplines and epistemic traditions, integrating a range of theoretical frameworks from which to study learning. The frameworks listed in Table 1 are among the most commonly used in CSCL: information processing, constructivism, social constructivism/sociocultural, and group cognition. These frameworks emerged from theoretical roots with different theoretical assumptions about the nature of knowledge, which resulted in differences with regard to perceived units of analysis t1.1 **Table 1** A summary of learning theories in CSCL that focus on cognition at different levels of scale

	Theory	Theoretical assumptions	Unit of analysis	Most common assessment
t1.2	Theory	Theoretical assumptions	Unit of analysis	Most common assessment
t1.3	Information processing	Cognition and learning occur as a function of psychological and biological mechanisms within the brain.	Individual processes occurring within the brain.	Individual measurement of acquired knowledge and skills before and after collaborative processes: reaction times, recall.
t1.4	Constructivism	Cognition and learning occur as a function of individual construction of knowledge based on previous experiences and existing knowledge	Individual processes occurring between individuals or between individuals and objects.	Individual measurement of cognitive growth after collaborative processes: assessments of conceptual change, performance tests in authentic contexts.
t1.5	Social constructivism/ sociocultural	Cognition and learning occur as a function of the individual's gradual internalization and appropriation of cultural beliefs, norms, expectations, practices, and value systems.	Collective processes occurring between individuals, between individuals and objects, within groups, or within communities.	Individual measurement of changes in discourse patterns, identity, social practices or artifact use.
t1.6	Group cognition	Cognition and learning occur at different levels, individual (cognition), group (group cognition) and community (practices), At the level of the group, individuals externalize individual thought through language and create new, shared understanding and knowledge.	Group processes occurring through language or through the creation of shared knowledge artifacts.	Collective changes in discourse patterns, social practices, or artifact use. More specific focus on the development of discussion, than the individual's contributions.

and ways to measure learning. Common assessments in CSCL have prioritized the examination of learning processes at an individual level.

Theoretical leanings influence methodological approaches. Researchers who adopt constructivist and cognitive theories conceptualize learning as occurring within the mind of individuals as they interact with the external world. From this perspective, the goal is to create optimal interactions between the individual and the external world to produce learning and development. As such, they may examine the utility of an intervention by measuring individual pre-post learning outcomes that arise from different forms of scripting, scaffolding, or interaction.

Social constructivist and socio-cultural perspectives in CSCL recognize that cognition is a nested phenomenon, yet still prioritize one level of analysis. For example, Arvaja (2007) used a socio-cultural lens to examine the contextual nature of collaborative knowledge construction. To do so, she analyzed groups' web-based discussions to determine how they used language to construct knowledge and how they used cultural resources, i.e., course materials, previous experiences, etc., to support this knowledge construction. Thus, Arvaja (2007) recognized that multiple levels of cognition were in play during group knowledge construction, but was interested in understanding how these different levels influenced cognition at the level of the group.

Group-cognition theory, also recognizes the nested nature of collaboration, but focuses primarily on the level of the small group, through case study analyses of collaborative, group communication processes (Stahl 2013). In explaining why deeper analyses of the small group is necessary, Stahl (2013) explains that cognition exists at multiple levels of analysis, as different forms of thought. At the individual level, this form of thought occurs as individual cognition. At the group level, there is a collective form of thought that is group cognition. Finally, at the level of the community, thought occurs as common practices that are passed down, maintained, and modified by the community. While all these levels are nested, group learning outcomes cannot be captured by individual learning outcomes, because shared (group) knowledge emerges from contributions spread across the group: "the meaning that is created is not a cognitive property of individual minds but a characteristic of group dialogue" (Stahl 2006, pg. 6–7). The situated nature of group cognition also implies that ideas and knowledge developed at a certain place and point in time may not be remembered later by any individual member; the group is more than the sum of its parts. However, knowledge created by the group can impact individuals and the community (Stahl 2006). Since the majority of what we know about collaborative learning has been conducted at the level of the individual, Stahl argues that we need to begin to prioritize the level of the small group (Stahl 2006, 2013). As such, Group-cognition theory recognizes the ecology in which groups operate, but primarily as a constraint that impacts the dialogical voices of individuals that enter the shared cognitive space where collaboration takes place (Stahl 2013).

The learning theories summarized in Table 1, along with their most common forms of assessment, have been successful in helping us to develop understanding of specific forms of learning. Nonetheless, concerns have been raised about constraints imposed by these theoretical stances (e.g. Barron et al. 2009; Järvelä et al. 2010; Mercier and Higgins 2015) and how research and development of innovative learning environments may be stalled or stymied by these constraints (e.g. Akkerman et al. 2007; Nathan and Alibali 2010).

Our main concerns are that our use of theories have not helped us to examine how cognitive processes develop across levels of activity and social interaction, and that we prioritize the learning of domain content over other forms of socio-emotional or metacognitive learning. Epistemologies guide the theoretical frame we use to examine learning, but can also interfere with our ability to identify the existence of, and interaction between, key interactional moments that occur at different levels of analysis in a single project or point in time. There is a problem in prioritizing individual or group cognitive learning factors over other critical factors in the orchestration process, i.e. metacognitive and socioemotional factors at differing levels of interaction (Dillenbourg et al. 2009). In doing so, we are unable to see the full complexity of the types of decisions that teachers make when implementing collaborative learning activities in technologically enhanced, real-world contexts. Moreover, we also do not see the role that the learners play in the orchestration process.

