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An instrumental perspective on CSCL systems

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Abstract The theory of instrumental genesis of Rabardel relates the social and the technical through the concept of instrument. An instrument is defined as a mixed entity made up by an artifact, the technical/material part, and a set of utilization schemes, the social/behavioural part, which both result from users' constructive activities. This theory is not dedicated to learning contexts, but it can help illuminate many aspects of instrument-mediated collaborative learning situations and CSCL systems. In the first part of this article, the foundational concepts of Rabardel's theory are summarized and discussed. Drawing from that perspective, the second part of the article stresses (1) the complexity of CSCL instrument geneses mainly due to their dual nature –with both teachers and learners involved in the process, and (2) the multifaceted mediating role CSCL systems can play during both task performance and resources elaboration activities. It is argued that the relative importance of teachers and learners during instrumental geneses is the essential discriminating characteristic of CSCL systems. In the resulting categories ("user-instrumentalizable systems" and "teacher-instrumentalizable systems"), the degree to which systems support the constructive activities related to their own development is considered another important differentiating factor. The third part of the article aims at elaborating and illustrating with representative examples of CSCL systems that theory-based classification. The article concludes by suggesting a number of directions for further research in the field.

Keywords Instrumental genesis · Mediating instrument · CSCL systems

Introduction

Many theoretical approaches are used to explain how learning can take place via social interaction over networked computers that mostly derive from constructivist and social cognitivist learning theories. Pierre Rabardel's theory of instrumental genesis (Rabardel 1995a, b), which is rooted in activity and developmental theories, is not frequently used or mentioned in the CSCL field, despite its originality and power. It probably suffers from the fact that it has been mostly published in French and is now mainly developing in the fields of work psychology and

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ergonomics. Rabardel’s approach can be used both at a macro level to analyze the global properties of any kind of instrument-mediated situation and at a micro level to analyze how actual users appropriate a given artifact for a particular purpose in a specific context.

This article proposes a macroscopic analysis of instrument-mediated collaborative-learning situations and CSCL systems based on Rabardel’s approach. Such an instrumental perspective helps identify two essentially different classes of CSCL systems and suggest directions for further research.

The structure of the article is the following. The second section summarizes the foundational elements of Rabardel’s theory that are: (1) a model of instrument-mediated activity situations, (2) a psychological definition of the concept of instrument as a mixed entity made up by an artifact (the technical/material part) and by the subject that uses it by applying utilization schemes (the social/behavioural part), (3) a description of instrumental genesis, i.e., how a subject elaborates his/her instrument, including an instrumentalization dimension, related to the artifact, and an instrumentation dimension, related to the utilization schemes. The theory is contrasted with the previous conceptualizations of mediation and appropriation and its interest for the educational field in general and the CSCL domain in particular is emphasized. The third section analyzes CSCL systems under the lens of the instrumental approach and discusses two main points: (1) the complexity of their instrumental genesis, and (2) their multifaceted mediating role during both task performance and resources elaboration activities. It is argued that the relative importance of teachers and learners during instrumental genesis is the essential discriminating characteristic of CSCL systems. The two resulting classes, termed “user-instrumentalizable systems” and “teacher-instrumentalizable systems,” are analyzed in the fourth section. The degree to which they mediate the constructive activities related to their own development is considered another important differentiating factor. The fourth section aims at elaborating and illustrating that theory-based classification of CSCL systems. Representative examples of CSCL systems in each category are discussed. The article concludes by suggesting a number of issues for the different classes of CSCL systems, which should be considered for further research.

