The group as paradigmatic unit of analysis: The contested relationship of Computer-Supported Collaborative Learning to the Learning Sciences

Gerry Stahl

This chapter looks at the relationship of two historically and institutionally related research communities: Computer-Supported Collaborative Learning (CSCL) and the Learning Sciences (LS). It presents them from the perspective of the author as a participant in those communities during the past twenty years. It reviews the institutional history of their relationship within the International Society of the Learning Sciences (ISLS). The question is then posed: Do CSCL or LS represent a new paradigm of educational research? Trends in the history of philosophy and social theory are reviewed to motivate a contemporary paradigm. A post-cognitive educational paradigm is proposed that focuses on group interaction as the unit of analysis. Finally, the author's CSCL research agenda is described as an illustration of a candidate approach. In conclusion, it is proposed that CSCL research should focus on the analysis of group processes and practices, and that the analysis at this level should be considered foundational for LS.

A participant's view of LS and CSCL

LS and CSCL are not easy to distinguish clearly. There are no objective or fixed definitions of these two fields. They are best understood as communities of researchers. Despite their fluidity, they do seem to evolve over time. The shifting nature of the communities appears differently to different participants and is often negotiated in discussions among them. In this chapter, I discuss the relationship between the CSCL and LS communities from the perspective of my own participation in them.

CSCL is post-disciplinary, requiring a mix of academic backgrounds. I came to CSCL from philosophy and computer science. In the 1960s and early 1970s, I studied twentieth-century continental philosophy and social theory at MIT, Northwestern, Heidelberg and Frankfurt, but supported myself as a math teacher and computer programmer. In the early 1990s, I studied computer science academically, specializing in artificial intelligence (AI), design theory, human-computer interaction (HCI) and computer-supported cooperative work (CSCW) at the University of Colorado in Boulder. On graduation in 1993, I decided to apply computer science to educational innovation. When Timothy Koschmann spent a year at Boulder during 1997/98 while I was starting my career as a research professor, I participated in his course on CSCL and he introduced me to local conversation analysts, whose courses I also attended. Koschmann was instrumental in organizing the first seven CSCL conferences and editing the seminal CSCL book (Koschmann 1996). I participated in all the CSCL conferences, starting in 1995, and also the International Conferences of the Learning Sciences (ICLS) from 1998 on. During 2001/2002, I lived in Germany for a year and worked on a European Union CSCL research project. That year, I met many of the Europeans active in the CSCL community and visited their labs, workshops and conferences.

Koschmann convinced me to be program chair of CSCL 2002 in Boulder. At the closing session of CSCL 2002, those present agreed to found a new organization, the International Society of the Learning Sciences (ISLS), to provide an institutional framework to bring together the CSCL and ICLS conference series and also the *Journal of the Learning Sciences* (*JLS*). It was decided that Timothy Koschmann, Janet Kolodner and Christopher Hoadley would share leadership of the society. I agreed to be on the founding board, to draft the by-laws, to set up the website and to design a logo.

The contested relationship of CSCL to LS soon flared up at CSCL 2003 in Bergen, when the legal incorporation of ISLS was announced there. The central participants in the CSCL community were largely European members of the AI-in-Education community. They felt that Roger Shank had betrayed the AI-in-Education community when he hosted their conference at Northwestern in 1991 and used that occasion to proclaim himself the leader of a new field, which he called "the learning sciences." Kolodner was seen as his protégée, who had extended his technical contribution in AI models of case-based reasoning and was the founding editor of *JLS*, the journal of LS. At the time, virtually all articles in *JLS* had been by North American authors and represented a strongly cognitivist approach. ICLS, the conference series for LS, was held exclusively in the United States until 2008, and had been dominated by a few American schools, primarily departments of education at elite US universities (e.g., Northwestern, Georgia Tech, Michigan, Washington, UCLA, Indiana, Berkeley, Stanford, Vanderbilt, Pittsburgh).

So at the Bergen conference, a group of European CSCL researchers raised harsh questions about whether ISLS was an attempt by American LS leaders to take over the field of CSCL and its conference series, which was finally being held in Europe in 2003—after Euro-CSCL 2001 in Maastricht was retroactively recognized as an official CSCL conference. Kolodner, Koschmann and Hoadley were unable to satisfy the concerns raised. There was lively discussion among the conference attendees, and a smaller group of us drafted a position paper overnight. The outcome was to proceed with the establishment of ISLS, but to set up a CSCL Committee within ISLS to represent the CSCL community. The CSCL Committee would exercise control over CSCL matters, such as the CSCL conference series. During the same conference, the idea of a CSCL journal was proposed; Hans Spada suggested that I found it with the co-editorship of Friedrich Hesse. Pierre Dillenbourg had already established a CSCL book series published by Springer. These initiatives helped to form links and establish parity between LS and CSCL.

ISLS gradually became established. Hoadley was the first president, and subsequent presidents included several prominent European and American CSCL researchers, including some who had raised the original critical questions at the 2003 Bergen conference. Kolodner served as executive director of ISLS throughout its formative years. The tension between CSCL and LS gradually dissipated; the CSCL Committee lingered on, primarily playing a symbolic role. ISLS, ICLS and *JLS* gradually made concerted efforts to become more international and to broaden their leadership. Although the assumption has generally been that the two communities have largely merged, my sense is that the theoretical differences between them and between the two conference series have not altered much during the intervening decade.

It is hard to define the difference between CSCL and LS other than, perhaps, in terms of the people involved. This is because both communities profess openness to the same range of theoretical and methodological frameworks, although both promote certain preferred orientations in subtle and unspoken ways. For instance, most researchers in both fields claim to accept the situated nature of learning and the sociocultural perspective, but if you look closely at their analyses, you find that they rely on methods and approaches that predate and may contradict these positions. (More on this assertion to come.)

Did CSCL or LS adopt a new paradigm?