The learning ecology

Not all learning contexts allow for collaborative learning to take place. Instructional practices, value systems, and forms of technology use can help or hinder collaborative processes (Clegg et al. 2013; Grant 2009; Guzdial et al. 2002; Hmelo et al. 1998). Collaborative learning and problem solving is hard work and requires a great deal of cognitive effort from those participating to promote positive outcomes (Barron 2003; Borge and White 2016; Borge et al. 2018; Kozlowski and Ilgen 2006). In order for students to put forth the effort to build and maintain healthy collaborative interactions they need a systemic culture of support where activities, technologies, and value systems all align to promote collaborative learning goals (Guzdial et al. 2002; Hmelo et al. 1998). Thus, key moments that arise during collaborative activities that impact multiple levels (i.e., individual, group, and community) can be essential to the creation and maintenance of the type of learning ecology where collaborative predispositions thrive (Schwarz et al. 2018; Damşa and Ludvigsen 2016).

Within a technologically enhanced collaborative learning context, there exists an individual-technology-group-community ecology. Individuals interact with technology as part of a small cognitive system (Norman 1986, 2013) and how this interaction plays out can impact group processes. For example, if a technology is too difficult to use, it could frustrate the user, increase negativity for the team, and interfere with task completion. Similarly, groups are systems that can impact how individuals interact with technology: whether they have equal access to technology or include everyone in discussions around technology use, stay on task, etc. Individuals and groups can also impact the larger community system. An easy example is the disruptive individual or group. Individuals or groups that regularly engage in dysfunctional social processes that stress the teacher or distract the rest of the community from learning can interfere with deeper learning by continually interrupting learning activity. Individuals and groups can also positively impact a community by engaging deeply with content, empathizing with peers, and helping the community overcome obstacles. The community also has the potential to impact individuals, groups, and their interactions with technology depending on the rules the community sets, the value systems they promote, and how the community decides to distribute responsibility across the community members. Each of these systems interacts with the others to influence a variety of cognitive, metacognitive, and socio-emotional outcomes, yet few studies examine collaboration across these systems as they occur to see how they impact each other.

In these learning contexts, teachers have the potential to impact all of these forms of interactions as the creators and facilitators of community values, rules, and responsibilities. They orchestrate learning processes, tasks, and problem resolution within the community. As such their feedback can significantly alter all of these systems.

Teacher orchestration is an important factor in collaborative contexts that has been getting increasing attention in CSCL (Dillenbourg et al. 2009; Dimitriadis 2012). As discussed, teacher orchestration processes have been described as a complex endeavor whereby the teacher has to manage and coordinate multiple activities occurring at multiple social levels at the same time (Dillenbourg et al. 2009). Yet, even when examining complex processes, like orchestration, researchers have still prioritized the individual cognitive level of the system. For example, researchers have examined the cognitive load of teachers as they work to orchestrate CSCL activities (Prieto et al. 2015; Sharma et al. 2017), teacher gaze patterns (Dessus et al. 2016), the impact of technologically enhanced monitoring support (Chounta and Avouris 2016; Rodríguez-Triana et al. 2017) and adaptive guidance for the purpose of enhancing individual students' conceptual learning (Schwarz et al. 2018). Studies that examine learning processes and outcomes in a more ecologically valid way, across the classroom ecology created by these interacting systems, would help identify the types of skills and knowledge that teachers would need to effectively support technologically enhanced collaborative contexts among different populations.

Towards an ecological approach in CSCL

Nathan and Alibali (2010) argue that methodologically and conceptually, our current research practices interfere with our ability to provide a more wholistic understanding of learning processes. Nathan and Alibali push us to reconsider what we examine, and how we examine it, as part of research. They have argued for the need to combine elemental research that examines classic cognitive and neural processes with systemic research approaches that examine macro level processes like teacher training and classroom social interactions. They point out that our inability to link theoretically and methodologically disparate research creates obstacles for our collective understanding of learning processes across differing levels of scale. They propose a framework that looks at learning across different timescales: from the 10^{-2} scale of biological processes which includes activity up to a second, to the 10^{7} scale which includes learning at the level of months and beyond, all the way to what they refer to as tran-scales which look at interactions between systems in a more ecological way. They argue that their framework provides a systematic way to "scale up" studies in order to examine similar phenomenon from multiple time scales. However, their framework places ecological models at the highest time-scale and they propose these types of studies can be done through historical analysis of systems or through other forms of meta-analysis research. This is not how we envision an ecological framework.

We use the term "ecological framework" to describe a conceptual framework that is grounded in the idea that cognition, including thinking and learning processes, is an ecological phenomenon. In contrast to theories that consider cognition as located solely within the participant's head or that prioritize interactions at one level of scale, we argue that cognition exists within and between these boundaries and should therefore be analyzed in a more ecological way. Furthermore, like Herrenkohl and Mertl (2010), we argue that cognition should be seen as more than the ability to understand and use knowledge and tools. We also need to examine different types of learning skills and knowledge that are being developed, including socio-emotional, cognitive, metacognitive, and domain specific.