An overview of Rabadel’s theory of instrumental genesis

Pierre Rabardel is developing a theoretical framework for the analysis and conceptualization of activities with instruments. The starting point of his analysis is a criticism of techno-centric approaches that tend to reserve a residual place to human activity. In these approaches, spontaneous human initiatives are considered “to disrupt, or even damage, the operation of expert automates and machines” (Rabardel 1995a, b). Rabardel favors an anthropocentric approach in which humans occupy a central position and the place of technology is defined in relation to them. He proposes a conceptualization of the mediating instrument based on such an anthropocentric point of view. His research is grounded in constructivist epistemologies, primarily in activity theories, and more precisely on the Vygotskian concept of mediation and the Piagetian concept of scheme. These relations will be further discussed after the presentation of the theory, in the last subsection.

A model of “instrument-mediated activity situations”

An activity consists of acting upon an object in order to meet a goal. In most cases, the relationship between the subject and the object is not direct, but involves the mediation of an instrument. The “Instrument-mediated Activity Situation” model (IAS model), shown in

Fig. 1, brings out the multiplicity of relations between these three different poles: (1) the subject S (user, operator, worker, agent, learner, etc.), (2) the instrument I (tool, machine, system, utensil, product, etc.), and (3) the object O towards which the action, aided by the instrument, is directed (matter, reality, object of work, etc.) Beyond direct subject-object interactions (S-Od), three other forms of interaction must be considered: interactions between the subject and the instrument (S-I), interactions between the instrument and the target object (I-O), and chiefly subject-object interactions mediated by the instrument (S-Om).

The "Collective Instrument-mediated Activity Situation" model (CIAS model), shown in Fig. 2, adds a fourth pole for describing the new situations linked to the emergence of instruments for collective work. In addition to the previously listed relation types between subjects, objects and instruments, the CIAS model includes interaction types between the subject and other subjects, either direct (S-OSd) or mediated (S-OSm).

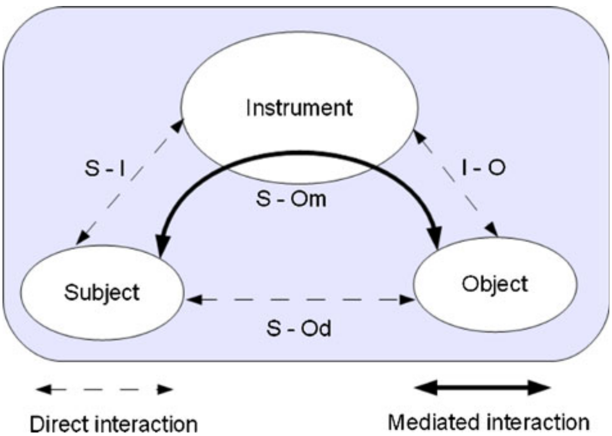
It is mainly with reference to the object that the instrument plays a role of mediation (S-Om). Rabardel distinguishes between two kinds of subject-object mediation. (1) The "*epistemic mediation*" is oriented toward the comprehension of the object, its properties and its evolutions resulting from the subject's actions. For Rabardel, the microscope is a good example of an instrument organized around this first kind of mediation. (2) The *"pragmatic mediation"* is oriented toward the transformation of the object and the achievement of results. For Rabardel, the hammer is a good example of an instrument organized around this second kind of mediation.

The interpersonal mediation between subjects (S-OS and S-OSm in the CIAS model) may also be epistemic or pragmatic in nature depending on whether it is a question of knowing others or acting upon them (Rabardel and Bourmaud 2003).

In Rabardel and Samurçay (2001), the approach is widened for taking into account that the subject does not only relate to the object and to the others, but also relates to him/herself. The "reflexive mediation" (also called "heuristic mediation"), must be taken into consideration when the subject's relation to him/herself (knowing, managing, and transforming) is mediated by the instrument. It would be represented by a subject-instrument-subject link (S-Sm) in both Figs. 1 and 2. Vygotsky has proposed the knot in a handkerchief as an example of instrument organized around the reflexive mediation, as it is destined to remind people to remember something.

Every instrument is potentially a mediator for all these relations. This can be termed "multimediation". However, as it will be shown later, one or other of the relations most of the time dominates.