In the introduction to his edited volume of CSCL studies, Koschmann (1996) proclaimed that CSCL provided a new paradigm of research on instructional technology. He used Kuhn's principle that a paradigm must be "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity" (Kuhn 1972, p. 10). A few years later, as Koschmann saw that there was no consistency in method among CSCL studies and that the vast majority of CSCL and LS studies had, in fact, not moved away from traditional approaches to measuring individuals' learning outcomes, he reconsidered that claim. He argued that

> Traditional theories of learning treat learning as a concealed and inferred process, something that "takes place inside the learner and only inside the learner" (Simon 2001, p. 210). CSCL research has the advantage of studying learning in settings in which learning is observably and accountably embedded in collaborative activity. Our concern, therefore, is with the unfolding process of meaning making within these settings, not so-called "learning outcomes." It is in this way that CSCL research represents a distinctive paradigm within IT. By this standard, a study that attempted to explicate how learners jointly accomplished some form of new learning would be a case of CSCL research, even if they were working in a setting that did not involve technological augmentation. On the other hand, a study that measured the effects of introducing some sort of CSCL application on learning (defined in traditional ways) would not. (Koschmann 2001, p. 19)

In his keynote talk at CSCL 2002, Koschmann proposed that "CSCL is a field of study centrally concerned with meaning and the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts" (Koschmann 2002, p.17). He then reviewed what he took to be a seminal CSCL paper by Jeremy Roschelle (1992) as an early instance of the CSCL paradigm, because Roschelle focused on the analysis of meaning-making practices (such as conversational moves) in a context of joint activity (dyads working on challenges) mediated by a designed activity (a software simulation).

Koschmann focused on the version that Roschelle published in *JLS*—which Koschmann himself later republished in his CSCL edited volume (Roschelle 1996). However, in terms of the relationship of CSCL and LS, the situation was rather more complicated as well as more interesting than what Koschmann reported. First, Teasley and Roschelle (1993) presented an analysis involving the co-construction of a "joint problem space" (JPS) by students, using Roschelle's dissertation data. The JPS was an explicit transformation of the cognitivist conception of a mental problem space in (Newell & Simon 1972) into the intersubjective realm of situated interaction. Newell and Simon's notion of cognitive production rules (mental mechanisms) was re-conceptualized as socially distributed, turn-taking, collaborative completions (discourse moves).

Stephanie Teasley was instrumental in bringing a post-cognitive framework to this analysis in her collaboration with Roschelle, while they were both interns at the Institute for Research on Learning (IRL) in Palo Alto. IRL was a hotbed of post-cognitive innovation, inspired by theories of conversation analysis, ethnomethodology, activity theory, situated action and situated learning. Teasley (then named Behrend) and Roschelle first presented their analysis with co-author Janice Singer at the CSCW 88 and ITS 88 conferences (Behrend, Singer & Roschelle 1988; Singer, Behrend & Roschelle 1988). These papers grew into the version later published as (Teasley & Roschelle 1993), presented at a NATO-sponsored workshop in Italy in 1989 (the first event ever to use the term "CSCL").

It was these early versions that really emphasized the intersubjective practices of meaning making in the context of joint activity. The authors explicitly juxtaposed their perspective to cognitivism: “Thus, in contrast to traditional cognitive psychology, we argue that collaborative problem solving takes place in a negotiated and shared conceptual space, constructed through the external mediational framework of shared language, situation and activity—not merely inside the cognitive contents of each individual's head” (Roschelle & Teasley 1995, p. 70).

In the *JLS* article reporting on this research, Roschelle argues that the ability of the dyad to “share” knowledge in a cognitive sense (as convergent mental contents) could be demonstrated by an analysis of the collaborative sense in which the students “share” a joint meaningful world (are engaged with co-constructed meanings and artifacts). Tying the analysis of intersubjective meaning making to the problematic of cognitive convergence had the potential of appealing to the *JLS* audience, because it put the argument in cognitive terms they could relate to without disrupting their paradigm. However, this made the argument more complex and probably detracted from its ability to stand as a clear example of a post-cognitive paradigm.

Koschmann concluded that CSCL could be a new paradigm if studies would maintain a focus on how groups of learners collaboratively achieve new understandings in the presence of computational artifacts. However, in most CSCL studies (as in LS studies) there is a conflict between the espoused and the applied theory of learning or between the motivating theoretical concerns and the bottom-line methods of analysis. After Roschelle and Teasley’s publications, most actual instances of research by the CSCL (or LS) community fell back on old traditions in educational psychology or other forms of measuring and correlating learning outcomes of individuals—sometimes despite the researchers’ best intentions and the needs of their research questions.

Measuring the effectiveness of dialog or collaboration is never a straightforward affair. It is highly dependent on the details of the setting and the group practices. Methodological concerns related to this were expressed early in the history of CSCL, for instance by Dillenbourg, Baker, Blaye and O'Malley (1996, p. 189):

> For many years, theories of collaborative learning tended to focus on how *individuals* function in a group. More recently, the focus has shifted so that *the group itself has become the unit of analysis*. In terms of empirical research, the initial goal was to establish whether and under what circumstances collaborative learning was more effective than learning alone. Researchers controlled several independent variables (size of the group, composition of the group, nature of the task, communication media, and so on). However, these variables interacted with one another in a way that made it almost impossible to establish causal links between the conditions and the effects of collaboration. Hence, empirical studies have more recently started to focus less on establishing parameters for effective collaboration and more on trying to understand the role that such variables play in mediating interaction. In this chapter, we argue that *this shift to a more process-oriented account requires new tools for analyzing and modeling interactions*. (Italics added)

In the first volume of the *International Journal of CSCL* (*ijCSCL*), Suthers (2006, p. 321) proposed a research agenda for CSCL: “To study the accomplishment (a post hoc judgment) of intersubjective learning we must necessarily study the practices (the activity itself) of intersubjective meaning making: how people in groups make sense of situations and of each other.” He agreed on the need for CSCL research to focus on analysis of group processes. He immediately noted, however, that few studies published in the CSCL literature have addressed intersubjective meaning making directly.

There are many pressures against research adopting a new paradigm and embracing new tools for analyzing interactions. For one, the study of interaction processes and group practices requires analytic skills that are not generally taught in standard college courses on research methods and statistics. There are also external influences. The public wants stories that meet common-sense images of science based on popular notions of traditional science, primarily Newtonian physics. Politicians and funding sources want simple numeric results that they can cite as clear measures of return on government or grant investments in education. Academic hiring and promotion committees want publications in well-established conferences and journals to justify their decisions. Conferences and journals rely on peer review by scholars trained in traditional notions of rigor. Systems of social rewards—which largely define behaviors in academic research communities—militate against methodological innovation, even as they reward superficial adherence to the latest trends.