The idea that learning and development are ecological is well established in developmental psychology. Bronfenbrenner's work (Bronfenbrenner 1974, 1977) has been particularly influential, though often misunderstood (Tudge et al. 2016). In his early work, he described the ecological environment to be "a nested arrangement of structures each contained within the next" (Bronfenbrenner 1977, pg. 514). He then named and defined each structure: the microsystem, which contains the developing child and their immediate interactions with other actors in one setting (i.e., a home or classroom); the mesosystem, which describes interrelations between microsystems; exosystems, which are other formal and informal structures that do not contain the child, but influence their microsystems (i.e., media, local government, parent's workplace); and macrosystems, which are the larger cultural or governmental systemic patterns that can explicitly or implicitly influence the ideologies, customs, and laws of a society. In his later work, time, (the chronosystem) was also a factor, because when things occur in time can influence the developmental ecology (Bronfenbrenner 1986).

We acknowledge the existence of these systems and believe CSCL research would benefit from a more general ecological approach, but the ecological experiment as described by Bronfenbrenner is not the focus of this paper. We build on Bronfenbrenner's idea of nested systems and the ecology of the developmental process. However, unlike Bronfenbrenner, whose work is experimental in nature and focused on individual outcomes, we are invested in the deep analysis of dialogical processes that occur at the level of the microsystem for the purpose of examining collective learning outcomes.

Unlike other theoretical approaches that prioritize one level of scale between individuals, learning objects, the small group, and the learning community, a micro-ecological approach focuses on the microanalysis of interactions between and accross these elements as a means to identify key points in the learning and orchestration process where different cognitive systems interact with each other to modify activity, which we define as transecological disruptions.

The decisions made by different actors during transecological disruptions have potential to help or hinder collaborative learning across different levels. As such, we argue that transecological disruptions can shed light on how and why CSCL contexts can lead to a variety of different learning outcomes.

An example of a micro-ecological approach

In order to show how a micro-ecological framework can help us to unpack a CSCL context and the orchestration processes that result, we present a case from an after-school design club program for 3rd to 6th grade students. This case was selected and transcribed because a variety of events occurred where problems and solutions interacted between different nested systems existing within the microsystem. Teacher orchestration throughout these interactions was taken on by club facilitators. Facilitators and students played key roles in how interactions played out and these interactions resulted in powerful learning outcomes across the nested systems. The events that unfolded during this session were also retold by older students to new students in future semesters that followed as new students joined the community.

The club members were students, eight to 12 years of age, who enrolled in the afterschool club at the beginning of the fall semester as part of a larger collection of afterschool programs run by the school. The club ran once per week for 1.5 h. There were 16 students enrolled, 43% female and 50% students of color. There were three facilitators: F1, a senior graduate student who was leading the session on that day; F2, the supervising faculty member, and a third novice graduate student that was primarily observing and planning to lead the end of day reflection. At this point in the semester, the teams had completed a Lego design, a garden for a fictional family, and had evaluated the quality of the design based on a profile of the family that included desired activities, needs, wants, constraints, etc. They had identified flaws in their design, created a revised plan for building the garden in a virtual (Minecraft) world, and had begun the building process.

Each session was roughly structured as follows: facilitators would introduce the days' activities by reflecting on the previous session and setting goals for the current session; teams would be given laptops; teams would work on their projects; facilitators would observe teams and help when needed; facilitators would end the session with a whole class reflection about the days' events. We will first present a narrative of the events told at the community level, followed by an micro-ecological analysis.

On this day, the community experienced a series of issues that prevented them from working on their semester project. The lead facilitator, F1, began the day with a whole class reflection, before handing out the technology and letting the groups begin their work. Soon the community realized that the university server that stored their creations and allowed them all to interact in the same Minecraft world was not working. One of the facilitators, F2, said she would handle the issue. So, the learners went on their computers to play online games while she resolved the issue. Then the other facilitator, F1, encouraged the kids to use their computers to go online and figure out how to create a local server that everyone could join.

So, all the kids attempted to figure out how to do so. A short while later, F2 figured out how to create a local server, told the community how to do so, and encouraged each team to play in their own Minecraft world, to explore features in Minecraft that they could apply to their project later. All went well for a while, until F2 heard screaming. She asked the community what happened and Group 3 complained angrily that a boy, Eric, from Group 2, went into their Minecraft world and destroyed all their creations. F2 resolved the issue by reminding the community of their core values: to explore, value and learn from mistakes, and to problem solve together.

We can analyze this event at a monoecological level to see how different interactions impacted learning processes at the community level. Figure 1 shows a diagram of the narrative events that took place at the community, or "C", level. In this representation time moves from left to right like a music track and is shown in five-minute intervals. For example, at timepoint C14 (Community level at 14 min into the session) F2 (Facilitator 2) tells the whole community (WC) she will fix the problem.

This diagram shows the importance that problems play in triggering teacher orchestration moves, but also shows how non-collaborative orchestration moves, moves that do not exemplify collaborative values connected to a learning community, can lead to more problems. After the community encountered a server problem at timepoint C12, Facilitator 2 (F2) told the whole community (WC) that she would fix the problem. This orchestration move was problematic because it positioned her as the problem solver and placed community members in the passive role of solution recipients. As a result, the community sought online games to play individually instead of working as a team to seek solutions to the problem. At timepoint C17, F2 further encouraged the community to explore Minecraft individually, while she worked on resolving the problem. At timepoint C23, the lead facilitator (F1), a graduate student, distributed responsibility for solving the problem to the whole community. This more collaborative move on the part of F1 led the whole community to stop playing online games and take on responsibility for problem solving until F2 shared with the community a solution for creating a shared server. F2 then instructed each group to create a shared server and use the session to explore Minecraft features that could help them enhance their projects for the next session, when they got the university server to work.