Fig. 1 The tripolar IAS model



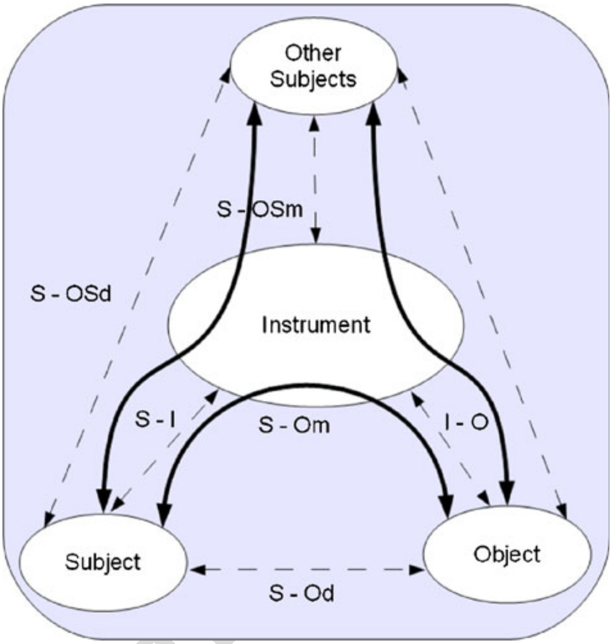


Fig. 2 The quadripolar CIAS model

The instrument as a mixed entity

Rabardel proposes a definition of the concept of instrument as a compound entity built up from an artifact (the technical/material part) and from the subject that uses it, by applying utilization schemes (the social/behavioural part). The term “artifact” may designate any collection of material and symbolic objects produced by the subject himself or by others. An artifact only becomes an instrument through the subject’s activity. For instance, two learners that use the same scientific calculator (artifact) may have different utilization schemes, and therefore different instruments. The term “utilization scheme” designates a cognitive structure that describes an invariant organization of behavior for a given class of situations (Vergnaud 1998), including both technical and conceptual aspects. As they cannot be observed directly, analysts focus on more or less stable sequences of interactions between the user and the artifact with a particular goal, which constitute their observable counterparts.

More precisely, Rabardel distinguishes three categories of utilization schemes. (1) Usage schemes are oriented “towards ‘secondary tasks’ corresponding to the specific actions and activities directly related to the artifact” (Rabardel 1995a, b). Q7 For example, in the case of a digital camera, usage schemes define how to use buttons, dials, and the menu system for interacting with the artifact (Folcher and Rabardel 2004). (2) Instrument-mediated action schemes “consist of wholes deriving their meaning from the global action which aims at operating transformations on the object of activity. They incorporate usage schemes as constituents and are related to ‘primary tasks’. They make up what Vygotsky called ‘instrumental acts’, which, due to the introduction of the instrument, involve a restructuring of the activity directed towards the subject’s main goal” (Rabardel 1995a, b). Q8 In the case of a digital camera, instrument-mediated action schemes are related for example to composing the photo and shooting (Folcher and Rabardel 2004). Rabardel and Bourmaud (2003) give a more realistic example related to a complex maintenance activity. A "reassignment scheme" describes how an organizer manages a request for an urgent intervention that implies the cancellation of an old assignment and a reassignment shortly afterwards. This action scheme constitutes an invariable structure with five successive steps. It is intimately associated to, and results from, the "activity table" artifact used by the organizers. The instrument for the reassignment situation is the mixed entity that associates the activity table artifact with the reassignment scheme. (3) Instrument-mediated collective activity schemes are associated with collective activities. They specify "the types of actions, the types of acceptable results, etc., when a group shares a same instrument or works with a same class of instruments. They also concern the coordination of individual actions and integration of their results as a contribution to the achievement of common goals" (Rabardel 1995a, b). For example, Cerratto (2005) studies collective activity schemes for integrating individual texts into a collective production during collaborative writing. Overdijk et al. (2008) describe the emergence of collective schemes as a progressive development over three stages: personal mastery ("corresponding to conscious, goal-directed actions oriented towards performing basic actions"), personal utilization (when "basic actions become non-conscious operations"), and collective utilization (when learners "coordinate their interaction with the artifact towards the common object"). The transition from personal to collective utilization may require learners to explicate and negotiate divergent personal utilization rules.

