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Instrumental genesis in technology-mediated learning: from double stimulation to expansive knowledge practices.

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Abstract. The purpose of the present paper is to examine the socio-cultural foundations of technology-mediated collaborative learning. Toward that end, we discuss the role of artifacts in knowledge-creating inquiry, relying on the theoretical ideas of Carl Bereiter, Merlin Donald, Pierre Rabardel, Keith Sawyer and L. S. Vygotsky. We argue that epistemic mediation triggers expanded inquiry and plays a crucial role in knowledge-creating learning; such mediation involves using CSCL technologies to create epistemic artifacts for crystallizing cognitive processes, re-mediating subsequent activity, and building an evolving body of knowledge. Productive integration of CSCL technologies as instruments of learning and instruction is a developmental process: it requires iterative efforts across extended periods of time. Going through such a process of *instrument genesis* requires transforming a cognitive-cultural operating system of activity, thus 'reformatting' the brain and the mind. Because of the required profound personal and social transformations, one sees that innovative knowledge-building practices emerge, socially, through extended expansive learning cycles.

Keywords: collaborative emergence, double stimulation, epistemic mediation, instrument genesis, knowledge building, knowledge practice, technological fluency

Introduction

The purpose of the present article is to analyze challenges and constraints involved in implementing technology-mediated collaborative learning and associated inquiry-based and knowledge-building pedagogies. Our central question is Why it is often difficult for teachers and students to appropriate the technology-mediated practices of learning and instruction that we promote, and to willingly adopt sophisticated learning environments created by CSCL researchers? This problem is not an accidental phenomenon or a characteristic of local conditions, but an essential aspect of technology-mediated human activity. For example, Collins and Halverson (2009) argued that there are some incompatibilities between traditional educational practices and potentials on innovative learning technologies and proposed that the future of learning is outside schools. From our perspective, those incompatibilities may be overcome if the social practices associated with schooling are transformed in association with the use of a technological medium. Indeed, since a technology "does not exist in a 'pure objective form' outside the context of social practices" (Tuomi, 2002, p.12), to analyze the implementation of new media in education requires one to put expansive knowledge practices in the center of the investigation. The slogan "technology enhances learning only through transformed social practices" (Hakkarainen, 2009) crystallizes our view. In order to work as an instrument of learning and teaching, educational technologies have to be integrated, "fused", with the social practices enacted by participants, which was a reason for introducing the concepts of "knowledge practices" and "chronotopes". Knowledge practices are defined as routine personal and social activities related to working with knowledge. They represent deliberate efforts to expand one's intellectual resources by creating and building epistemic artifacts (Hakkarainen, 2009; Knorr

Cetina, 2001). The patterns of space-time management emergent during the enactment of knowledge practices have been called *chronotopes* (Ligorio & Ritella, 2010).

We will address this issue by building on the contributions of Vygotsky, Donald, Bereiter, Rabardel, and Sawyer. Vygotsky's and Donald's theoretical frameworks assist in explaining and understanding how cultural-historical development profoundly transformed the human cognitive architecture in a way comparable to major leaps in biological evolution, bringing radical externalization and collectivization of cognition. For Vygotsky (1978), cultural-historically developed tools are included in mediated cognitive processes through the process of double stimulation and afterward become psychological tools that expand the depth and scope of psychic processes. Donald's (1999; 2000; 2001) investigations indicated that human beings are "maximal cognitive over-achievers" whose complex creative and intellectual achievements are piggy-backed by the cultural invention of external cognitive technologies and the associated cultural "reformatting" of the mind and the brain. A crucial role in the emerge of our civilization was the emergence of External Memory Fields (EXMFs) that allowed using our powerful visual system for elaborating, sharing, and building on externally represented ideas and creating exponentially growing External Symbolic Storage Systems (ESSS). As explained below, in-depth socialization to function in interaction with such cognitive-cultural networks constitutes the semiotic-material basis of human cognition and requires the gradual development of the "cognitive-cultural operating system" required to capitalize on external cognition.

In the present period, practices of learning and instruction prevailing at schools and educational institutions are being profoundly transformed through intensive use of ICTs in general and CSCL technologies in particular. In understanding this process, the pioneering contributions of Bereiter's (2002; Bereiter & Scardamalia, 2006) knowledge building theory provide fruitful material. These researchers have provided a theory of knowledge-creating inquiry, developed the Knowledge Forum (KF) environment to transform practice, and carried out design experiments in a close interaction with practitioners. Bereiter construes knowledge building as involving a process of advancing externalized conceptual artifacts, but the focus of his theoretical reasoning has been mainly on the development of ideas, as immaterial objects of Popper's (1972) world of cultural knowledge (World 3). It appears to us that Bereiter's approach may be usefully extended by addressing the importance of building knowledge at the EXMF provided by CSCL environments, through the construction of knowledge artifacts; these constitute locally created cognitive-cultural networks and exert epistemic mediation. Learning to engage in knowledge building requires deliberate transformation of learning activities, capitalizing on the epistemic mediation provided by the cultural worlds embodied in external artifacts.

Rabardel (Beguin & Rabardel, 2000; Verillon & Rabardel, 1995), in turn, assists us in understanding the developmental processes that individuals have to go through in order to gradually transform artifacts into instruments of their activity. Appropriating novel tools for remediating activity requires adapting and transforming both the external tools (instrumentation) and the cognitive-cultural schema (instrumentalization). We think that Rabardel's ideas of instrument genesis are complementary to Vygotsky's notion of double-stimulation. Such stimulation permits one to explain instrument genesis and mediation in terms of inclusion and use of artifacts in the processes of problem solving, thinking, and inquiry. The concepts of instrumentation and instrumentalization permit us to improve our understanding of the "mutual shaping" between persons and tools (Overdijk & van Diggelen, 2008, p. 3) that occurs when double stimuli are iteratively used as instruments. Such a developmental process – sometimes called "appropriation" (ibidem) – is close to the transformation of the cognitive-cultural operating system of activity that Donald (2000) emphasized. Finally, we see technology mediated knowledge practices essentially as cultural, social practices, which can be fruitfully analyzed using the theory of collaborative emergence, addressed by Sawyer (2005). He has argued that the phenomena studied by social scientists emerge from "complex systems of individuals in interaction" (2009, p. 1). We consider

technology-mediated learning practices a phenomenon of this type, involving both real-time and long standing trajectories of development, which are reached firstly at the interpsychological (social) level and then at the intrapsychological (individual) level (Vygotsky, 1978).