No other discussions occurred at the level of the whole community until F2 heard screaming at timepoint C57. F2 asked the whole community what happened and Group 3 (G3) angrily complained about a student named Eric (E) saying he destroyed their world. This move by G3 both articulated a problem and was itself problematic because G3 was looking for Eric to be punished for his actions. In response to G3's move, F2 goes off to speak to Eric

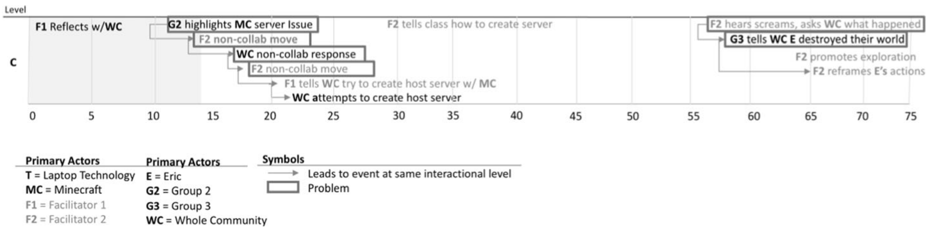

Fig. 1 Diagram of the narrative events taking place at the community (C) level with primary actors, problems, and relationship between events are depicted with symbols

individually. She returned to the whole community at timepoint C65 to remind the community about the importance of exploring and to explain how Eric's actions could help the community.

This analysis seems incomplete because many questions emerge from it. For example, why did F1 choose to contradict F2's instructions at timepoint C23? Did the students play any role in resolving the server problem? Why would Eric destroy Group 3's world and why did F2 choose to reaffirm community values at timepoint C64 instead of reaffirming the importance of respect for other people's creations?

Let us look at these events from a more ecological perspective, one that examines multiple levels and their interactions at once. Figure 2 is more complex, introducing two new levels. Below our original community (C) level is the group level (G) and below that is the individual level (I). There are also more actors depicted within the different levels and a new symbol, the thicker darker arrow, depicting relationships between events at different levels of activity. What this perspective allows us to see is the prominent role that problems play across all levels in shaping the classroom ecology as the majority of trans-level disruptions, events that have ripple effects across levels, result from problems and their proposed solutions.

In Fig. 2, we can see that the problem that was brought to the community's attention at timepoint C12 originated in Group 2 (G2); they were the ones who first realized the Minecraft server was down (at timepoint G8). When G2 shared this problem with the class (see Problem 1 at timepoint G12), F2 responded with the non-collaborative set of moves discussed in the previous analysis and also led to non-collaborative activity in the community as the community shifted from group interactions through and about technology to individual interactions with technology.

This more ecological analysis highlights the role that individual students played in resolving the server problem and the non-collaborative play. Aron, from Group 2 (shown as A in the diagram), ignored the teacher's instructions and attempted to create his own shared server in

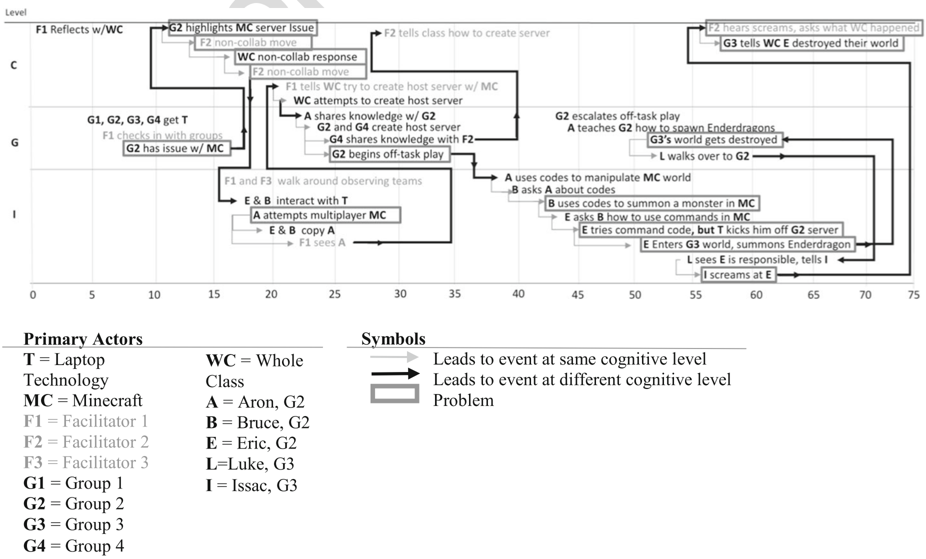

Fig. 2 Diagram of the events taking place at three different levels of cognition, shown on the left of the diagram: community (C) level, group level (G), and individual level (I): primary actors, problems, and relationship between events are depicted with symbols

Minecraft (see timepoint I18); this is highlighted as a type of problem because the individual was not following instructions. F1 saw what Aron was doing (see timepoint I22) and made a critical orchestration move. Rather than punishing Aron for not following instructions, she interpreted it as a positive, exploratory behavior and decided to encourage the entire community to emulate it. This was why she chose to counter F2's original instructions by telling everyone to "take a risk and go online and figure out how we could create a local server for free that everyone could join" (see timepoint C20).