It is hard to determine how many publications in CSCL or LS break free of the cognitivist paradigm's stronghold on publication. For instance, studies of CSCL publications bring their own paradigmatic blinders or filters (e.g., Akkerman et al. 2007; Jeong & Hmelo-Silver 2010; Jeong, Hmelo-Silver & Yu 2014; Kienle & Wessner 2006; Lonchamp 2012; Tang, Tsai & Lin 2014). They sometimes eliminate from consideration any paper that does not focus on "empirical" data analysis, often excluding ethnographic case studies and certainly theoretical articles. They generally miss many of the most influential papers or more innovative approaches. Many highly rated journals in the educational field advertise that they only publish papers that conform to traditional empiricist methodological standards. The stances of these journals in turn influence the attitudes of reviewers for other journals and conferences. Attempts to categorize publications in CSCL and LS often succumb to a similar fate, imposing implicit or explicit criteria on the selection of papers to be categorized.

We have seen that it is hard to determine the extent to which a post-cognitive paradigm is making headroads in CSCL and/or LS research. What would a CSCL paradigm look like that systematically thematized the mutual engagement of small groups in meaning making and problem solving, as suggested by Koschmann; Roschelle and Teasley; Suthers; Dillenbourg, Baker, Blaye and O'Malley? The following sections explore the implications of the post-cognitive theories that are so often espoused within the CSCL and LS communities, but relatively rarely carried through in the published analyses. They trace these recent theories back to their roots in the history of philosophy, noting the historic junctures that provide the ontological and epistemological motivations for various alternative methodologies. They conclude by recommending that a CSCL focus on group cognition be taken as foundational for LS.

The post-cognitive philosophical paradigm

The post-cognitive CSCL paradigm studies *meaning making as a joint (or group) activity*. For instance, the analysis by Teasley and Roschelle (1993) in terms of the collaborative activity of constructing a joint problem space was an early instance of this new paradigm. However, the analysis of the same data in terms of cognitive convergence reduced the meaning making to measures of traditional individual mental phenomena—externally influenced by computer images and internally involving corresponding mental representations of those images in the heads of the students. To grasp the significance of this distinction between cognitive and post-cognitive, consider the schematic history in Figure 5-1 of a strand within Western philosophy and social theory that contributed to the theoretical foundation of this paradigm shift.

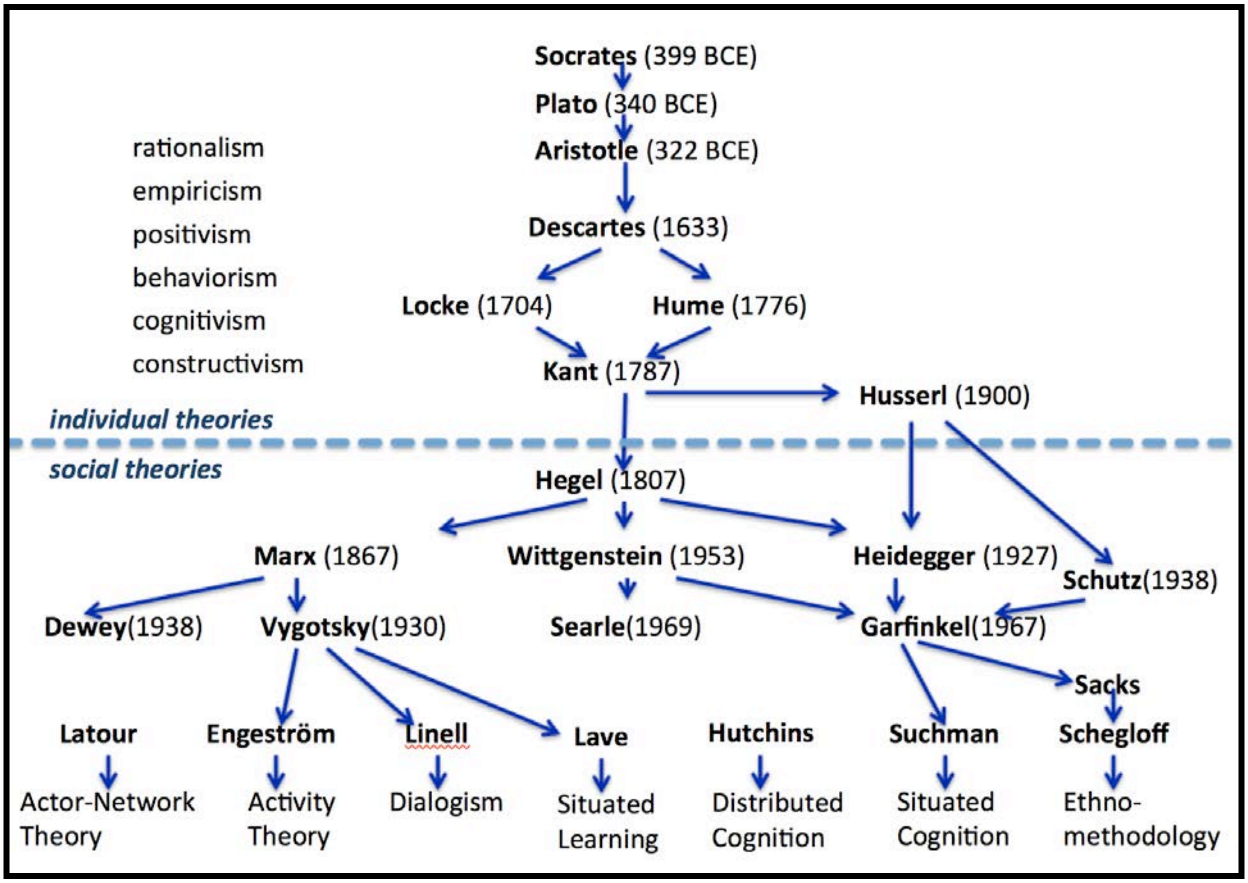

Figure 5-1. The evolution from individualistic to social theories in philosophy and social science. A major paradigm shift in theory occurred two centuries ago, but has still not affected most CSCL and LS analyses.

Philosophy began with the classic Greeks locating knowledge in eternal ideas, rather than in the social norms of the polis or the traditions of mythology. Descartes relocated these ideas in the individual mind, and thereby created the epistemological problem: How can ideas in the mind correspond to valid knowledge of the non-mental world? Locke and Hume gave opposing views in response to Descartes, emphasizing individual human reason or individual human experience. Various mixtures of these philosophies motivated scientific paradigms of rationalism, empiricism, positivism and behaviorism. Kant overcame the conflict between rationalism and empiricism by arguing that the human mind constructs what it can know of the world by structuring sense perception with categories of space, time and causality. Thus, Kant provided the philosophic basis for the paradigms of constructivism and cognitivism: people construct knowledge, so an analysis of human behavior and learning must take into account the role of cognition in making sense of the world.