Utilization schemes can have a private and a social dimension. "The private dimension is specific to each individual. The social dimension comes from the fact that schemes develop in the course of a process in which the subject is not isolated" (Rabardel 1995a, b). Other users, as well as artifact designers, can contribute to the emergence of schemes. They "can be the object of more or less formalized transmissions and transfers": information passed on from one user to another, training, different kinds of users' support like classical instruction manuals, users' guides and various other supports introduced or not in the artifact itself. The term "social utilization scheme" is used by Rabardel for emphasizing the social nature of some schemes. It should not be confused with the fact that some of the social utilization schemes are relative to collective activities (collective activity schemes).

An analysis in terms of utilization schemes can reveal, at a micro level, how actual people appropriate and use instruments in a particular setting. A representative example can be found in Restrepo's thesis (2008), which studies the dragging process in a dynamic geometry software in terms of both usage schemes (such as "dragging an object" or "distinguishing the different types of points"), and instrument-mediated action schemes (such as "dragging for validating a geometrical construction" or "verifying that two straight lines are perpendicular"). Restrepo's work focuses on the elaboration of these schemes and the possible difficulties that students may encounter.

Instrumental genesis - the development of instruments

The appropriation and elaboration of an instrument, called "instrumental genesis," is a non-trivial and time-consuming process that is influenced by the two dimensions of the instrumental entity that are the artifact, with its potentialities and constraints, and the subject, with his/her knowledge and former working habits. Rabardel differentiates two sub-processes, artifact-oriented and subject-oriented, which jointly contribute to instrumental genesis. (1) The instrumentalization process concerns the emergence and evolution of the artifact side of the instrument: "selection, regrouping, production and institution of functions, deviations and catachreses, attribution of properties, transformation of the artifact (structure, functioning, etc.)" (Rabardel 1995a, b). "Catachresis" is the linguistic concept of using a word in place of another that has been extended to the use of an artifact in another way than it has been designed for. Three levels of instrumentalization may be considered. First, an instrument is momentarily instrumentalized for a particular action and the specific circumstances under which that action occurs. It is the case, for example, when a wrench is used as a hammer. Second, the new function is more permanently linked to a class of situations. It is the case for example when a discussion forum is used as a synchronous meeting tool. The instrumentalization is lasting if not permanent. For these first two levels the artifact itself is not changed, but simply takes on new properties for a subject. Third, the artifact can be permanently modified in terms of its structure so as to perform a new function. It was the case in the previously evoked example (Rabardel and Bourmaud 2003) when the "activity table" document has been changed for better supporting the reassignment of operators with the creation of a specific area for noting down cancelled interventions not yet reassigned. There is a shift from the idea that a user's knowledge guides the way the artifact is used and "shapes the artifact" in a weak sense to the idea of an actual transformation of the artifact structure and functioning. (2) The instrumentation process is relative to the emergence and evolution of the human side of the instrument, i.e., its utilization schemes: "their constitution, their functioning, their evolution by adaptation, combination, coordination, inclusion and reciprocal assimilation, the assimilation of new artifacts to already constituted schemes, etc." (Rabardel 1995a, b). Q12

These two processes are distinguished by their orientation: the instrumentation process is directed toward the subject, whereas the instrumentalization process is directed toward the artifact component of the instrument. In the instrumentation process, the subject develops, while in the instrumentalization process, the artifact evolves. In other terms, subjects are intentionally engaged in activities of task performance, called "productive activities," and simultaneously engaged in activities of elaborating resources, called "constructive activities". Constructive activities concern "the development of the subject's internal and external resources as a whole, i.e., instruments in terms of their psychological and material components" (Rabardel and Samurçay 2001). All previously mentioned forms of mediation (epistemic, pragmatic, reflexive and interpersonal) can occur within both productive and constructive activities.