In short, in this article we argue that all of these investigators address complementary aspects of the transformations that are needed for productive participation in technology-mediated collaborative learning; such learning is tightly integrated and embedded in social and collective practices cultivated within a community. In the following sections we firstly discuss the role of epistemic mediation in human learning and activity. Secondly, we address the relations between instrument genesis and double stimulation. Thirdly, we look at the space-time relations (chronotopes) involved in knowledge-creating learning, and at the collaborative emergence of innovative knowledge practices. In the end, we discuss how all of these elements permit one to obtain a critical understanding of technology-mediated learning and to contribute to bridge the gap between theory and practice in CSCL.

Epistemic mediation and technology-mediated collaborative learning

The present investigators examine technology-mediated collaborative learning as a process of transforming the present knowledge practices in schools toward ones that engage students, teachers, and their communities in building knowledge embodied in epistemic artifacts. This process capitalizes on the epistemic mediation provided by those artifacts, which play the role of stepping stones for reaching deeper understanding. In order to examine the psychological underpinnings of such a process, a short excursion regarding human cognitive evolution is in order. According to Donald's (1991; 2001; see also Olson, 1994; Sterelny, 2004) analysis, the emergence of literacy transformed the human cognitive architecture as profoundly as earlier leaps in biological evolution, allowing radical externalization and collectivization of cognition. A central aspect of the fundamental cognitive transformation in question was harnessing the extremely powerful human visual system to support thinking and reasoning. Ideas and concepts materialized with human vocal apparatus were ephemeral and impossible to explore analytically. Production of knowledge by writing on sand, paper or a digital surface opened up an External Memory Field (EXMF) in which complex ideas and associated epistemic systems can be extensively refined in a way not attainable for the unaided human mind. In fact, thinking and learning very profitably capitalize on literate practices involved in externalizing, crystallizing, and objectifying ideas and thoughts occurring in inquiry processes to epistemic textual or graphic artifacts, as shown in the following anecdote:

> *"When the Nobel-winning American physicist Richard Feynman gave a manuscript full of text and diagrams to Charles Weiner who was investigating the history of his thought, the latter asked if this was "a record of the day-to-day working". "I actually did the work on the paper" Feynman responded. Slightly confused Weiner specified:"Well, the work was done in your head, but the record of it is still here." " No, it's not a record, not really. It's working. You have to work on paper, and this is the paper. Okay?" (Gleick, 1992, p. 409, quoted by Donald, 2001, p. 301).*

Human beings do not have cognitive capacities to engage in the development of complex ideas within their individual minds; in order to pursue "longer trains of thought" (Darwin, quoted by Gruber 1981), they have to "work on paper". Experts' complex reasoning and memory capabilities become internalized only through sustained pursuit of externally embodied cognitions (Galperin, 1957). Writing and visualization allow human beings to establish a *theoretic culture* based on gradually accumulating the External Symbolic Storage Systems (ESSSs).

Humans are biologically cultural and social creatures (Donald, 2001; Rogoff, 2003; Tomasello, 2009) whose intelligence is adapted to co-evolve with cognitive-cultural macrostructures that are subject to cultural-historical change. Our intelligence is not only inside of the mind but in its multi-faceted networking connections and downloaded to various peripherals, i.e., artifacts that can be

understood as *cognitive prostheses* that expand and augment human creativity and intelligence when integrated with the cognitive architectures of the participants' minds (Clark, 2003, Skagestad, 1993). Following Donald's (2001) line of thought, a wide range of in-depth learning accomplishments may be interpreted as the developmental process of acquiring the *cognitive-cultural operating system* that productive working at EXMF, utilizing ESSS, requires. Here we are referring to learning that involves a profound expansive transformation of participant's practices (level II and III learning of Bateson, 1972). The operating system is an internalized aspect of a socio-cultural or socio-technological activity system (Engeström, 1987), i.e., an integrated array of tools, instruments, objects, division of labor, specific social structures with particular rules and principles. Thus deep intellectual socialization to massively distributed cognitive-cultural networks, facilitated by years of systematic education, augments the participants' cognitive capacities to the extent that enables them to solve significantly more complex problems than would otherwise be possible. Such capacities are best not thought of as individual characteristics, but rather as the appropriations, within individuals, of the capabilities of the culture in which they live. Across such an expansive transformation process, culture literally *reformats and re-programs the human cognitive architecture* (Donald, 1991; 2001; Clark, 2003; Hakkarainen, 2003); as a consequence of extensive cultural re-shaping, cultural knowledge and competencies become internalized as a part of human cognitive architecture and affect the available cognitive resources at many levels. When artifacts become fully integrated with our activity, they are represented in our brain in a way comparable to our physical limbs; cultural programming takes place through creating novel functional systems (Luria, 1974) or "virtual machines" (Dennett, 1991), for pursuing culturally programmed rather than biologically given problem solving.

From this perspective ICT may be seen as continuation of the collectivizing cognitive evolution at a new level of integration of internal, external, and distributed cognitive processes (Donald, 2000). Indeed, As McLuhan (McLuhan & Lapham, 1994; see also Goody, 1977; Olson, 1994) theorized, ICT generates new media having different *material* features from other media, which transform semiotic processes in terms of perceptual features of semiotic arrays, workability of semiotic arrays and shareability of semiotic arrays. For example, Word processor software, as implemented permits one to modify texts without re-writing them on new sheets of paper (workability), or to visualize them in different sizes, different colors, different brightness, and so on (perceptual features), and often to share documents with anyone in real time (shareability). Microsoft Excel, on the contrary, easily visualizes symbols and words in tables and graphs that trigger different cognitive processes than a discursive text (Goody, 1977). Those features of ICTs allow delegating cognitive processes to technological systems, creating technologies for fusing intellectual efforts in collaboration, and complementing personal epistemic resources with global networks that are immediately accessible. ICTs impel the creation of qualitatively different ESSSs, by permitting integration of hybrid and heterogeneous forms of media in a way unthinkable in the past. Rather than examining digital artifacts as merely isolated tools and signs, it appears useful to examine how digitalization will likely revolutionize human cognition and activity (Rückrem, Ang-Stein & Erdmann, 2011). Technological instruments are at the same time medium and sign (Cole, 1996), and the characteristics of medium (material relations) are as important as the ones of the signs and symbols (semiotic relations).

