# Towards a Cognitive Ecological Framework in CSCL

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**Abstract:** The field of computer-supported collaborative learning uses a range of theories, grounded in different epistemic frameworks, to conduct research and design learning opportunities. While some studies use multiple theories, and attempt to bridge the frameworks, most use a single theory, considering learning from just one perspective. We argue that this can lead to a reduction in what we can understand about learning from each study, and has implications for the quality of designs and limits the possibility of uptake of CSCL tools beyond the specific research context. Drawing on other fields, we identify the potential and need for an ecological framework to inform research and design work, and argue for its importance in the development of the CSCL field (1).

## Introduction

> "Another success of the past two decades of theory-based research can be seen in the evolution of theories and models themselves—a move away from a major focus only on individual behavior change and toward broader multi-level behavior and social change models. By the late 1980s, the limited reach and staying power of even our most effective individual health behavior interventions, based on theories emphasizing intrapersonal and interpersonal determinants of health behaviors, made it clear that an exclusive reliance on individually oriented interventions would be inadequate to achieve our pressing population health and health care goals. These failures led to a fundamental "paradigm shift" in our understanding of what the targets of effective interventions needed to be, not just individuals but the broader contexts in which they live and work. This shift fueled the rise of ecological models of health promotion that have guided the development of powerful interventions in public health and health care arenas." - Orleans, 2008

Many fields have made paradigmatic shifts in how they design and evaluate interventions, which have resulted in changes in the theoretical frameworks they use to guide and interpret research. In fields that emphasize the design of tools and interventions, theoretical frameworks have evolved from linear to more systemic conceptual models to guide their understanding of complex social phenomenon (Carroll, 2009; Engeström, 2000; Sallis, Owen, & Fischer, 2015). This shift is particularly necessary for unpacking problems that include social factors. Unpacking problems associated with decreasing bee populations is one example. Bees are social animals, so to understand why their populations are dwindling, it is necessary to identify possible environmental causes of bee death, the ways that individual bees deal with such environmental stressors, and how these changes affect the social dynamics and long-term outcomes of a colony (Perry, Søvik, Myerscough, & Barron, 2015). In other words, it is an ecological problem that has to be examined within an ecological framework.

In Computer Supported Collaborative Learning (CSCL), we aim to understand learning as it occurs in a socio-technical context. There are different theoretical frameworks that guide our research. Influenced by different historical perspectives on cognition and learning, each framework focuses on a small aspect of the learning system and have different views on where cognition occurs and how learning happens (Greeno, Collins, & Resnick, 1996). Differences between these perspectives have fueled debates between researchers on where cognition occurs and what counts as learning. However, there is ample evidence to support the claim that cognition is a multilevel, systemic phenomenon. As such, selecting only one framework to guide research limits our ability to understand learning on a broader scale and introduces bias into our research, as we commit sampling errors and ignore other possible explanations for research outcomes. Given the complex nature of computer-supported collaborative learning, we argue that it is necessary for CSCL to begin moving towards a cognitive ecological framework in order to better inform how we examine learning, trade-offs associated with different technologies and interventions, and our evolving understanding of how learning happens in social contexts.

## Different theoretical frameworks to examine learning processes

The Learning Sciences, and CSCL as a part of the Learning Sciences, emerged from multiple disciplines and epistemic traditions, integrating a range of theoretical frameworks from which to study learning (see Table 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 |
|---|---|---|---|
| **Information Processing** | Learning occurs as a function of psychological and biological mechanisms within the brain. | Individual processes occurring within the brain. | Individual measurement of acquired knowledge and skills: multiple choice tests, essay, and short answer; standardized tests. |
| **Constructivism** | Learning occurs 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: assessments of conceptual change, performance tests in authentic contexts. |
| **Social Constructivism/ Sociocultural** | Learning occurs as function of the gradual internalization and appropriation of cultural 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. |
| **Group Cognition** | Learning occurs at the level of the group as individuals externalize individual thought through language and create new shared understanding; group cognition | Group processes occurring through language or through the creation of shared knowledge artifacts. | Collective changes in discourse patterns, social practices, or artifact use. |