This developmental view of instruments has three important consequences. First, the study of an instrument is "the study not of an object, but of a process, the genesis of its significance to a particular user for a particular purpose" (White 2008). Q13 Second, it changes the way the design process is understood, as users become actors of the overall design movement, though clearly in a different way from what Rabardel calls the "institutional designers". A technical artifact is "merely a proposal" to the subject (Rabardel 1995a, b). Q14 Its design is continued in usage: the extrinsic and constituted functions and properties extend the intrinsic and constituting functions and properties. Instrumental genesis is thus part of an overall cyclic process whose actors are both institutional designers and users (see Fig. 3). Redesign is inspired by the constituted functions and the utilization schemes: the new design can either follow them or sometimes take a radically opposite direction (Galinier 1997). Third, the developmental view of instruments leads to the idea of building "instrumentalizable artifacts". As highlighted by Rabardel (1995a, b), Q15 "Contemporary artifacts seem to be evolving toward an inscription in their structure of functionalities facilitating their instrumental adaptation in line with the user's needs or wishes". This point is central to the discussion of CSCL systems that follows.

Discussion

This subsection relates Rabardel's theory of instrumental genesis to the main theories on which it is based. Some influences that are less directly related to the purpose of the article

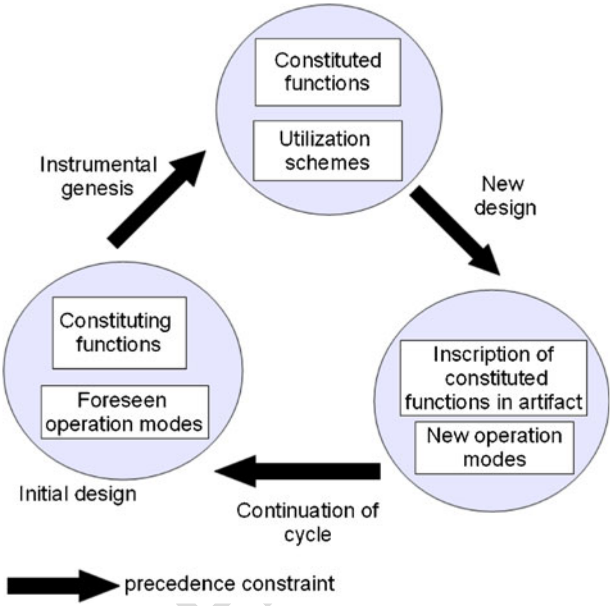


Fig. 3 The overall cycle of designing an artifact

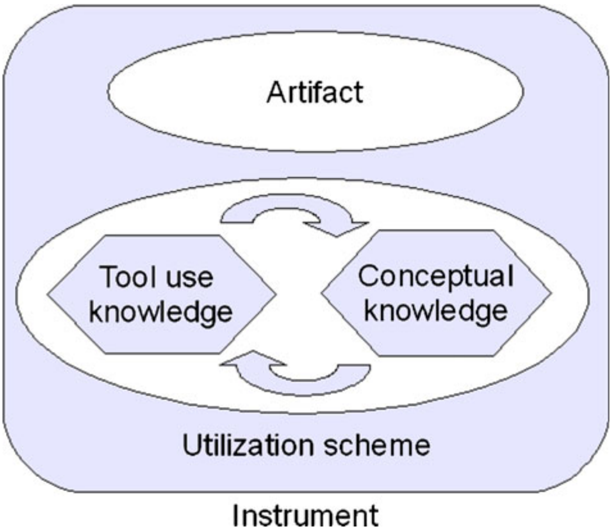
are not examined in detail. It is the case, for example, of participatory design approaches, which are discussed by Béguin (2003). The aim is to emphasize those concepts that expand and refine prior theoretical constructs and show the global relevance of the theory of instrumental genesis for the educational field in general and the CSCL domain in particular. A few recent works from researchers in the same school of thought who have extended Rabardel's contribution to collective aspects of tool-use are also included in the discussion.