It appears that the Internet represents a revolutionarily expanding digitalized aspect of ESSS relevant in the present day knowledge-intensive society. In depth intellectual socialization to digital literate practices throughout educational careers provides the basic elements of the cognitive-cultural operating system that contemporary society requires. In order to profit from the "extension" of cognitive system that internet provides, people need to adapt their internal cognition to the features of the EXMF they use (both medium and sign system). In this regard, it is essential that the young generation appears to represent "digital natives" (Prensky, 2001; 2010) who are able to completely merge ICTs with their intellectual system. Because a revolutionary expansion of the

digital ESSS has taken place in an extremely short period of time, investigators do not know the longitudinal psychological consequences of ICT-intensive activity. Some investigators worry that constant embodiment of human activity in ICT in general and the Internet in particular may have some undesirable neurological effects (Carr, 2007; Wolf[1]). They are concerned that constant interruptions associated with the Internet, shallow surfing from one website to another, and a tendency to work with relatively short fragments of text produce 'grass-hopper minds' (Carr, 2007; Papert, 1994) unable to undertake coherent and disciplined thought; minds for whom knowledge is a matter of 'cut and paste.'

A limitation of Carr's (2010) position is that he focuses mostly on using the Internet for acquiring and consuming rather than creating knowledge. From a psychological perspective, using ICT for pursuing collaborative inquiry and shared building of knowledge appears critical if students are to master large bodies of knowledge and learning; to synthesize and extend rather than merely to consume knowledge (Bereiter, 2002; Hakkarainen, 2004). Writing, then, has to be considered the principal vehicle of epistemic mediation, and promoting corresponding knowledge practices plays an essential role in CSCL. Pioneering research on epistemic mediation by Bereiter and Scardamalia (1987) focused on teaching experts transformative ways of working with knowledge in promotion of students' learning; these studies revealed that these novices' capacity to produce knowledge can significantly be procedurally facilitated when presenting materially embodied critical questions and hints (pieces of paper) at their EXMFs during writing process. Later on, such cognitive scaffolding played a crucial role in the design of knowledge-building technologies focused on assisting students' engagement in complex and challenging inquiries in which material practices of writing played critical role. Practices of knowledge-building classrooms differ from ordinary oral discourse taking place in conventional classrooms; participants' intangible insights entered to learning environments databases are transformed to digital form and therefore, also, materially embodied ideas that exist outside of the participants' minds. Such entities are conceptual artifacts (Bereiter, 2002) having both ideal and thing-like characteristics. From this perspective, conceptual artifacts in Bereiter's theory roughly correspond to the semiotic arrays that constitute EXMF.

Epistemic mediation plays an important role in "knowledge-creation learning" that the last author and his colleagues have been developing (Paavola et al., 2004). To summarize, we refer by epistemic mediation to a deliberate process of deepening inquiry by creating external knowledge artifacts (written notes or visual representations) at EXMFs that crystallize and materialize evolving understanding and provide stepping stones for directing and guiding further personal or collective inquiry efforts. We say that the use and operation of these artifacts, is a process of *epistemic mediation* between the user (or user community) and the evolving objects if their activity. We are talking about an *object-centered* approach to CSCL because the nature of the epistemic objects worked on significantly determines the nature of inquiry; they are centers around which corresponding practices are organized. When designing technology-mediated learning environments for supporting knowledge building inquiry, CSCL investigators deliberately create new types of EXMFs. Such environments provide the material agency (Pickering, 1995) that enables even elementary-school students to participate in deliberate knowledge advancement, with adequate guidance and facilitation by teachers. The current textual practices prevailing at school, however, often guide students to use writing mostly for reporting what their textbooks say about issues being studied rather than use writing for epistemic mediation, i.e., as a tool of extending thinking and deliberately generating new ideas and working theories. Adopting and cultivating a cognitive-cultural operating system that enables effective use of writing as a tool of thinking is difficult; it is an extended struggle to acquire embodied, and to a large extent tacit capabilities rather than direct assimilation of well-specified skills (Russell, 1997).

[1] See http://www.guardian.co.uk/commentisfree/2011/aug/14/marshall-mcluhan-analytic-thought

Double stimulation and instrument genesis: the micro-genesis of cultural-cognitive operating system

As indicated above, the extended mind approach constitutes a theoretical framework that helps account for the role of technological tools in cognitive processes related to knowledge building. In the following, we discuss how the framework can be fruitfully enriched using the concepts of double stimulation (Vygotsky, 1978) and instrument genesis (Rabarbel & Bourmaud, 2003, Lonchamp, this issue). While we conceptualize *double stimulation* as a basic principle regarding the incorporation of artifacts in problem solving, thinking and learning; *instrument genesis* regards the process of appropriation, or operating system reformatting, necessary for the transformation of artifacts into instruments. 'Instrument genesis' regards short-term developmental processes of appropriation of technological tools across situations, analogous to the long-term formatting and re-programming of the mind that reflects the historical development of technology-mediated cultural practices. We think that micro-genetic and middle-/long-term processes both account for the use of technological tools in learning: while the theories explained in the preceding paragraph permit one to explain the macro-level, in this section, we focus on the micro-level of analysis and use the concepts of double stimulation and instrument genesis to account for the role of instruments in knowledge building.

Double stimulation is a complex concept that can be examined at multiple levels. Here the present investigators stay close to the original Vygotskian interpretation associated with the process of psychological development (for application of the method for examining the transformation of activity systems, see Engeström, 2007). Basically, the setting of Vygotsky's (1997) double stimulation experiments was as follows: a participant is given a task or problem to solve (first stimulus). Additionally, a neutral stimulus is placed at the perceptual field of his or her activity. While engaging in creative problem-solving efforts, the participant is likely to adapt and transform the neutral stimulus (second stimulus) into an instrument, opening a pathway toward the zone of proximal development (Vygotsky, 1962). The classical example Vygotsky uses to describe the principle is the experiment of the meaningless situation, in which a subject is observed while waiting a long time for the experiment to begin. The author notes that people in this situation transform the "meaning-less situation" by the use of external tools present in the environment. For example, people may take decision that when the minute hand of the clock will be in a certain position, he/she will undertake an action. So, the clock is used as a tool to frame the challenging situation in a way that makes agency possible. In the same way, students facing a problem can frame the problem by using any kind of tool present in the educational environment, e.g. finding appropriate information in a book or in the net; representing ideas with pen and paper or in the virtual space; transforming artifacts to fit the need of the moment, and so on.