These frameworks range from those that take the individual learner as the unit of analysis to those that focus on the group. The richness that these different perspectives bring allow us to develop a nuanced and complex understanding of learning at multiple levels of analysis. However, concerns have been raised about the constraints of these theoretical stances, and how research and development of innovative learning environments may be stalled or stymied by these constraints (Akkerman et al., 2007; Jarvela, et al., 2010). The epistemological foundations of different theories are at odds, and therefore, for researchers who are attentive to such features, place roadblocks when trying to address learning at multiple levels in a single design research project or study.

Webb (2013) describes an information processing approach to understanding the outcomes of collaborative learning. This approach focuses on individual learning, suggesting that students learn through actively processing information while engaging in collaborative activities. From this perspective, individual cognition is what leads to the formulation and presentation of ideas; individual cognition is necessary for explaining, actively listening, and responding to a collaborator and can be positively impacted by collaborative learning. This approach, which focuses on knowledge in the individual's mind, closely relates to constructivist theories of learning (e.g. Piaget, 1965). These theories pose that learning happens as a result of experiencing disequilibrium, the constructivist, cognitive processes of assimilation and accommodation, which may be caused by peer interaction. Studies that take this approach tend to focus on the individual learner, comparing pre- and post-test scores given to each participant (e.g. Meier, Spada, & Rummel, 2007; Webb, Nemer, & Zuniga, 2002).

A socio-constructivist theory of collaborative learning, places increased emphasis on the role of interaction with more-expert peers and the societal use of tools and language to pass down knowledge through generations (Golbeck & El-Moslimany, 2013). While Vygotsky maintained a focus on the individual learner, the emphasis differs from Piaget in that Vygotsky takes into account the need for a learner to "master the items of cultural experience" and "the habits and forms of cultural behavior" (Vygotsky, 1929, p 415). Interpretations of Vygotsky's theory range from those that emphasize the role of the expert in learning and the zone of proximal development (e.g. Wood, Bruner, & Ross, 1976) and others that emphasize that learning is an act of increasing participation in the cultural norms and tool use of a community (e.g. Hakkarainen, et al., 2013). Studies that remain close to a Vygotskian perspective often examine how learners at different stages of development or experience perform during interactions (e.g. Azmitia, 1988; Schmitz & Winskel, 2008). Studies that take a broader socio-cultural approach also examine how students co-construct knowledge, regardless of their prior experience or development level, and consider the use of tools in knowledge building. These studies may use individual learner outcome measures, but often make attempts to consider the non-independence of the data; these studies look at the quality of interaction, often attempting to tie it to learner outcomes (e.g. Barron, 2003; Mercier, 2017).

Group cognition theory alters the focus from the individual learner to the group interaction. Described by Stahl (2013) as a post-cognitive approach, where the nature of interaction among group members produces knowledge that cannot be attributed to any individual contribution nor understood as a sequence of contributions from the individuals in the group. In this way, group cognition shares similarities with psychological theories of macrocognition, which is defined as "the process of transforming internalized knowledge into externalized team knowledge through individual and team knowledge-building processes (Fiore, et al., 2010). These theories of group cognition are rooted in theoretical perspectives that perceive cognition as contextually situated and distributed among individuals, tools, and artifacts that are part of the sense-making processes (Fiore & Schooler, 2004; Stahl, 2006). Thus, from this perspective, collaborative learning can be seen as an emergent property of the group, not as something that can be attributed to an individual. Assessment of learning from a group cognition perspective is often ethnographic in nature, focusing on analyzing the processes of learning that occurred during the interaction, rather than relying on post-test learning measures of individuals (e.g. Mercier, et al., 2013).