In response to this move, the entire class stopped playing individual, online games and began working collaboratively as a community to resolve the server problem (see timepoint C21). This led Aron to share his knowledge with his team and discuss what he had been trying to do previously (see timepoint G22). It also allowed Group 4 and Group 2 to work collaboratively and find a solution (see timepoint G24).

After figuring out how to create a local server for their team, Group 4 made a collaborative move and shared their solution with F2 (see timepoint G25). Their move is what led F2 to share the solution with the whole class (see timepoint C28). Thus, Group 4 played an important role in helping the class make progress towards their shared goal.

Unlike Group 4, Group 2 did not respond in a collaborative manner. They created their shared server and then used it to begin off-task play. Bruce (B) and Eric (E) began play fighting in Minecraft, each trying individually figure out how to destroy the other's avatar with weapons. This off-task play was especially problematic because it violated a community rule: no play fighting in Minecraft.

Since his partners were occupied, Aron played individually with Minecraft features (see timepoint I38). Aron opened a pseudo programming environment in Minecraft that allowed him to enter programming codes to make things happen in their world. "I am God", he said laughingly, and used the coding features to make it rain (see timepoint I38). Bruce and Eric, curious, looked to see what Aron was doing and emulated his actions for the purpose of summoning monsters into their world to destroy the other's avatar (see timepoints I40 – I44). However, when Eric attempted to use the programming features, he encountered a problem, he exited his group's world and unknowingly entered Group 3's (G3's) world (see timepoint I46).

Eric summoned multiple fire-breathing dragons, called Enderdragons, to try to destroy Bruce's avatar (see timepoint G51), not realizing he was in another world. These dragons destroyed Group 3's world and Group 3 became frustrated, not understanding what was going on. Then Luke (L) from Group 3 heard excited talk from Group 2, walked over to Eric and saw that he was responsible for the destruction (see timepoint I54). Luke ran back to his group and told his groupmate, Issac (I). Issac stood up and screamed at Eric, "STOP ERIC" (see timepoint I56). This is what F2 heard at timepoint C56, which prompted her to ask the community what was going on. Group 3 angrily complained about Eric, loud enough for the entire community to hear.

As the diagram in Fig. 2 shows, the problem had escalated beyond the individual level, where Eric was engaging in off-task behavior and not paying attention to what was going on in the group. Eric's lack of regulation affected Group 3 and the entire community by disrupting the day's activities. Nonetheless, F2's first attempt to resolve the problem was to address the individual level by speaking to Eric (see Fig. 3 for ecological diagram of facilitator and student responses).

F2 had diagnosed the problem as a self-regulation issue, thinking that Eric's impulsive behavior could have been prevented had he taken time to check to make sure he was in the right world. However, when she attempted to teach him this strategy by saying, "What do you think is a good idea for you to do if you are entering someone's world?" (see timepoint I57),

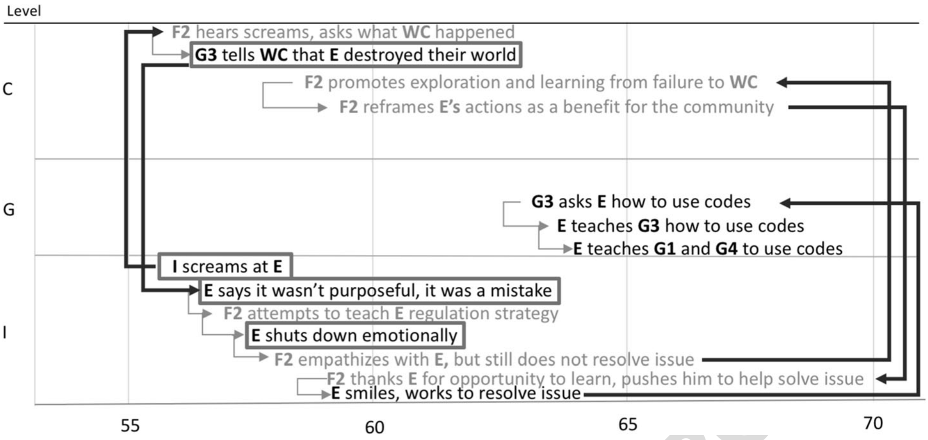

Fig. 3 Diagram of the how F2 responded to the problems caused by Eric's Off-task behavior at three different levels of cognitive activity, following similar symbols as Figs. 1 and 2

Eric shut down emotionally and walked away from his team, saying softly, "I didn't mean to do it" (see timepoint I57.5). When F2 saw how emotionally upset Eric was, F2 walked over to Eric and changed tactics. This time she used an individual socioemotional strategy, she empathized with Eric. F2 said softly, kindly, "I know, I know; I understand because when you're exploring sometimes things happen". This did not resolve the issue, Eric repeated sadly, "I didn't know it was going to happen" (see timepoint I58).

At this point, F2 realized that this was not an individual issue, it was a community issue because the community was not creating a space where people could feel safe to explore and make mistakes. So, she got the entire community's attention and said:

11. F2: What's the coolest thing about Minecraft? What does it allow you to do?
12. Luke: It allows you to umm, do a lot more things more freely.
13. F2: Yeah, and you can explore a lot of stuff, but what happens when you are exploring stuff? ...
14. Issac: Sometimes things fail.
15. F2: Sometimes things fail and sometimes things go wrong. Okay. So, Eric was exploring, he got really excited and something went wrong. That's okay. He didn't do anything wrong, but then we just have to figure out how to fix it. That's it (smiles).