Apart the apparent simplicity of the principle, double stimulation is not a mechanical process; the prevailing instruments and procedures have to be creatively adapted for solving the problems encountered. Indeed, once the second stimuli are picked up, people willingly adapt them to their aim and use them to transform their psychological model of problematic situation. His or her ways of interpreting, modifying, adapting, and using the second stimulus, reveal a great deal of information concerning how the participant interprets the task and what kinds of principles are utilized in the process of solving the problem. It is essential that the artifacts be materially embodied so as to transform the semiotic array of EXMF and become a sign on the basis on which a subsequent leap of inquiry can be accomplished; without external embodiment that double stimulation would not work and assist in bringing about novelty.

Learners participating in CSCL experiments are in a similar situation to that of the children investigated by Vygotsky: while starting to pursue their inquiry, they encounter challenging learning tasks that cannot be solved without using meditational means. They have to appropriate, through participating in educational practices, various instruments and methods and eventually use

them as a second stimulus. Nevertheless, as Rasmussen and Lund (2008, p. 390) suggest, in order to use double stimulation in CSCL, one needs "to align this principle with situations where we have a series of complex tools as second stimulus", instead of a neutral relatively stable tool as was the case in Vygotsky's experiment. Moreover, CSCL environments often offer a multiplicity of tools so that investigating "which tools are actually picked up and appropriated by learners and how they put to use for object-oriented endeavors" (Lund & Rasmussen, 2008) is a foundational issue. In fact, educational environments often consist of systems of tools that can be arranged in different ways and used at different times of the learning process. Investigating students' and teachers' strategies of tool selection and tool use appears to be a promising area of research that may be explored according to the theoretical perspective presented in this paper.

The creative process of double stimulation involves, then, turning the artifacts (which constitute the ESSS) to instruments (Beguin & Rabardel, 2000, see Virkkunen, 2006) of participants' inquiry. Rabardel argued that the process of appropriating and integrating external artifacts as instruments of human activity is a developmental process (for a description of Rabardel´s approach see Lonchamp, this issue) described in terms of two dimensions: *instrumentation* and *instrumentalization*. 'Instrumentalization' refers to the "technical/material part" of instrument genesis, i.e., the emergence and evolution of the artifact to support activity in local cultural context. Available cultural tools have to be adapted to local needs and purposes of activity; a potential for flexible adaptation and customization is, of course, a central characteristic of ICT. In CSCL context, this has involved both tailoring hardware and software to support inquiry projects in question, and structuring associated activities. 'Instrumentation', in turn, is related to the "human part" of instrument genesis and involves gradual formation and evolution of scripts (Schank & Abelson, 1977) and schemas (Piaget, 1985) of using the instrument in question in practice. One of the strengths of this conceptualization is that Rabardel examines both the transformation of the external artifact and the transformation of the user in instrument genesis. Indeed, productive utilization of epistemic mediation in learning and inquiry presupposes sustained efforts to use associated technologies in practice and cultivation of required personal skills and practices. In our view, the basics of double stimulation investigated by Vygotsky correspond roughly to the first level of instrument genesis in Rabardel's theory. Indeed, at the first level of instrumentalization "an instrument is momentarily instrumentalized for a particular action" (Lonchamp, this issue), so that a relatively neutral stimulus is transformed in a relevant tool. Beyond this "situational" aspect, instrumentalization involves linking the instrument permanently to a category of situations and transforming it to perform the new functions in a certain type of situations. Through the process of instrument genesis, technological artifacts that initially were at the centre of conscious attention (their exploration being the object of activity) gradually become tools that are used automatically and, partially, an invisible background; the participants become aware of these tools only when encountering disturbances and breakdowns of activity (object-tool dialectics, Engeström, 1987).

In light of these considerations, it appears useful to expand the Vygotskian notion of double stimulation to consider extended processes of knowledge creation. Such processes involve *expansive stimulation* (Virkkunen & Schaupp, 2011; Barowy & Jouper, 2004, see also Engeström, 2009; Stetsenko, 2005) in respect of going through a complex process of internalization and externalization and creating a whole series of materially embodied epistemic artifacts in parallel with reshaping internally represented knowledge. Collaborative pursuit of epistemic artifacts piggy-backs the advancement of young students' inquiry within knowledge building classrooms by capitalizing on *double stimulation*. The epistemic artifacts created appear to have "pointers" (hints, implicit directions) regarding what is missing from the picture; thereby intuitively suggesting which ways to look and how to focus further inquiries (Knorr Cetina, 2001). In the course of activity, epistemic artifacts may become instruments for subsequent inquiry efforts, making them a part of the invisible background of activities – intuitively guiding and constraining further inquiries (Engeström, 1987). By using the created epistemic artifacts as stepping stones for reaching deeper

knowing and understanding, an inquirer and his or her community may gradually break their epistemic boundaries. From this perspective, knowledge creation may be seen as a process of building a bridge across a river so that earlier rocks (epistemic artifacts) are used as a basis for laying new ones (novel epistemic artifacts) until one has created a dynamic pathway from older (initially known) to newer knowledge and understanding (initially unknown). Learners may appropriate knowledge-building practices to the extent that pursuit of epistemic mediation relevant for knowledge-creation becomes their second nature, i.e., an integral aspect of their activity system. Sustained participation in such process is not cognitively neutral; going through a long series of double stimulation processes that involve creating epistemic artifacts massively reformats and restructures the participants' minds (compare representational re-description, Karmiloff-Smith, 1992) across long-standing efforts. Sustained expansive stimulation is likely to elicit maximal cognitive adaptations (Ericsson & Lehmann, 1996) that play an important role in formation of the Long-Term Working Memory (Ericsson & Kintsch, 1995); such adaptation transforms the cognitive architecture of a participant through providing a virtual space for experts' complex cognition.