## How different frameworks create tensions in the field

These different frameworks work well as a means to deeply understand learning at specific levels of interest. Information processing and constructivist theories have greatly added to our understanding of individual sense-making and knowledge building. Socio-cultural and socio-constructivist theories have helped us to recognize the importance of dialogic forms of learning, how cultural values and expectations impact sense-making activity and learning outcomes, and the importance of situated practice. Group cognition has helped us to develop a better understanding of how groups learn as it pushed us to examine verbal interaction as a form of shared thought and show how learning and cognition can occur at the level of the group. Each theoretical perspective has implications for how we measure learning outcomes and design learning contexts for individuals, groups, or communities of learners (Greeno, Collins & Resnick, 1996). However, prioritizing one of these frameworks over another and focusing solely on a singular level of learning activity is problematic.

While using research designs grounded in a single theoretical perspective is relatively unproblematic, difficulties arise when we begin to ask questions such as why collaborations are successful or consider designing CSCL activities that we wish to implement in classroom contexts. Multiple studies (e.g. Barron, 2000; Kapur & Kinzer, 2007; Webb & Mastergeorge, 2003) report that their findings explains some of the variance that emerges between groups, but few studies account for all of the variance. This limitation results in a patchwork of findings that provide some insight into the nature of successful collaboration, but does not give a full picture of what is occurring at the multiple levels of learning and interaction that occur during collaborations.

One particular example is the classic study by Roschelle (1992) in which he explored the central role of knowledge convergence to collaboration. He argued that the co-construction of knowledge is a process through which individuals converge on a shared meaning, making sense together, and as such, co-create knowledge at the group level, while developing an individual understanding of a phenomena. He found that neither the Piagetian concept of the individual's cognitive development, nor the Vygotskian emphasis on the need for a more knowledgeable peer can account for the type of learning that went on between students during the collaboration that he observed, and that a more nuanced understanding of learning and knowledge across levels is necessary to account for this type of collaborative learning. He argues that there is little doubt that each student was engaged in individual sense-making or cognitive processes, but that there was also evidence for joint cognition, and that some of the learning occurs during the interactive processes of the dyad. The group was neither merely providing incentive for accommodation and assimilation at the individual level, as Piaget would suggest, nor was there a more knowledgeable peer supporting the learning, as both students were making sense of the information for the first time. Thus, he argues for a more complex theory of collaboration to account for the observed processes.

Group cognition as a theoretical framework, addresses some of Roschelle's concerns, but does not allow for the central nature of individual sense-making during the co-construction of knowledge that Roschelle reported. Group cognition alleviates the reliance on a more knowledgeable peer, as is central to Vygotskian theory, and provides a framework to account for the knowledge creation that happens between people, when all are novices or when they encounter a new problem. However, there is no place in this theory for individual cognition, and no way to consider what the individual may learn from participating in such an activity.

Salomon & Perkins (1998) argue for the importance of recognizing the synergistic interaction between the individual and social aspects of learning. Reviewing the literature that situates the individual mind and social interaction within different conceptions of where information processing lies, they suggest that it is necessary from a design standpoint to understand how these two processes may interact and, rather than foreground one or the other, account for how they play equal parts in learning as we design instruction. Similarly, Jarvela, Volet, & Jarvenoja, (2010) also note a need to move beyond the situative and cognitive divide when we consider the role of motivation on collaboration. They argue that social and individual processes occur simultaneously and in interaction with each other, and that by limiting our focus to one level of analysis, we cannot fully understand the nature of the phenomena we are studying.

Akkerman and colleagues (2007), argue for a need to bridge the divide between sociocultural and cognitive approaches to collaboration, but note that few studies successfully manage this. The studies that successfully cross the boundaries between both individual cognition and group cognition in their analysis, point towards the need for the field to develop theories that allow for such analyses without the epistemic divide central to these two approaches. However, basic differences in what counts as knowledge, hinder our ability to do this successfully. This suggests the need for a more coherent framework – not just merely the juxtaposition of multiple frameworks in our analysis, but a new framework that allows for a broader conception of knowledge and collaborative learning.