Note that up to this point, human nature and human cognition were posited as based in the individual person, as fully determined from birth ahistorically or universally—not dependent on one's biography or social context. Remember that the views that minds develop (Freud), that social relations transform (Marx) or that humanity evolves (Darwin) all came after Hegel—inspired by his dynamic philosophy. The outmoded pre-Hegelian, ahistorical view survives in our culture as common sense and as a pervasive ideology of individualism. It also survives in the empiricist and rationalist assumptions about science, which persist in positivist notions of objectivity and reductionism to individual cognition.

Hegel (1807/1967) argues that human consciousness emerges through productive activity in the social and physical world: individuals are formed as such (i.e., as self-conscious individuals) through the interaction with each other and with artifacts (tools and products of work) in the world. Hegel describes the emergence of self-consciousness from within the process of mutual recognition of self and other.

Marx (1867/1976) builds on this analysis of social interaction. He situates Hegel's idealist analysis in the historical context of capitalism. For Marx, individuals in capitalist society are analyzed as results of their interactions as wage laborers, owners of the means of production or consumers of commodities. The "cell form" of social analysis is the interaction between worker and owner that produces artifacts for the market. Marx critiques the traditional notion of the abstract individual as an ideology that obscures concrete human reality as fundamentally social.

In the cognitive paradigm, one assumes that an interaction such as takes place in a CSCL setting can be analyzed in terms of individuals, who can be characterized independently of the interaction context, for instance by characterizing their mental states and internally stored knowledge. The sense making that takes place is attributed to the individuals, who then may compare their understandings. By contrast, in the post-cognitive theories listed across the bottom of Figure 5-1, interaction is primary. For instance, Linell (2009) describes his post-cognitive dialogical approach:

> In the analysis of sense-making as it occurs in communication and interventions into the world, as well as in solo thinking or the reading of texts, etc., we must start out from the encounters, interactions, events etc. as the basic phenomena; they are primary, not secondary or derived. This idea makes dialogism different from mainstream psychology, which is based on the assumption—self-evident for its adherents—that individuals are there first, and then they sometimes interact with other individuals. Interaction for them is "external," that is, of a secondary nature. Dialogists, by contrast, assume that individuals have become what they are in and through interaction.

Toward a post-cognitive educational paradigm

An interrelated set of attempts to propose approaches to education, sociology and psychology embodies new paradigms of research in keeping with the post-cognitive philosophical paradigm. Some of them are included in Figure 5-1. They focus methodologically on group interaction and study dynamic processes rather than just outcomes. Most of them are inspired by Vygotsky or, more generally by Marx, Heidegger and Wittgenstein. They include Bruner (1990), Cole (1996), Engeström (1987), Garfinkel (1967) and their colleagues or followers, each of whom emphasizes different aspects of the paradigm.

Vygotsky adopts Marx's ontology: the primary unit of analysis is the interaction among people mediated by artifacts. Artifacts are both physically present in the world and meaningful to people. Vygotsky's notion of artifact includes both tools and language. Their meaning is not projected from individual minds, but is intersubjectively emergent from social interactions, as in the dialectical analyses of Hegel and Marx. Consider Vygotsky's programmatic attempt to show how the individual mind is grounded in activity within the physical and social world. His description of the genesis of the pointing gesture illustrates a typical early experience of meaning for a small child; it shows how the meaning of this artifact is created in the intersubjective world and only subsequently incorporated (internalized) in the child's own sense-making repertoire:

> We call the internal reconstruction of an external operation *internalization*. A good example of this process may be found in the development of pointing. Initially, this gesture is nothing more than an unsuccessful attempt to grasp something, a movement aimed at a certain object, which designates forthcoming activity…. When the mother comes to the child's aid and realizes this movement indicates something, the situation changes fundamentally. Pointing becomes a gesture for others. The child's unsuccessful attempt engenders a reaction not from the object he

> seeks but from another person. Consequently, *the primary meaning* of that unsuccessful grasping movement *is established by others*…. The grasping movement changes to the act of pointing. As a result of this change, the movement itself is then physically simplified, and what results is the form of pointing that we may call a true gesture. (Vygotsky 1930/1978, p. 56, italics added)

Here we see the *genesis of the meaning* of a pointing gesture. The recognized, practical and formalized gesture becomes an artifact: it embodies meaning in the physical world. The meaning is a reference to that which is pointed at. The baby intended some object; the mother recognized that the baby intended that object; the baby recognized that the mother recognized this. The multiple mutual recognition entails that the baby and the mother recognize each other as people who can have intentions and who can recognize intentions of other people. This is a first glimmer of self-consciousness, in which the baby becomes conscious of his own and other people's intentionality. (Of course, the baby cannot yet express this self-consciousness in any verbal or conceptual sense, but only behaviorally.) The key point for us here is not the birth of intentionality, social recognition or self-consciousness. It is the analysis of an artifact, such as the pointing gesture, a ubiquitous form of reference or deixis. In the origin of this gesture, we already see the basis for intersubjective, *shared understanding* of an artifact's meaning. The subsequent usage of this pointing gesture is premised on the mutual recognition of an underlying intention, which emerged within the mother-child interaction.

The view of shared intention as co-constructed in the world stands in sharp contrast to the rationalist assumption that individuals first have intentions—as though produced through logical calculations of self-interest by a homunculus in their heads—which they subsequently express in speech or action. Marx, Wittgenstein and Heidegger—and their successors—soundly reject this cognitive assumption (see, e.g., Dennett 1991; Dreyfus 1992; Suchman 2007). Heidegger (1927/1996), for instance, replaces Descartes' dichotomy of mental and physical with a philosophy of human being-there-together-in-the-world. Ones comportment in the world precedes ones reflection on objects in the world. People understand the shared world through their involvement with and their care for the world with other people who also inhabit that world, not initially through mental representations and plans. Human involvement is fundamentally processual or temporal: we aim at our projects for the future, based on having been thrown by our social past, into our shared situation in the present.

In their seminal post-cognitive analysis of agency, drawing on contemporary philosophy and social science, Emirbayer and Mische (1998, p. 962) conceptualize agency in Heideggerian temporal terms. Applied to the group unit of analysis as "group agency," their post-cognitive concept could inform CSCL analysis (as in Charles & Shumar 2009; Damsa 2014). It is important to reconsider the notion of agency (and causality)—as Latour (1990; 1992) does by extending it to other people and artifacts in actor networks. The traditional conception of agency contributes to the difficulty of overcoming cognitive habits of thought. A post-cognitive paradigm could include group cognition, collective intentionality and group agency.