Then she turned to Eric, smiled and said to him loudly, "so think about it this way, Eric, you gave them an opportunity to figure something out. That was a good thing… alright? And you can help us to figure out how to do better next time". Eric says, "Alright". F2 looks at Eric, smiles, and says, "Thanks for helping us figure things out" (see timepoint I59). Eric smiles at F2 and then rejoins his group and tries to figure out what went wrong.

After this episode, the students from Group 3 were no longer upset. They rebuilt their creations and asked Eric how he summoned the Enderdragon. Eric showed Group 3 how to pull up the coding features in Minecraft and enter codes to summon different things. Other individuals began experimenting with the programming features and summoning Enderdragons. Isaac from Group 3, at one point stated loudly, "Why are just so many people trying to let loose Enderdragons and just destroy everyone?" Upon hearing this, F1 asked Issac if there was no way to limit the ability for others to spawn or destroy structures with command codes. She encouraged him to Google it and he did, finding a possible solution. The rest of the session went smoothly as students experimented with the pseudo-coding environment and other features in Minecraft.

At the end of the session, the facilitators asked students to finish up and take part in their whole class reflection on the day's activities. The facilitator, F3 asked the kids if they could take time to talk about what they learned as individuals and as a group. As students began to excitedly talk amongst themselves about the day, Eric stood up and, somewhat uncomfortably, admitted to making a mistake and accidently destroying someone's world. F1 said to the community, "And that is really important because Eric felt bad, but it gave us a moment to realize that when we are exploring, sometimes stuff goes wrong and if we are really developing a design community in here, then we have to help each other and (laughing) forgive each other when things go wrong." Bruce responded with, "We don't need to forgive for that. That was totally awesome, Eric," and high-fived Eric. Eric smiled and laughed and the class discussed all the different things they were able to learn from the day's session.

Discussion

Examining these events from a more ecological perspective allows us to see the important role that individuals, groups, authority figures, technology, and the problems that result from their interactions play in shaping a collaborative ecology. We were able to see how a technology issue could derail an entire class session yet still provide opportunities for learning. We saw how a facilitator's seemingly innocuous instructions for the community to entertain themselves while she resolved an issue disrupted collaborative activity because it encouraged disengagement from the community through individual gameplay. We saw how important the facilitators' interpretations of student behaviors were to resolving problems and promoting a more collaborative environment. We saw that groups were able to devise solutions that no one in the community knew previously when provided with opportunities to solve authentic problems. We were also able to see how problems could escalate when not addressed and trickle down to produce more problems at multiple levels as occurred with the Enderdragon episode. Finally, we saw how it was necessary for the facilitator (F2) to move between different cognitive systems in order to resolve a problem that impacted all three cognitive levels.

Now, some readers may ask, "but what was learned?": what important design skills or concepts did learners develop and how can we measure this learning? If we were simply examining the event from the perspective of the small group, we would have been disappointed by the lack of small group collaboration that occurred. From this perspective, the biggest learning event was groups 2 and 4 working together to figure out how to create a shared server. Even when examining the dialogue between Eric and the other groups as he taught them to use the pseudo-programming features, the talk was more instructional and cooperative than it was collaborative, because Eric was sharing instructions and little to no synthesizing or negotiation of different individuals' ideas occured. What is more, the off-task behavior that led to the larger learning event might have been discouraged, since it interfered with the possibility of deeper collaboration.

From an individual cognitive and social constructivist perspective, we could test individuals to see how many could create shared servers and use the pseudo-coding features. We could then compare individual learning outcomes to the types of social interactions that took place. We could also measure how much learners enjoyed the daily sessions and try to connect these outcomes to different social processes.

From a socio-cultural perspective we could track Eric's participation in the community and his shift from peripheral to central participant to see how he became more central overtime. We could also examine tensions between desired and existing practices, values, roles, and ways of interpreting problems so as to identify obstacles to design interventions.

The problem is that none of these approaches on their own could help us to see how orchestration moves and learner interactions across cognitive levels can facilitate a collaborative ecology. On their own none of these approaches could show the prominent role that problems had in shaping the ecology and the opportunities for learning they provided, especially for critical socio-emotional learning like managing emotions related to failure.

Managing failure is an important socio-emotional skill that is crucial to the ongoing success of a design community (McGrath 1999; Van der Panne et al. 2003). Innovation does not happen in the absence of failure, but rather often because of or in spite of it (Van der Panne et al. 2003). In engineering and software design, practitioners are taught to test to failure, the goal being to push a design until it fails in order to develop a better understanding of its limitations and iteratively reduce them.

Though accepting failure is such an integral part of product design, it also happens to be one of the most difficult skills and values for individuals and communities to develop (McGrath 1999). Communities that do not manage failure well, by harshly punishing those within its community who make mistakes, risk producing a less creative environment: One where community members learn to fear failure, actively avoid creative risk-taking, and hide errors, failures, and gaps in knowledge from the community. These types of risk-averse behaviors are associated with less organizational learning and less potential for innovation over time (Edmondson 1999).