We consider Rabardel's theory extremely relevant for CSCL research because we investigators have had a tendency to underestimate challenges and constraints involved in instrument genesis. Rabardel's approach to instrument genesis highlights the importance of developmental processes involved in appropriating technology-mediated practices of learning and instruction. In this regard it appears to come close to ideas and visions of the *pragmatic web* (see Hakkarainen et al., 2009 for references) that underscore the crucial role of *social practices of using technology* in gradual learning and socialization to use ICT. With respect to technology-use-practices, the present discourse of Information and Communication Technologies is biased in respect of focusing, as the term implies, either on the information-transmission genre or social-communication genre. Otherwise attractive visions regarding the emergence of collectively intelligent *metaweb* (Nova Spivack[2]) are "flat" because it is assumed to arise from increased information connectivity, on the one hand, and social connectivity, on the other hand. The pragmatic web guides one to examine social practices related to the historical-developmental use of technology, as the topography or third dimension of the Metaweb, a dimension which reveals an extremely rough terrain of the surface. Going through instrument genesis in learning to use a new technology and appropriating associated scripts initially requires so large an investment of both personal and collective efforts that it can be compared with climbing to the top of a steep mountain. Required cognitive adaptations do not take place without extended effort of adapting, tailoring and reformatting technology-mediated competences. After going through such an extra-ordinary effort, the participants may be reluctant to start climbing another mountain without very good reasons for doing so; it is always easier just to slide down the familiar hill in terms of relying on already mastered ICT. Personal appropriation of even relatively simple technology, such as email, is initially challenging because it requires appropriating new social practices in gradually adapting and changing one's cognitive-cultural operating system of activity.

Instrument genesis may be studied at personal, community or collective levels. Transformations, at the personal level, of competencies of using ICTs are, of course, crucial. Skills and competencies of using ICTs in general and CSCL environments in particular, which emerge through genesis of a transformed cognitive-cultural operating system and enable participation in creative personal and educational activity, are called *technological fluency* (Barron, 2004; 2006). Technological fluency emerges on the condition that participants have appropriated ICT tools as "intellectual prostheses" (Clark, 2003) to support their personal learning, peer collaboration, social networking, and creative working with knowledge. Technological fluency implies that ICTs are used as flexible tools of personal and collective activity. Only after teachers and students have developed novel practices of using ICTs as instruments for pursuing their epistemic objectives and cultivated corresponding

[2] See http://novaspivack.typepad.com/nova_spivacks_weblog/2004/04%20/new_version_of_.html.

knowledge practices, are significant advantages of educational technology likely to emerge. Barron (2006) stated that the development of technological fluency requires agentic efforts in building self-sustained networks of learning by integrating school knowledge with extended authentic knowledge sources and disciplinary systems, actively seeking connections with tools, practices, and knowledge of expert cultures, and various actors capable of supporting and mediating learning efforts. It appears also that only technologically fluent teachers are able to stretch technology to support their pedagogical goals and purposes.

Remediating practices of classrooms or whole schools by ICT appears many degrees more challenging than transformation of personal practices. The specific challenge of CSCL is to have a whole, heterogeneous and often unwilling learning community appropriate shared CSCL technologies and corresponding knowledge practices. It is difficult to get a whole community to climb to a mountain rather than to do it individually, only by themselves. The exact route cannot be planned beforehand; participants need to learn, improvisationally, to negotiate partially unforeseen challenges and obstacles. As explained in the section addressing collaborative emergence, the transformation is difficult because there are no ways of moving straightforwardly from present to new practices; an iterative and expansive process of transforming practices, gradually, step by step in the desired direction is needed (Engeström, 1987). Human beings cannot directly change their cognitive-cultural operating systems; transformations take place gradually through interacting practical exploration and reflection supporting directed evolution of technology-mediated practices. Consequently, technology-mediated practices of learning and instruction consolidate very slowly, and advancements tend to take place in courses and practices of exceptionally enthusiastic and committed teachers with a high level of technological fluency (Barron, 2004). Because such teachers are not common and many of the others are reluctant to use ICTs, technology-mediated practices of even the best schools are likely to remain very heterogeneous across long periods of time.

Although it is not realistic to expect profound overall transformations of educational practices to take place in the short run, some groups of students and teachers are likely to appropriate new ICT tools, go through personal developmental learning processes and cultivate "information ecologies" (Nardi & O'Day, 2000), i.e., local practices and innovations of using technology. To summarize, technological artifacts become instruments of human activity only through sustained and iterative efforts of using them in practice, a process through which the cognitive-cultural operating system of activity gradually transforms and adapts according to evolving practices of using technologies. This evolution is reflected in deep-level changes in mental processes, such new capabilities being, in effect, cognitive prostheses adapted to changed modes of learning and creating knowledge. Such technologies are themselves being developed and tailored to requirements of activity.

The space-time of technology-mediated learning practices

The view of technology-mediated learning proposed in this paper prioritizes external processes and the role of the context in cognition. In particular, we consider double stimulation and instrument genesis as the basic principles that explain how artifacts constitute external memory fields and exert epistemic mediation. Rather than being a simple part of an observable physical space, we consider EXMF part of a dynamic semiotic field that intersects the boundaries of mental, virtual, and social spaces of activity (Nonaka & Konno, 1998). In order to describe such a dynamic space, we use the concept of heterotopia. Heterotopia was described by Foucault (1967) as "juxtaposing in a single real place several spaces, several sites that are in themselves incompatible". The examples chosen to illustrate this concept are theaters, cinemas, libraries, or ships. This concept led Foucault to predict the birth of a "heterotopological science." If it is applied to our context – education – we may consider the schools and universities as highly complex heterotopias in which heterogeneous physical, relational, organizational, cultural, and virtual spaces overlap and alternate. As in a cinema, where the audience and screen spaces overlap, or in a library, where the physical space

overlaps with both the timeless space of the written pages and the "historicised" space of the culture laid down within those pages, so in a university we can see a complex overlap of heterogeneous spaces. These spaces exist, both in the classroom and in other working spaces – laboratories, textbooks, computer labs, or informal meeting places such as the corridors or the playground.

Learning environments, then, are heterotopias in which multiple EXMF are generated, relying on different types of media. We consider a medium as a space-type within a heterotopia, which mediates the semiotic processes at stake in learning activities and permits the generation of EXMF. As argued above, new media drastically transform the heterotopia that previously consisted of more stable symbolic spaces (initially clay, then papyrus, paper and so on), bringing ESSS that are qualitatively different from old ones, especially in terms of workability and shareability of epistemic artifacts. In this sense, digitalization brings a revolution that involves essentially the "medium" (Ruckriem et al., 2011). Learning environments involving ICT are often multimedia, so that students and teachers are embedded in a diversified heterotopia filled with semiotic resources of different types.