The need for a post-cognitive CSCL paradigm

A paradigm shift can be motivated by anomalies in the established theories (Kuhn 1972; Lakatos 1976). Consider anomalies in the paradigm of measuring learning outcomes: from the research of Vygotsky and from CSCL research.

In his well known discussion of the "zone of proximal development," Vygotsky cites a study in which children "could do only under guidance, in collaboration and in groups at the age of three-to-five years what they could do independently when they reached the age of five-to-seven years" (1930/1978, pp. 86f). CSCL can be seen precisely as such an effort to stimulate students within their zones of proximal development under guidance, in collaboration and in groups. If the desired results of this do not show up as learning outcomes measurable in individuals (outside of their group context) for several years, then the key effect will be systematically missed by traditional methods of testing individuals. The failure of the cognitive paradigm of instructional research to account for processes in the zone of proximal development—so central to learning—should be considered an anomaly, suggesting the need for a paradigm shift.

In his less quoted section on "Problems of Method," Vygotsky (1930/1978, pp. 58-75) called for a new paradigm of educational research almost a century ago. Arguing that one cannot simply look at visible post-test results of an experiment, he proposed a method of "double stimulation" where a child is confronted by both an object to work on and an artifact to mediate that work. Vygotsky does not call for a controlled experiment that compares learning outcomes with and without the furnished artifact. "The experiment is equally valid," he points out, "if, instead of giving the children artificial means, the experimenter waits until they spontaneously apply some new auxiliary method or symbol that they then incorporate into their operations." Taking this approach in a collaborative setting requires an attention to the children's interaction and the sense making that is involved in creative, unanticipated collaborative accomplishments. It involves understanding the unique trajectories of different groups, which cannot be statistically aggregated or sorted into standardized categories.

Relatedly, a number of CSCL studies have repeatedly documented "productive failure" (Barron 2003; Kapur & Kinzer 2009; Pathak, Kim, Jacobson & Zhang 2011; Schwartz 1995). This is one of the most intriguing findings of CSCL to date. However, it has so far been analyzed in terms of learning outcomes, rather than group practices within zones of proximal development. When a number of small groups of students work on a challenging problem, the groups sometimes fall into two categories: (1) groups that fail to solve the immediate problem but excel at solving future related problems and (2) groups that succeed at solving the immediate problem but are less successful than the first groups at solving subsequent related problems. The robust and repeatable result of these experiments presents an anomaly for traditional educational theory. One could speculate that in the "failure" groups students are further developing their zone of proximal development or that these groups are co-constructing helpful new meanings, whereas the groups that solve the immediate problems are focused on efficiently applying their existing skills. The analysis of group processes effecting outcomes this way requires a post-cognitive perspective.

A CSCL researcher's agenda

As an example of a CSCL research project conducted in a post-cognitive paradigm, I describe my own work during the past decade. It is post-cognitive in that it analyzes the group processes that constitute collaborative learning in a computer-mediated setting. It neither defines learning in terms of outcomes nor interprets utterances in terms of mental phenomena. Without denying the reality of either individual consciousness or societal practices, it nevertheless focuses on the temporal sequentiality of small-group interaction.

The Virtual Math Teams (VMT) Project has been a collaborative effort with researchers from the Math Forum, Drexel University and Rutgers University at Newark, as well as with visiting scientists and colleagues abroad. The project is extensively documented in four books (Stahl 2006; 2009; 2013c; 2016), nine doctoral dissertations and many other presentations (http://gerrystahl.net/vmt/pubs.html). It is a design-based research project, intended to develop technology and pedagogy for supporting online collaborative learning of mathematics. As a research prototype, the VMT environment has been used in more than a thousand student-hours at the Math Forum (http://mathforum.org), as well as independently by researchers in Turkey, Singapore, Brazil and New Jersey. The current version of VMT's software and curriculum features GeoGebra (http://geogebra.org), a popular dynamic-mathematics application.

In a typical session, three to five middle-school or high-school students collaborate synchronously online for about an hour. Often, the same group will work on a series of challenging problems during five to ten weekly sessions in an after-school or in-class setting organized by a teacher who has completed the Math Forum's teacher-professional-development program associated with VMT. Students interact through text chat and GeoGebra actions (see Figure 5-2). The GeoGebra app has been converted to a multi-user version, so that actions by one student are synchronously shared with others in the group.