## In support of a multi-level, systemic model of cognition and learning

Regardless of our particular theoretical stances most can agree that there are many different types of knowledge that can be tacitly or explicitly held. There are also many types of learning: cognitive, metacognitive, sociocognitive, and socio-metacognitive learning. For example, let us examine what students could learn when they play an online, collaborative science game. Students could develop their knowledge about the features and functions of the game, they could develop knowledge about the scientific content contained within the game, or they could develop knowledge about different strategies that can be used to overcome obstacles in the game. However, students could also be learning other things as well. Metacognitively, they could be learning how to monitor and regulate their playing processes to achieve desired gaming outcomes. Sociocognitively, they could learn how to problem solve with other students in order to figure out how to overcome difficult aspects of the game. They could also learn that their peers react negatively to teasing during gameplay. From a meta-sociocognitive perspective, they could also learn about desired social and emotional practices and how to monitor and regulate their own and others' social interactions to promote a more positive learning environment.

There are also many variables that can influence all these forms of learning and interfere with knowledge development. These variables include identity formation, beliefs, values, interests, proclivities, skills, and the ongoing outcomes of interactions between our unit of analysis (the individual, the group, or the community) and other environmental factors such as access to food, educational resources, mentors, social acceptance, access to ongoing positive educational experiences, stable homelife, fear of violence, etc.

It is also possible that one form of learning could interfere with another. A computer game may help students develop specific in-game skills and knowledge, but over long periods of use could interfere with social forms of learning as the individual becomes immersed in gameplay thereby reducing social discourse and interactions with others. Sherry Turkle's work points to growing evidence that supports this relationship. For example, Turkle (2016) discusses how social media and cell phones may increase our factual knowledge about where people are, what is going on in the world, and what people like, but diminish our ability to develop the social skills to connect with people who are different than us or engage in meaningful conversations.

Another possibility is that learning at one level of analysis (the individual, the small group, or the community) can help or hinder learning at another level. For example, if an individual develops knowledge that others lack, a small group may ignore that person's contributions and fail to build on this unique knowledge. This is because groups have tendencies to build on shared knowledge over unique knowledge (Stasser & Titus, 2003). Individuals who have not learned how to share authority may also dominate group conversation and interfere with the entire group's learning and performance (Barron, 2003; Borge & Carroll, 2014; Woolley et al., 2010). Groups can also develop knowledge in a situated context, but fail to undersdtand the series of individual contributions and decision-making processes that led to that knowledge development. As a result, individuals would not learn the whole of the knowledge and the community may be unable to reproduce it. Organizational learning, learning at the level of the larger community, is also subject to many problems. Individual and small group level characteristics can prevent learning from occurring across the community. For example, toxic individuals or small groups that make others feel devalued can create an environment that feels psychologically unsafe. Such environments prevent individuals or small groups from or sharing errors, admitting when they do not understand, or contributing viewpoints, thus interfering with organizational learning that occurs across individuals and small groups in the community (Edmondson, 1999).

What these collective studies imply is that learning and behavior is not linear, or even nested. It is ecological, meaning it is a multilevel, multisystemic model. Learning occurs as part of interrelated, social systems (Cole & Engestrom, 1993; Jonassen & Rohrer-Murphey, 1999). Learning occurs in different ways at different levels and can be affected by different factors within levels and interactions between factors across levels. If we accept that learning is an ecological phenomenon, one that is dependent on a relationship between different people, groups, communities, and their physical surrounding, then we can come to understand that an instance of learning within such complex systems cannot be fully understood by examining that instance in isolation from its interconnected parts. Many other fields have come to recognize this problem and have moved to more ecological models to guide their developing understanding. For the field of CSCL to continue moving forwards, it is necessary that we consider moving to an ecological model of learning.