As this case demonstrates, working collaboratively in groups and as part of a community was a challenge for club members. They were largely unaccustomed to making joint decisions or sharing resources to create collective products. To help students work in groups, facilitators focused on using process problems as opportunities to reflect on aspects of socio-emotional learning; model cognitive regulation strategies such as predicting consequences; model emotional regulation strategies such as reappraisal, reframing, and perspective taking; and discuss how individual actions can cause systemic impacts to a learning community. In doing so, students were learning to think more systemically, become more open to reflecting on their own experiences, and share their feelings with the community: something that poses huge emotional risks. All of this socio-emotional learning allowed other forms of learning to occur, like learning how to use the pseudoprogramming features. These types of learning experiences could then be used to introduce more complex forms of programming. More importantly, individuals learned that they could experiement with more complex activities and fail and that was okay, even if it caused problems for the community. They learned this from experience, because they saw that the community valued the potential learning opportunities that resulted from Eric's failure and therefore could feel safe to try new things, make mistakes, and share their learning, positive and negative, with the community. This learning experience was really important to this community, which is why the story of the "distructive Enderdragon" was retold over the next 2 years by older members to new members, without prompting, when ever the concept of the of learning from failure was discussed by facilitators.

Conclusion

We have argued that the primary theoretical frameworks we currently rely on may be inadvertently limiting the scope of our investigations and the impact of our research. As Greeno et al. (1996) stated, when focusing on the design and assessment of learning environnments and efforts to contribute to fundamental scienctific understanding:

> “In research and development of this kind, questions about theory are not limited to whether or not use of theory is coherent and leads accurate predictions, we also ask, as a central question, whether it works - that is, do the concepts and principles of the theory inform practice in productive ways” (pg. 41).

Though the field of CSCL has had many successes, Wise and Schwarz (2017) have highlighted an important and central problem in the field, that our current use of theories causes tensions and often does not address our very reason for being: transforming classroom practice into more equitable, higher-order, social learning spaces. We should be highly concerned with how we use learning theories to understand complex collaborative systems and prioritize the use of theory for helping to make these processes more accessible to teachers and facilitators. While we are in no way arguing that our analysis and diagrams are simple to create or understand, the development of better more refined micro-ecological diagrams and examples could help teachers and facilitators to reflect on their approaches to classroom management and think about whether the way they respond to problems is helping or hurting the development of a collaborative ecology. For example, after creating these diagrams and sharing it with the graduate student facilitators, they were surprised to realize how beneficial interactional problems that occurred during the session were to the community and began seeing new interactional problems as opportunities for them to practice collaborative orchestration processes. This may seem like common sense to some, but there is a negative stigma attached to interactional problems that pushes teachers/facilitators to try to resolve them as quickly as possible, without thinking about the opportunities they could provide for learning. Novice facilitators and teachers are likely to be too cognitively overloaded with orchestrating these complex environments to pursue such opportunities at first, but ecological analysis as part of professional development could be used as a means to help teachers/facilitators make sense of complex activity, identify problems, and devise strategies for how they could use these problems to promote a more collaborative ecology.

References

Akkerman, S., Vandenbossche, P., Admiraal, W., Gijselaers, W., Segers, M., Simons, R., & Kirschner, P. (2007). Reconsidering group cognition: From conceptual confusion to a boundary area between cognitive and socio-cultural perspectives? *Educational Research Review, 2*(1), 39–63.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*(3), 307–359.

Barron, B., Martin, C. K., Mercier, E., Pea, R., Steinbock, D., Walter, S., et al. (2009). Repertoires of collaborative practice. In *Proceedings of the 9th International Conference on Computer Supported Collaborative Learning - CSCL'09* (pp. 25–27). https://doi.org/10.3115/1599503.1599513.

Borge, M., & White, B. (2016). Toward the development of socio-metacognitive expertise: An approach to developing collaborative competence. *Cognition and Instruction, 34*(4), 323–360.

Borge, M., Ong, Y. S., & Rosé, C. P. (2018). Learning to monitor and regulate collective thinking processes. *International Journal of Computer-Supported Collaborative Learning, 13*(1), 61–92.

Bronfenbrenner, U. (1974). Is early intervention effective? *Early Childhood Education Journal, 2*(2), 14–18.

Bronfenbrenner, U. (1977). Toward an experimental ecology of human development. *American Psychologist, 32*(7), 513–531.

Bronfenbrenner, U. (1986). Ecology of the family as a context for human development: Research perspectives. *Developmental Psychology, 22*(6), 723–742.

Chounta, I. A., & Avouris, N. (2016). Towards the real-time evaluation of collaborative activities: Integration of an automatic rater of collaboration quality in the classroom from the teacher's perspective. *Education and Information Technologies, 21*(4), 815–835.

Clegg, T., Yip, J. C., Ahn, J., Bonsignore, E., Gubbels, M., Lewittes, B., & Rhodes, E. (2013). When face-to-face fails: Opportunities for social media to foster collaborative learning. In *Tenth International Conference on Computer Supported Collaborative Learning* (pp. 272–276).

Damşa, C. I., & Ludvigsen, S. (2016). Learning through interaction and co-construction of knowledge objects in teacher education. *Learning, Culture and Social Interaction, 11*, 1–18.

Dessus, P., Cosnefroy, O., & Luengo, V. (2016). "Keep your eyes on'em all!": A Mobile eye-tracking analysis of teachers' sensitivity to students. In *European Conference on Technology Enhanced Learning* (pp. 72–84). Cham: Springer.

Dillenbourg, P., Järvelä, S., & Fischer, F. (2009). The evolution of research on computer-supported collaborative learning. In N. Balacheff, S. Ludvigsen, T. Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-enhanced learning* (pp. 3–19). Dordrecht: Springer Netherlands.