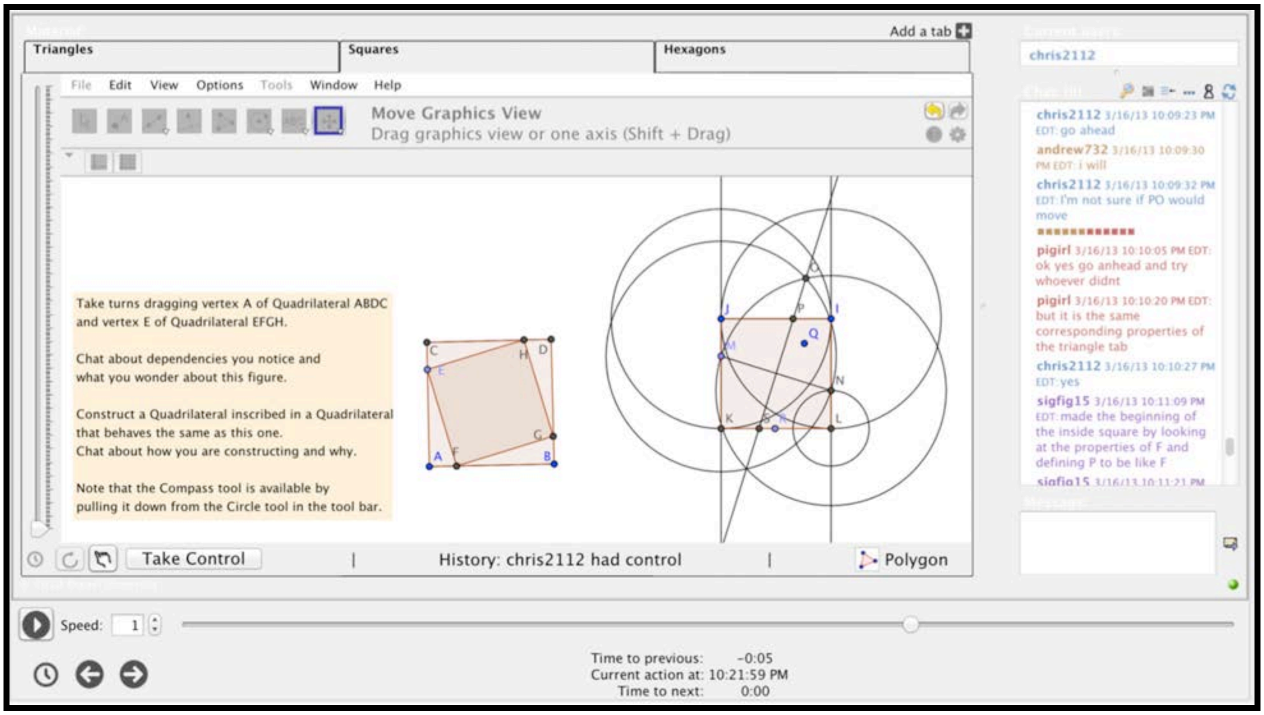

Figure 5-2. The VMT Replayer shows what everyone in the group saw and allows a researcher to step through an entire session with the controls added across the bottom. In this screenshot, the group is in the midst of constructing a solution that the researchers had never seen or thought of themselves.

The VMT environment is instrumented to provide the data necessary for analysis of group process. To track a group's meaning making, one must have a complete record of all group interaction. Otherwise, one does not know if unrecorded events contributed in unknown ways to the shared understanding. This requirement involves two aspects: (1) controlling the interaction so that no group communication takes place outside of the recorded setting and (2) recording the interaction in a complete, detailed and undistorted manner. Technologies of recording data can make possible new paradigms of research. For instance, conversation analysis came into existence only with the tape-recorder for capturing and replaying speech.

Capturing group collaboration in a face-to-face classroom is "messy" and often impractical: There is so much noise that clear speech capture is difficult; transcription is laborious; and non-verbal communication through action and gesture is impossible to capture completely. Traditional analyses generally proceed by coding and counting. Recordings of speech utterances are transcribed as sentences. Then sentences attributed to the individual speaker are categorized according to some standardized schema. The number of sentences falling into each category is compared for different individuals, groups or experimental conditions. In the process of recording, transcription and aggregation, many researcher interpretations are introduced (Suchman & Trigg 1991) and any sense of temporal process is lost. In particular, it is unlikely that any surprising results (such as causes of productive failure or creative group moves) will still be identifiable. Thus, there have been practical barriers to LS making the paradigm shift to studying group interaction. CSCL can overcome these barriers because the computer-mediated collaborative setting makes problem-solving processes observable.

Because students collaborate online in the VMT environment (http://vmt.mathforum.org), all communication and action is mediated by the VMT technology. It is therefore possible to capture a complete record of everything that is visible to the student group itself. The same technology is used to replay the session for researchers, who can then slow it down or proceed posting-by-posting and action-by-action, viewing exactly what the students in the group all viewed (see Figure 5-2). In addition, a convenient summary log is automatically generated in spreadsheet formats (see Figure 5-3). The text chat is reproduced just as posted by the students, and the GeoGebra actions are listed in detail. The data of the actual interaction are available and the process of interpretation begins with the analysis, not with the data generation and reduction. Researchers can share the replayer files and spreadsheets, so that others can check any analytic descriptions for plausibility.

	A	B	C	D	E	F	G	H	I	J
1	Line	Date	Start Time	Post Time	Duration	EventType	andrew732	pigirl	sigfig15	chris2112
742		3/16/13		23:49.6	0:00:01	Geogebra:Squares			tool changed to Move Graphics View	
743		3/16/13		23:49.7	0:00:00	Geogebra:Squares			release control	
744	155	3/16/13	23:50.9	23:52.3	0:00:01	chat			it works	
745	156	3/16/13	23:56.7	23:57.3	0:00:00	chat		nice		
746	157	3/16/13	23:54.2	23:58.7	0:00:04	chat	wow, great			
747	158	3/16/13	23:59.3	24:08.1	0:00:08	chat		can you simply explain how you made it		
748	159	3/16/13	24:14.3	24:26.6	0:00:12	chat				If you notice on the example, Length CE is equal to GB
749	160	3/16/13	24:27.6	24:51.3	0:00:23	chat				so you can use to compass tool to make a circle around B with point G on it such that as you move E, G moves correspondingly
750	161	3/16/13	24:53.5	24:59.4	0:00:05	chat				Then make a line going through EG
751	162	3/16/13	24:59.6	25:08.0	0:00:08	chat				and a circle with cenger E point G
752	163	3/16/13	25:08.2	25:13.3	0:00:05	chat				and a circle with cetner G point E
753	164	3/16/13	25:13.5	25:32.7	0:00:19	chat				so that a line perpendicular to EG and through the intercepts of the circles is the midpoint line
754		3/16/13	25:33.5	25:34.3	0:00:00	awareness				[fully erased the chat message]
755	165	3/16/13	25:34.5	25:35.3	0:00:00	chat				of EG
756	166	3/16/13	25:35.5	25:58.1	0:00:22	chat				and whatever points on that line intercept the outside sqaure would then make up the other two points of the inner square
757	167	3/16/13	26:03.4	26:05.8	0:00:02	chat			okay good	
758	168	3/16/13	26:34.4	26:36.5	0:00:02	chat		that makes sense		
759	169	3/16/13		26:55.2	0:00:18	system			Now viewing tab Hexagons	
760	170	3/16/13	26:49.0	26:55.6	0:00:06	chat		can we move to "hexagons"?		
761	171	3/16/13		27:00.0	0:00:04	system				Now viewing tab Hexagons
762	172	3/16/13		27:06.4	0:00:06	system		Now viewing tab Hexagons		
763	173	3/16/13		27:46.6	0:00:40	system	Now viewing tab Hexagons			
764	174	3/16/13	27:57.8	27:59.8	0:00:01	chat			ill drag	
765		3/16/13		28:02.2	0:00:02	Geogebra:Hexagons			take control	
766		3/16/13		28:02.3	0:00:00	Geogebra:Hexagons			tool changed to Move	
767		3/16/13		28:10.3	0:00:08	Geogebra:Hexagons			updated Point A	
768		3/16/13		28:30.6	0:00:20	Geogebra:Hexagons			updated Point G	
769		3/16/13		28:32.3	0:00:01	Geogebra:Hexagons			tool changed to Move Graphics View	

Figure 5-3. A spreadsheet automatically logs all text chat postings and dynamic-geometry actions of each student. It can easily be filtered by event type or re-formatted for log excerpts in publications. Columns for each student give a visual impression of the interactional flow.