## The effects of ignoring multi-level, systemic models

Many fields have recognized that ignoring the multilevel systemic nature of human activity is problematic for the design of tools to help people improve their activities. The fields of Computer Science and Public Health are two examples. Both of these fields began making sense of human learning and behavior from an individualistic information-processing perspective. They designed tools and interventions that were uninformed by the activity systems that their subjects belonged to, but came to recognize that this approach was largely ineffectual and costly.

When computer science was emerging in the 1970s most computational technologies were developed by computer scientists for computer scientists and enthusiasts. When personal computing became more prominent in the 1980's the need to create technologies for computer novices became necessary. As a means to address this need, many universities and research institutions began examining how everyday people completed tasks, how computers could help to simplify these tasks, and how computers could be built to be fairly usable by these workers. This is how Human-Computer Interaction (HCI) emerged as a field: strongly tied to cognitive science and human factors research and mainly confined to the study of individual computing activity (Grudin, 2008).

HCI changed over time as human activity and technology creation co-evolved. As technologies became more prevalent and intertwined within different aspects of human activity, the ways that people worked, played, and communicated also changed. Overtime, the field of HCI began to recognize the systemic and ecological nature of human behavior, learning, and artifact use. As a result, the theories that HCI used to inform design gradually shifted from theories that explain the individual to theories that explain activity systems and the interplay between learning, behavior, and emotion (Carroll, 2009). This shift has helped HCI to grow and for various fields outside of Computer science to recognize the importance of Human-Centered Design.

Similar methodological progressions can be found in health medicine. In their book on health and human behavior, Glanz, Rimer, and Viswanath (2008) capture the increasing complexity of health intervention research. The history of the field shows striking similarities to the growing complexity and theory application described in HCI. Unlike HCI, the emphasis is not on the development of products, but the creation of interventions to change existing health practices. In the 1980s, most educational health interventions were informed by individual theories of learning and behavior, but no matter how theoretically informed these interventions were, they remained largely ineffective. These failures led the field to conceptualize human behavior and interventions as existing within an ecological system. Glanz et al. (2008) discuss how this shift resulted in the design of educational interventions that targeted and evaluated change at multiple levels of analysis: the individual level, interpersonal level, and the community and organizational level. This approach, they say, helped the field to better identify where problems occurred and how interventions could be improved, which resulted in more effective interventions.

These examples highlight that theoretically informed interventions are not enough in and of themselves to produce effective tools. Ignoring the systems to which human activities belong can lead to the development of costly and ineffective interventions. These examples also illustrate how our theoretical leanings can prevent us from paying attention to important and potentially confounding factors, leading to a biased understanding of the phenomenon under study and the needs of those we are designing for. For example, for many years, HCI believed that all users needed was basic usability, systems that simplified tasks, so most of their studies paid attention to designing intuitive systems and largely ignored how those systems made users feel and interact with others. They also did not carefully consider the impacts of these systems on organizations and society in the long-term.

Our field shares many similarities with HCI and health medicine in that we are designing tools, cognitive and technological, with the goal of improving how students accomplish tasks and learn about complex phenomenon. For this reason, we should consider the potential problems that may result from our own theoretical leanings. One of the biggest practical issues that can result from ignoring multilevel systemic models is lacking professional development and biased measurements of learning outcomes.

A key concern that should be central to our field, is the relative lack of impact we have had on classrooms and schools. The work on Design Based Implementation Research (DBIR) seeks to address some of the issues that emerge from traditional research paradigms that have been central to our field. While there is great challenge in creating a CSCL activity to engage learners in lab settings, and great value in understanding the nuances of the different features that we can design, approaching design from an implementation standpoint requires a different stance. The learning opportunities we have created and tested in controlled settings, are rarely suitable for use in more typical learning contexts (Penuel, Fishman, Cheng, & Sabelli, 2011). Taking into account the multiple levels of the learning ecology within which they could be used during design is necessary if the tools and activities are to be useful in contexts outside the immediate research venue.