Therefore, educational activities can be said to be *laminated* (Prior, 1998) thanks to the heterogeneity, multimodality and multimedia triggered by the coexistence and by the alternated and/or the combined use of many tools and artifacts. Those artifacts generate multiple semiotic resources useful for the activity and used in a coordinated way by researchers. Besides the spatial frame (semiotic field distributed in tools), also the time frame (in terms of typical ways to organize temporally actions) of the activity is impacted by the features of media. In order to deal with the space-time relations as they are changed by the presence of new media - which introduce, in human relations, changes of proportion, rhythm or schema (McLuhan, 1964) – we use the concept of chronotope (Bakhtin, 1981) that permits to propose a perspective on knowledge creation that is able to capture how the spaces of interaction offered by the instruments impact the temporal organization of the activity and how the management of the work time impacts the selection and the use of different tools. In other words, there is a strong relationship – investigable through the use of the concept of chronotope – between the way in which people organize their time and the way in which they organize (dynamically) the space (full of tools and artifacts) in which activity is embedded. We argue that by carefully investigating those spatial and temporal configurations of technology-mediated practices, and how they change over the instrument genesis process, one may achieve a deeper understanding regarding how new technologies can productively be implemented in educational and knowledge-intensive activity. Although there is research about either space or time in knowledge creation settings, the way in which these dimensions are interrelated with each other has not been on the agenda of scholars.

The concept of chronotope was originally devised by Bakhtin (1981) for understanding how literate genres of novels define specific ways of interconnecting spatial and temporal relations. Adapting the concept to our investigations, we define *chronotope* in ICT-mediated activities as the emergent configuration of temporal and spatial relations in knowledge creation practices as they are impacted by ICT. In fact, the entire flow of activity, in terms of temporally organized sequences of actions undertaken by subjects, is impacted by the use of different types of technology. As shown by Norman (1994), the use of an instrument requires the accomplishment of temporally layered procedures and practices that differ significantly from the practices carried out while using a different instrument for the same purpose. The spatial transformation related to the use of ICT, instead, involves 1) sharing inquiries regardless of location and making remote information sources immediately accessible and 2) interacting with qualitatively different external resources that provide subjects with spaces of interaction organized in multiple ways. Suffice it to think of the difference between the ways in which books are organized in a library from the way in which they are organized in Google books. Technology-mediated practices of working with knowledge, then, both transform the flow of activity and bring qualitative changes when dynamic ICT-based tools are integrated as instruments of activity. Following Bakhtin, we consider these spatial and temporal

processes to be fused: chronotope invoke a whole, so that 'reciprocal impact' of space and time is an approximation in the understanding of the process.

An examination of the chronotope of technology-mediated learning is important because ICTs break many traditional spatial and temporal boundaries of human activity. From our perspective, research on CSCL has serious lacks if it merely focuses on either providing an account of here-and-now practical activity and associated social interaction or analyzing the content of textual artifacts (and ideas involved) generated. In order to obtain comprehensive understanding of the chronotope of technology-mediated learning, such learning has to be studied as multimodal and "laminated" (spatiotemporally layered) activity (Prior, 1998) in which social practices related to epistemic mediation play a crucial role. Following a similar thread from the perspective of classroom pedagogy, Brown and Renshaw (2006, p. 249) have shown how pupils' participation in classroom activities is linked to the way in which they discursively shape "the space-time context of the classroom" and to the way they "ground" their thoughts. In our perspective, we designate by chronotope the emergent pattern of spatial and temporal structure and arrangement of activity within a computer-supported community. Being at the intersection between space and time, it has been characterized elsewhere by a musical metaphor for the analysis of the *tempo* of the flow of activity. So, three chronotopes have been identified, related to different rhythms emergent in collaborative interaction (Ligorio & Ritella, 2010): 1) adagio, characterized by a slow flow of the activity 2) andante, characterized by an acceleration in the flow of the activity and 3) allegretto, in which the configuration of participation allow a fluid and dynamic course of actions. Some specific features such as the "the depth and the size of the space of interaction" and "how participants move around the computer and within the digital space" play an important role in the emergence of chronotope (Ligorio & Ritella, 2010).

Moreover, as we argued previously, the creation of epistemic artifacts impacts the entire practice of knowledge creation and the underlying cognitive processes by altering the space-time structure of knowledge creation. Knowledge-creating learning is mediated by deliberate construction of epistemic artifacts that crystallize the participants' intellectual processes, the evolving network of which guides subsequent inquiry efforts of the participants. The temporal structure of activity is transformed at a very fundamental level in this process. In fact, technology-mediated collaborative learning impacts the context of learning, providing participants with amplified semiotic resources based on integrated and partially merged physical, virtual, social and mental spaces of activity. Pursuit of such artifacts also entails cultivation of corresponding social practices that channel the participants' activities in a way that elicits advancement of inquiry; hence ICT-mediated knowledge practices may define certain chronotopes that allow deliberate collaborative pursuit of knowledge advancement. As mentioned above, expansive stimulation is an integrated aspect of such advancement in that epistemic artifacts provoke a long series of double-stimulation experiences that guide the further direction of inquiry (Hakkarainen et. al., 2009). The following principal features appear to characterize the chronotope of knowledge practices for technology-mediated learning:

- The chronotope is marked by changes in the tempo of the ongoing activity and occasional spatio-temporal intensification of collaborative activity, and it permits us to explain variation in the pace as well in the emerging organization of the collaborative process (Ligorio & Ritella, 2010);
- The chronotope of knowledge-creating learning is mediated by collaborative technology, such as Knowledge Forum, that amplifies and expands the possibility of inquiry of a physically present learning community, generating "blended learning communities" (Ligorio & Sansone, 2009). While other types of virtual learning may have their own chronotopes, they are not the focus of the present investigation.
- The architecture of sophisticated technology-mediated learning is that of a literate culture; consequently epistemic mediation plays a crucial role in the corresponding chronotope. Epistemic

mediation is the principal mechanism of temporal integration between past, present, and future. Thanks to text durability and workability enhanced by the ICTs, past inquiries crystallized in epistemic artifacts transform current distributed problem space and provide anticipatory guidance for directing future inquiry.