The VMT system's ability to generate data, which (1) provides an automatic record of the actual interaction and (2) documents the complete group interaction, has made it useful to a number of researchers. Using this data source, they have been able to analyze group processes, rather than just individual actions or outcomes. Here are some examples from before the integration of GeoGebra, when a generic shared whiteboard was used for mathematical figures:

- Sarmiento and Stahl (2008) extended the notion by Teasley and Roschelle (1993) of a Joint Problem Space, observing how students co-construct such a shared conceptualization and how it incorporates a temporal structure, integrating past sense-making results into current discussions aimed at a projected future problem solution.
- Çakir, Zemel and Stahl (2009) observed how a student group integrated their visual/graphical reasoning, numeric/symbolic expression and mathematical discourse in their problem-solving work within the VMT chat and whiteboard media—moving successively from one discourse to another.
- Zhou, Zemel and Stahl (2008) looked at the important role of questioning as a common driving force in collaborative interaction, eliciting responses and providing a guiding group agency.
- Zemel, Çakir and Stahl (2009) analyzed "reading's work" as a contribution to the analog of conversational turn taking as it is materialized in online text chat.
- Zemel and Koschmann (2013) studied how deixis and linguistic reference work within interactions in the VMT environment.
- Koschmann, Stahl and Zemel (2009) examined the nature of several key group practices in VMT collaboration.
- Wee and Looi (2009) investigated pivotal moments in group processes of mathematical knowledge building in VMT chats.
- Medina and Suthers (2013); Medina, Suthers and Vatrapu (2009) probed the nature of representational practices in a series of one VMT group's sessions, observing how practices primarily contributed by one student are later associated with the other students, as they become adopted as group practices.
- (Trausan-Matu, Dascalu & Rebedea 2014) analyzed the polyphonic nature of VMT chats, graphing the intertwining of dialogical voices in a number of groups.

The idea of focusing on the group unit of analysis or group cognition does not exclude analyses at either the individual or the community units of analysis. There are important and different phenomena and processes at each of these (and other) levels. In fact, it is often most fruitful to analyze cognition on multiple levels and to see how the processes at the different levels work together. However, the simultaneous and integrated study across levels is a current challenge for CSCL. A variety of *interactional resources* are typically at work bridging the levels (Stahl 2013a; 2013b; Stahl & Öner 2013). Since incorporating GeoGebra into VMT, research has included designing sequences of such curricular resources to guide collaborative exploration (Stahl 2012; 2015).

In VMT case studies, topics in mathematical combinatorics or dynamic geometry centrally figure as interactional resources that bring together individual, small-group and community cognitive processes. *Sequentiality*, *co-attention* and *shared understanding* are fundamental to collaborative learning. By observing group interaction in VMT, we can see how student groups enact these mechanisms and thereby integrate individuals into groups adopting community practices. For instance:

- In Stahl (2011), two students solve a high-school math problem that has stumped them for some time. The problem-solving steps that the dyad goes through as a team are strikingly analogous to how proficient students solve problems individually. In the discourse captured in this case, one can see how the *group* integrates contributions from the two *individual* participants to accomplish a task in accordance with *community* standards of practice—illustrating the productive interplay of cognitive levels. A sequence of ten discourse moves (similar to extended adjacency pairs in Schegloff 2007) by the group details their *sequential organization* of the problem.

- In Stahl, Zhou, Çakir and Sarmiento-Klapper (2011), three students develop techniques for helping each other to see what they are seeing in the diagram they have drawn for a math problem. This *persistent co-attention* to a shared object of analysis allows the team to solve their problem as a group.
- Similarly in Çakir and Stahl (2013), the students are able to work together because they effectively manage their *shared understanding* of the problem.
- Stahl (2016) follows a group of three young girls longitudinally through eight hour-long sessions in the VMT chat room with a multi-user version of GeoGebra. It describes the display of mathematical reasoning by the team discussing the dependencies of a series of dynamic-geometry figures. By analyzing the network of mutual responses, it tracks the meaning-making process and observes how the team enacts effective practices in collaboration, mathematical discourse and dynamic geometry.

When a group enters the VMT environment, it is presented with a challenging math problem, which is designed to guide the group interaction in an academically productive direction. The problem acts as a resource for the group. The group must interpret the problem statement, elaborate the way in which they want to conceive the problem and determine how to proceed. A math problem can serve as an effective interactional resource for bridging across cognitive levels. Typically, it introduces content—definitions, elements, procedures, principles, practices, proposals, theorems, questions—from the *cultural* traditions of mathematics and from school curriculum. In so doing, it recalls or stimulates *individual* cognitive responses—memories, skills, knowledge, calculations, deductions. It is then up to the *group* interaction to bring these together, to organize the individual contributions as they unfold in the on-going interaction to achieve the goals called for by the community, institutional, disciplinary and historical sources. In this way, the group interaction may play a central role in the multi-level cognition, interpreting, enacting and integrating elements from the other levels, producing a unified cognitive result and thereby providing a model for future community practice or individual skill.

Group cognition is not the same as individual cognition. It relies on individual cognition to make essential contributions; however, one cannot say that all of the cognition is reducible to the individual units, because the work of assembling the high-level argumentative structure typically occurs at the group unit of analysis. Surely, putting together problem-solving arguments must be considered a cognitive activity as much as the memory or computation that goes into making the detailed contributions to individual steps. This group cognition may be considered to involve students in their zone of proximal development, with the expectation that they will later be able to conduct such extended problem-solving argumentation individually based on their group experiences.

In addition, the individual discourse contributions are not actually separable from the group processes. They are largely responses to what has gone before in the group interaction. These contributions are expressions that would not have occurred without the preceding opening for them and the elicitation of them by the group process. Many of the contributions are largely reactions at the group level, which reference and inter-relate resources available in the discourse context more than they introduce new elements from the personal perspective and individual background of the actor. The important knowledge-building achievement is emergent at the group level, rather that a simple collection of expressions of individual cognitive accomplishments. Note that the emergence of group cognition is quite different from the emergence of complexity from the non-linear interaction of simple rules in chaos theory; group cognition emerges primarily through the intertwining of subtle linguistic phenomena of indexicality and sedimented shared meaning inherent in sequentially organized utterances of multiple voices.