When conducting CSCL research in classrooms, it is hard to ignore the ecological nature of learning. Students are individuals, who make sense of information in individual activities and when interacting with others, and their learning can be assessed in individual post-tests after a collaboration. However, knowledge building does happen within groups, and groups of students talk to other students within the classroom during collaborative activities. The teacher intervenes in groups, working with individual students, groups of students, or deciding to discuss an issue with the whole class (e.g. Mercier, 2016; Webb, 2009). Teachers also use consolidation activities during or at the end of tasks, asking group members to share their progress or final answers, which can serve as both an assessment exercise and a learning opportunity for other students (Joyce-Gibbons, 2017; Kaendler, et al., 2015). Finally, students learn through participation with the wider community, bringing their prior knowledge and experiences to the classroom (Moll et al., 2009), and with and through the tools and technologies of the culture within which they are situated (Barron, Walter, Martin, & Schatz, 2010). If we focus our design activities on one of these levels, and only look for learning at that level, we are likely to provide important insight into the nature of collaborative learning at that level on analysis, but be unable to determine how these changes impact the larger system. Without this understanding, we may be unable to generalize positive effects or prevent the development of unintended negative consequences. In no way do we argue that the field should abandon the careful analysis of collaborative learning, but, alone, it is not sufficient for the field to have a significant impact on practice.

## Moving forward: Adopting a cognitive ecological framework in CSCL

The idea that learning is a multi-level systemic phenomenon is not new. Many scholars before us have made this claim (Barron et al., 2009; Cole & Engestrom, 1993; Jonassen & Rohrer-Murphy, 1999). Prior to the information age, Greeno, Collins, and Resnick (1996) discussed the relationship between underlying theories of cognition and learning and called for the need to rethink how we use them to inform educational research. They argued that questions about theoretical frameworks should not be limited to whether or not use of theory is coherent and leads to predictions; we need to start asking whether how we are using these theories is working. Current trends with educational design and technology use necessitate that we take up this call and start asking whether our existing theoretical frameworks are sufficient to inform practice, design, and the identification of tradeoffs associated with different instructional practices.

Our understanding of the different frameworks and the growing complexity of computer supported collaborative contexts suggests it is necessary for CSCL to begin moving towards an ecological framework of cognition. Doing so would help to relieve tensions in our field and better inform how we examine and design for collaborative learning. We could more fully investigate the trade-offs associated with different technologies and interventions and enhance our evolving understanding of how learning happens in social contexts. For example, studies that measure the impacts of technology on individual learning outcomes could also examine the impacts of the technology on social discourse. Studies that examine group learning could also examine impacts on individual learning processes and changes in the community. No one researcher would have to investigate the entire system, but they could partner with those that specialize in a complementary form of cognition, learning, or social interaction or identity development.

Adopting an ecological framework does not mean that we need to abandon previous theories of learning, but rather that we synthesize and extend them. It means we must bridge our epistemic silos, and treat knowledge and cognition as occurring at multiple levels simultaneously. If we begin to account for the notion that knowledge and cognition exist at multiple levels and are affected by multiple interconnected factors, we can move towards a deeper understanding of learning.

The implications of taking an ecological approach are not trivial. We may have to revisit how we design and report research studies. When designing studies, we need to ask questions that explore learning at multiple levels of scale and distribute strands of analysis among experts with different theoretical underpinnings in order to examine the impacts of technological interventions on a wider aspect of the ecological system. It would require us to modify how we report studies so that we acknowledge the limitations and possible unintended consequences when not accounting for learning and interaction multiple levels of scale. It would also require that we describe and consider the learning context in detail, considering the implications of the particular context and how that influences the generalizability of claims. The evolution of our theoretical frameworks may facilitate the development of deeper understanding of learning, the creation of more generalizable interventions, and growing impact on policy and practice.

## Endnotes

(1) We note the relevance of this argument to the wider field of the Learning Sciences; due to our focus on design-based implementation research, social processes, and the limitations of the format, we have limited our paper to focus on CSCL.

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