- Simultaneously, the chronotope of technology-mediated learning is heterogeneous and multi-modal in nature. If follows that epistemic mediation should not be examined only as an actual production of texts because it involves actions hybridizing and inter-mixing modalities and medias. Typically, discursive activities also involve successive periods of reading and writing, searching information and exchanging emails, thinking and talking, drafting and reviewing, intensive writing and taking a break, and solo and collaborative working. Writing taking place in CSCL is laminated/layered in respect of taking place in the context of heterogeneous networks activities from field trips to classroom experiment, library visits, internet searches and so on.
- The chronotope of technology-mediated learning is also laminated in respect of being locally improvised in conjunction with being mediated by socio-historically developed genre, technology-based instruments, and educational practices (Prior, 1998). So, while the chronotope may be examined in terms of situational and improvised here-and-now activities, it is essential also to address not only micro- but also meso- and macro-level fluctuations and transformations of activity. As explained below, a chronotope of mature inquiry is a developmental achievement that emerges collaboratively through sustained collective efforts.

Collaborative emergence of innovative knowledge practices

Despite two decades of intensive efforts, methods and practices of technology-mediated collaborative learning have not yet fully penetrated educational systems in Finland, Europe or elsewhere. This is partially because there were neither the required technological infrastructure nor human capital (teacher competence) when the practices of technology-mediated learning were first promoted in the 90s. Although the situation has radically changed in respect of building information networks and training new generations of teachers who are familiar with ITC, technology-intensive practices of learning and instruction have not become predominant, beyond exceptional communities and schools. It appears to us that beyond institutional and structural reasons, ICTs in general and CSCL technologies in particular have not penetrated the educational system because CSCL researchers–including the present investigators–have underestimated the in-depth challenges associated with instrument genesis at the personal and collective levels. In particular, we have argued for the necessity to understand the transformations that the ICTs bring in the space-time of learning activities and for the requirement of transforming the cognitive cultural operating system to capitalize on the resources that the new contexts of learning offer. Further, the problem of developing cultural practices of learning that trigger meaningful pedagogical uses of technology has not yet been successfully addressed.

In many cases, participants of our CSCL experiments have been expected to appropriate educational technologies provided and be able to find meaningful practices of using them without questioning pre-existent practices of schooling or reflecting on the role that every technology plays in transforming the context of education. When there are no sufficient opportunities to socialize to the use of technology, it remains as a weakly integrated external tool that does not mediate participants' overall activity. Many CSCL studies focus on one-shot experiments in which a group of students has to learn both a novel pedagogy (knowledge-building inquiry) as well as re-mediate their activities with a collaborative technology. The temporal scope of the experiment is, in many cases, such that the participants cannot truly go through the expansive learning required for instrument genesis, transformation of the participants' cognitive-cultural operating systems, and cultivation of novel technology-mediated collaborative practices of working creatively with knowledge. When ICTs are starting to be used, traditional school learning is likely to prevail with associated personal roles and responsibilities, individual learning tasks and assessments, and patterns of asking fact-

seeking questions and reproductive use of information sources. The technology is initially likely to represent a mere additional layer of activity, and its usage easily involves excessive copying of knowledge. Rooting innovative inquiry practices within a learning community requires sustained iterative and expansive efforts of cultivating shared practices that channel, spatiotemporally, the participants' effort in a way that elicits advancement of inquiry. Although it may be difficult to go through personal and social transformations that the initial rise of innovative technology-mediated knowledge practices requires, new cohorts or generations of students may be directly socialized to advanced inquiry practices that channel their activities in a way that elicits in-depth inquiry, epistemic mediation, collaborative sharing of knowledge and so on (Hakkarainen, 2003). We argue that all successful cultures of CSCL are simultaneously also expansive-learning communities (Engeström, 1987) focused on problematizing current practices, envisioning changes, and gradually, step-by-step, consolidating novel inquiry practices (Hakkarainen, 2004; Hakkarainen, Bollström-Huttunen, & Pyysalo, 2008). The development of practices concerning innovative knowledge-creating inquiry is, then, a collaboratively emergent process (Sawyer, 2005), seldom analyzed by investigators who either pursue one-shot experiments or describe locally created, mature, inquiry cultures. *Collaborative emergence* is a methodological perspective for studying the dynamic and fluid, recursive and iterative aspects of inquiry and evolving knowledge practices (Sawyer, 2005). Detailed multi-level developmental or longitudinal data on transformative personal and collective activities are needed so as to be able to account for such dynamic emergent processes. In fact, directed evolution of practices is elicited by selectively consolidating *ephemeral* (temporally varying patterns of using collaborative technologies and participating in relation to evolving themes and contexts) as well as *stable* (emerging local practices of using ICTs, stabilizing group cultures, enacted discursive practices, collective memory inquiry efforts) emergent possibilities of technology-mediated learning. Through sustained collaborative improvisation, ideas, artifacts, methods and practices that do not belong to any one of the individual participants emerge situationally and interactionally from self-organized collaborative processes (Fleck, 1979). Tensions, ruptures, breakdowns, and discontinuities of activity may be seen as important signs of the collaborative emergence of novelty (Engeström, 1987). Emerging novel elements or aspects of activity break the smooth flow of activity down and push the participants personally or collectively to explore novel possibilities, transform prevailing instruments and practices, and utilize resulting changes in the situation in order to find opportunities to move inquiry forward (Wertsch, 1998). The collaborative emergence of new chronotopes and new knowledge practices may be studied at micro-, meso-, and macro-levels. The micro-level involves analyzing real-time improvisational activity; the meso-level addresses collaborative emergence in pursuing an inquiry project as a whole; and the macro-level involves expansive learning across generations or evolving networks of projects (Blunden, 2010). Through projects emerge collaboratively, ephemeral possibilities that need to be recognized, utilized, extended and stabilized so as to advance inquiry.