Of course, coherent and impressive examples of group cognition—such as solving a math problem that the group members would not have been able to solve on their own—do not occur every time that people come together in conversation. In fact, the research field of CSCL has documented that desirable forms of collaborative knowledge building are disappointingly rare. The studies summarized above indicate some reasons for this. First, it is difficult to set up a group interaction where everything relevant to the cognition at the group level of analysis is captured in a form adequate for detailed analysis. It took years to iteratively design, develop and deploy the VMT group sessions to successfully generate adequate data of successful group cognition. Secondly, the group interaction must be directed and guided to focus on an appropriate cognitive task. Certain challenging math problems, carefully presented, seem to provide effective interactional resources for stimulating interesting episodes of group cognition. In addition, groups must work consistently to ensure the presence of certain preconditions of effective group cognition. They must persist in building *longer sequences* of responses to each other, they must maintain continuous *co-attention* to a shared focus of discussion and they must build and sustain a *shared understanding* of the topic of conversation.

The VMT studies listed above are focused on the small-group unit of analysis. This is consistent with other contemporary attempts to shift away from an exclusive concern with individual cognition, for instance, in actor-network theory, ethnomethodology, distributed cognition and activity theory. In the VMT project, most analysis has focused on the under-researched unit of the small group (Stahl 2006; 2009). However, recent work on VMT looks at the interactions among the individual, small-group and community units of analysis (Stahl 2013a; 2013c). This has the potential of bridging to other analytic approaches in LS and CSCL, although it raises new methodological issues about studying the relationships of the different levels.

The foundational relationship of CSCL to LS

The post-cognitive paradigm assigns an analytic priority to group cognition, as the level at which important processes of learning take place. Applying this to the study of learning is motivated by Vygotsky's developmental principle:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (*interpsychological*), and then *inside* the child (*intrapsychological*). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher [human mental] functions originate as actual relations [interactions] between human individuals. (Vygotsky 1930/1978, p. 57)

Cognitive phenomena such as learning occur first in group interaction and then only subsequently—through complex and extended transformations—appear as individual skills or outcomes. In this sense, LS should be seen as founded on CSCL. Collaborative learning is not just an optional and rare mode of instruction, but rather a foundation of learning. More generally, group cognition is a basis of human cognition: individual, small-group or community.

This paradigm argues for study at the small-group unit of analysis (Stahl 2010) in addition to the individual and community units. Too often, LS researchers reduce group-level phenomena either to individual-psychological constructs or to societal institutions and practices. But, as we have seen in VMT case studies, there are often important practices and processes taking place at the small-group unit of analysis that are not reducible to the mental behaviors of an individual or to the institutions or established practices of a community.

This does not mean there is some kind of "group mind" at work or anything other than the interaction of the students. Rather, it means that the analysis of cognitive achievements may be most appropriately conducted at the group unit of analysis—in the VMT context, in terms of the interplay of the text-posting and geometric-drawing actions shared by the group.

CSCL is not the science of some existing, objectively observable phenomenon, such as physics or psychometrics may be. It is the search for a new form of learning—taking advantage of technologies that are yet to be developed and group processes that are difficult to observe and have largely gone unnoticed. Therefore, it cannot be studied in the manner of a summative assessment, by comparing measureable learning outcomes. It is more of a design science, using design-based research to transform "existing situations into preferred ones" (Simon 1981). To guide redesign, it is not sufficient to "predict" the percentage increase in outcomes that is attributable to a particular, currently available technological condition. What is needed is insight into how students in realistic situations may actually make sense of and take advantage of possible technologies, as well as what barriers students may encounter in trying to use them. This means looking at how groups of students interact with various technological artifacts and observing their meaning-making processes, their enacting of the technologies and their problem solving as mediated by the technologies.

Of course, not all groups of students will act the same way under similar conditions. Groups are unique—with students at different zones of proximal development for different skills and with interactions highly situated within un-reproducible discourse trajectories. Therefore, statistical generalization is not a relevant goal in such research. What one seeks, rather, is a detailed understanding of the practices that are actually found to be at work in observed cases. According to ethnomethodology, communities tend to use shared practices (Garfinkel & Sacks 1970). Otherwise, intersubjective sense making would not be possible—any more than communication would without a common language. Therefore, the practices that one observes in a single case may be representative of widely used practices. Researchers familiar with a domain—such as experienced math educators—can often tell what seems like a typical group behavior within that educational arena.

LS and CSCL have made significant progress in recent decades, as documented in Sawyer (2006) and in the current volume. However, it may be timely to pursue a new research paradigm explicitly—one in which CSCL plays a foundational role. For the CSCL and LS research communities to make the major paradigm shift advocated here will involve significant re-tooling and adoption of new methods. It will also require increased collaboration with colleagues in social science who are more familiar with analyzing interaction and language and with formulating rigorous descriptive accounts of group-interactional processes. Fortunately, the requisite technological recording capabilities are available and the evocative research questions are at hand.

The settings studied by LS and CSCL today are complex. Many diverse studies can contribute to an understanding of the learning taking place. Such studies can pose a broad spectrum of research questions, each with its own theoretical framing and methodological approach. Certainly, traditional quantitative and qualitative analyses at the individual unit of analysis can provide important parts of the picture, as can considerations of social practices and community participation. However, it is also necessary to consider the temporal processes of group interaction, through which the individual and the community are often mediated and through which learning takes place as a process, not just as an outcome.

In his reconsideration of the CSCL paradigm, Koschmann (2001, p. 21) concluded that "we have yet to develop a consensus within the CSCL community with regard to what it means to learn and how to study the process." I have argued here that a paradigm-shaping research question for LS would

- *Treat learning as essentially an intersubjective, interactional process.*
- *Study learning by investigating the dynamic developmental processes through which individual, small-group and community cognitive practices emerge.*

The seminal analysis by Teasley and Roschelle (1993) pursued a specific version of this question by asking how dyads of students created a joint problem space around a computer representation of velocity and acceleration. The VMT Project is currently pursuing a different approach to the same question by exploring how students co-construct interactional, group-cognitive and mathematical group practices in small online groups mediated by collaborative-dynamic-geometry tasks and tools (Stahl 2013c; 2016). Following approaches such as these, research in a post-cognitive CSCL paradigm can lead research in LS by working out the interactional foundations of all learning through taking advantage of technologies, pedagogies and understandings afforded by CSCL.

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