Dimitriadis, Y. A. (2012). Supporting teachers in orchestrating CSCL classrooms. In *Research on e-learning and ICT in education* (pp. 71–82). New York: Springer.

Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly, 44*, 350–352.

Grant, L. (2009). 'I DON'T CARE DO UR OWN PAGE!'A case study of using wikis for collaborative work in a UK secondary school. *Learning, Media and Technology, 34*(2), 105–117.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15–46). New York: Macmillan.

Guzdial, M., Ludovice, P., Realff, M., Morley, T., & Carroll, K. (2002). When collaboration doesn't work. In *Proceedings of the International Conference of the Learning Sciences* (pp. 125–130).

Herrenkohl, L. R., & Mertl, V. (2010). *How students come to be, know, and do: A case for a broad view of learning*. Cambridge University Press. Q5

Hmelo, C. E., Guzdial, M., & Turns, J. (1998). Computer-support for collaborative learning: Learning to support student engagement. *Journal of Interactive Learning Research, 9*(2), 107–129.

Hogan, K. (1999). Thinking aloud together: A test of an intervention to foster students' collaborative scientific reasoning. *Journal of Research in Science Teaching, 36*(10), 1085–1109.

Järvelä, S., Volet, S., & Järvenoja, H. (2010). Research on motivation in collaborative learning: Moving beyond the cognitive–situative divide and combining individual and social processes. *Educational Psychologist, 45*(1), 15–27.

Kerr, N., & Tindale, S. (2004). Group performance and decision making. *Annual Review of Psychology, 55*(1), 623–655.

Kozlowski, S., & Ilgen, D. (2006). Enhancing the effectiveness of work groups and teams. *Psychological Science in the Public Interest, 7*(3), 77–124.

Looi, C. K., & Song, Y. (2013). Orchestration in a networked classroom: Where the teacher's real-time enactment matters. *Computers & Education, 69*, 510–513. Q6

McGrath, R. (1999). Falling forward: Real options reasoning and entrepreneurial failure. *Academy of Management Review, 24*(1), 13–30.

Mercier, E., & Higgins, S. E. (2015). The four Ts of the collaborative classroom. In *CEUR Workshop Proceedings* (Vol. 1411, pp. 15–19).

Nathan, M. J., & Alibali, M. W. (2010). Learning sciences. *Wiley Interdisciplinary Reviews: Cognitive Science, 1*(3), 329–345.

Norman, D. A. (1986). Cognitive engineering. In D. A. Norman & S. W. Draper (Eds.), *User- centered system design* (pp. 31–61). Hillsdale: Lawrence Erlbaum Associates.

Norman, D. (2013). *The design of everyday things: Revised and expanded edition*. Basic books.

Prieto, L. P., Sharma, K., Wen, Y., & Dillenbourg, P. (2015). The burden of facilitating collaboration: Towards estimation of teacher orchestration load using eye-tracking measures. In *Proceedings of the 11th International Conference on Computer-Supported Collaborative Learning (CSCL 2015)* (pp. 212–219). Sweden: Gothenburg.

Rodríguez-Triana, M. J., Prieto, L. P., Vozniuk, A., Boroujeni, M. S., Schwendimann, B. A., Holzer, A., & Gillet, D. (2017). Monitoring, awareness and reflection in blended technology enhanced learning: A systematic review. *International Journal of Technology Enhanced Learning, 9*(2–3), 126–150.

Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. E. O'Malley (Ed.), *Computer-supported collaborative learning* (pp. 69–97). New York: Springer.

Roschelle, J., Dimitriadis, Y., & Hoppe, U. (2013). Computers & education classroom orchestration : Synthesis. *Computers & Education, 69*, 523–526.

Schwarz, B. B., Prusak, N., Swidan, O., Livny, A., Gal, K., & Segal, A. (2018). Orchestrating the emergence of conceptual learning: A case study in a geometry class. *International Journal of Computer-Supported Collaborative Learning, 13*(2), 189–211.

Sharma, K., Jermann, P., Dillenbourg, P., Prieto, L. P., D'Angelo, S., Gergle, D., ... & Rummel, N. (2017). CSCL and eye-tracking: Experiences, opportunities and challenges. In B. K. Smith, M. Borge, E. Mercier, & K. Y. Lim (Vol. Eds.), *Making a difference: Prioritizing equity and access in CSCL: 12th International Conference on Computer-Supported Collaborative Learning: Vol. I*, (pp. 727–728). ISLS

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge: MIT Press.

Stahl, G. (2013). Theories of collaborative cognition: Foundations for CSCL and CSCW together. In *Computer-supported collaborative learning at the workplace* (pp. 43–63). Boston, MA: Springer.

Tudge, J. R., Payir, A., Merçon-Vargas, E., Cao, H., Liang, Y., Li, J., & O'Brien, L. (2016). Still misused after all these years? A reevaluation of the uses of Bronfenbrenner's bioecological theory of human development. *Journal of Family Theory & Review, 8*(4), 427–445.

Van der Panne, G., van Beers, C., & Kleinknect, A. (2003). Success and failure of innovation: A literature review. *International Journal of Innovation Management, 7*(3), 1–29.

Wise, A. F., & Schwarz, B. B. (2017). Visions of CSCL: Eight provocations for the future of the field. *International Jounral of Computer Supported Collaborative Learning, 12*(4), 423–467.

Zurita, G., & Nussbaum, M. (2004). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education, 42*(3), 289–314.

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