Technological and social innovations are interdependent (Batane et al., submitted; Perez, 2001; Venkataram, 1991). Arrival of novel technological innovations encourages hyper-intensive investment in building infrastructure of technology mediated activity. Despite some educators' illusory hopes of solving persistent educational problems, new ICTs are initially used to promote traditional practices of teaching and learning. Only after appropriating and using technologies through intensive iterative efforts for multiple purposes, do radical transformative possibilities start emerging, ones that change the logic and scope of prevailing activities. Going through successive waves or generations of technology-intensive practices of learning and teaching, which involve criticizing and rising above preceding approaches, appears to play a crucial role in ICT-related educational transformations. Although it is not realistic to expect profound overall transformations of educational practices to take place quickly, those communities of students and teachers which are engaged in expansive learning efforts are likely to appropriate new ICT tools, go through personal and collective transformation processes and cultivate "information ecologies" (Nardi & O'Day,

2000), i.e., local practices and innovations of using technology. In order to elicit expansive learning, it is essential to engage participants in practical activities which gradually *integrate* the use of CSCL to shared knowledge practices (Beguin & Rabardel, 2000). On one hand this impacts the perception and the arrangement of the physical and symbolical space of knowledge practices. On the other hand, it requires practice to adapt to a new space and the new time perspective associated with it. Initially fragile and error-prone activities become more stable after corresponding operations and actions become consolidated and the participants' capacity to troubleshoot ruptures and breakdowns improves. Although the participants are likely to be initially dependent on guidance provided by visible ICT mediated objects, structures, and processes, such are gradually replaced by anticipatory response to the likely progress of the situation.

Discussion

The socio-cultural foundations of technology-mediated collaborative learning were addressed in the present paper. In particular, we showed some interconnections between theoretical ideas and traditions that may serve complementary roles in research on technology-enhanced learning. We examined the role of epistemic mediation in knowledge-creating inquiry and the importance of the process of instrument genesis for integrating CSCL technologies with shared inquiry practices. We argued that the cognitive extension and the cumulative expansive stimulation provided by epistemic mediation play a crucial role in complex cognition; consequently, it is of strategic importance to put corresponding knowledge practices in the center of technology-mediated learning. We also emphasized that because ICTs are transforming the learning context, changes of the spatial and temporal frames of learning practices need to be addressed in order to knowledgeably manage the implementation of newel educational environments. Dealing with all of these issues constitutes the integrated agenda of research we are undertaking.

From the sociocultural perspective, it is essential that students engage in using collaborative technologies, creating shareable external digital artifacts for supporting collective knowledge building and personal learning, because this permits them to exploit both the advantages of participating in a dynamic literate culture and the advantages that new media may provide to such cultures (especially thanks to the shareability and workability of semiotic resources that they allow). Scardamalia and Bereiter's (2006) research and development of technologies and practices of knowledge building, aimed at collectivization of learning and inquiry, have played a pioneering role in this regard. Knowledge building is not, however, only a matter of creating, elaborating and sharing ideas; CSCL environments appear to be children of hybridization, providing material technology for sustained working with shared digital (but objectified, and materially embodied) artifacts (Hakkarainen, 2009).

There appears to be discontinuity between CSCL studies that report failures of developing productive practices of using collaborative technologies and those reporting activities of mature CSCL cultures. What appears often to be left between these extreme poles is the instrument genesis – i.e., temporally extended developmental process through which collaborative technologies become instruments of the participants' activities (Rabardel & Bourmaud, 2003). Technology appropriation is difficult because instead of learning discrete and well-specified skills, it requires adapting and changing the cognitive-cultural operating system both at personal and collective levels. Cultivation of knowledge-building practices implies, among other things, extending cognitive resources by deliberately capitalizing on epistemic mediation, i.e., using CSCL environments as instruments for externalizing ideas to digital artifacts forming evolving network intentionally used as a stepping stone of advancing inquiry. The participants have to go through a messy struggle of learning to use writing as an instrument for solving problems, thinking, and extending knowledge (Russell, 1997; Prior, 1998). Changing core epistemic aspects of human activity that epistemic mediation and fruitful participation in knowledge building appear to require, is not possible without extended participation in cultivating corresponding knowledge practices.

Going through the transformation is easier if a participant has an opportunity to gradually socialize and grow up to established and consolidated technology-mediated social practices cultivated by advanced knowledge-building communities. We have these kinds of deeper transformation in mind, when we argue that technology enhances learning only through transformed social practices. Participants have to be able to personally, as well as collectively, align their epistemic activities with technology-mediated pursuit of collaborative inquiry.

Many studies of CSCL are biased because they either focus on shallow here-and-now interaction or they analyze mere ideas (contents of epistemic artifacts) created by participants. Although it is relatively easy either to categorize knowledge produced to CSCL environments' databases or videotape activities around computers, it is much more difficult to analyze instrument genesis and collaborative emergence developmentally across multiple timescales (Lemke, 2001). We are too often carrying out one-shot experiments or relying on retrospective generalizations of past technology-mediated activities (Reis & Gable, 2000). Consequently, only a few investigations have revealed the heterogeneity, hybridity, and multi-modality of enacted CSCL practices or provided rich and multi-faceted descriptions of the longitudinal emergence of innovative inquiry practices. Instead, we have descriptions of poor CSCL implementations in which novel epistemic practices did not have time to emerge, as well as static analyses of mature inquiry cultures that take almost no account of the developmental processes. In order to make progress, it appears essential to initiate developmentally oriented investigations of participants appropriating ICTs as tools of learning and teaching; such studies should aim at acquiring deeper understanding of associated challenges of personal and social learning (Williams, Stewart, & Slack, 2005).

Some of our own investigations involve collecting both longitudinal video data of CSCL practices in conjunction with teacher's reflective diaries and database data; such bodies of data allow one to trace the emergence of collaborative learning and design processes (Viilo et al., 2011). In order to provide an account of collaborative emergence of knowledge-creating practices, multi-level longitudinal data have to be collected. Such data involve real-time video data of enacted classroom practices, screen recordings of ICT-mediated inquiries, contextual sampling of students and teachers' reflective self-report (e.g., project diaries, Bolger et al., 2003), analyses of contents and processes of artifacts at CSCL environment's database, CSCL log files, and possible pre- and post-test measures. It is essential to develop instruments and methods of repeatedly and contextually sampling technology-mediated activities and associated user experiences (Muukkonen et al., 2009). On the basis of these kinds of considerations, we are planning to engage in major efforts in following instrument genesis from primary to higher education level by collecting multi-level qualitative and quantitative data of technology-mediated learning and instruction (data of teachers, students, parents, classrooms, school, and neighborhood); within the frame of an overall longitudinal follow-up study, we will carry out and investigate pedagogic effects of CSCL interventions. Embedding CSCL studies in such broader investigative frame appears essential to give a proper account of instrument genesis, collaborative emergence and psychological and social effects of technology-intensive knowledge practices.

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