Rabardel essentially adopts Vygotsky's central concept of object-oriented, artifact-mediated activity (Vygotsky 1978). Rabardel argues that Vygotsky lays the ground for a general framework of a tool-use theory, but fails to develop one that considers the differences and similarities of various artifacts and the way they are used as means to mediate human activity. Vygotsky fundamentally distinguishes between two kinds of mediation and artifacts, namely mediation by "material tools," and mediation by "psychological tools." Material tools, like a hammer, are "externally oriented" and represent a means for the subject to act "on the material world". Psychological tools, like language or other symbols, are "internally oriented" and represent a means for the subject to act "on his/her own psyche or that of others" (Rabardel 1995a, b). For Rabardel, this distinction between material and psychological tools, and other possible categories like semiotic tools (Cuny 1981) or cognitive tools (Rogalski and Samurcay 1993), is not pertinent, as the same tool can have different orientations. Rabardel (1999) aims at defining a general theory for all the different kinds of tools, regardless of their nature (symbolic, material, conceptual, internal or external) and their direction (external, self or others). In his approach, the different forms of mediation (epistemic, pragmatic, reflexive, and interpersonal) enables analyzing "the differences and similarities of all the different kinds of tools" (Kern 2008). Such unified perspective is of great interest for analyzing and designing redundant collections of heterogeneous tools, which are quite frequent in the CSCL field.

The concept of a utilization scheme that draws on Jean Piaget's notion of scheme (Piaget 1968) is of primary importance for investigating how people learn with tools. Piaget explains knowledge construction and learning by three elements: (1) schemes (the organization of information on how things work), (2) assimilation (integrating exterior elements into existing schemes), and (3) accommodation (developing schemes in order to integrate the environment). Learning is the predisposition of an individual to adapt to his environment, which means establishing equilibrium between the schemes and the environment. Continuous interactions among existing schemes, assimilation, accommodation, and equilibrium create new learning (Kern 2008). In Rabardel's view, utilization schemes include both domain-related conceptual knowledge and tool-use knowledge. For example, the development of a scheme for setting the viewing window in the graphing module of a symbolic calculator requires tool-use skills for setting the dimensions of the viewing window, but also related insights that through the window only a small part of an infinite plane can be displayed (Drijvers and Trouche 2008). During instrumentation, techniques for use and insights into concepts are intertwined and co-evolve in a close relationship (see Fig. 4). That makes Rabardel's instrumental approach particularly well adapted for investigating the relation between tool use and learning and designing technology-rich learning practices.

Even if Rabardel emphasizes individual and social dimensions in schemes, his approach is insufficient for explaining the dynamics between individual and collective aspects of tool-use (Kern 2008), which is central in the CSCL perspective. He only introduces the idea of a "shared functional zone" that allows exchanges and interactions about the functional value of socially constructed artifacts (Rabardel 1999). The work of Yves Clot, a French work psychologist who has often collaborated with Rabardel, complements well the theory of instrumental genesis in the collaborative direction. Clot transposes Bakthin's concept of "speech genres" (Bakhtin 1986) into "activity genres" and uses the concepts of "genre" and "style" to conceptualize the dynamics between individual and collective activity. The genre groups collective elements while the style reflects individual elements of the activity. The genre is defined as "an open system of unwritten impersonal rules that define in a certain habitat the usage of objects and the exchange between subjects" (Clot 1999). It can be seen as a social memory, "a fabric of support incorporated as a resource" (Roger et al. 2007) and, therefore, as a basis for stability: routines and rules are "memorized" within genres. Genre is clearly related to Bourdieu's notion of habitus (Bourdieu 1980), defined as the set of socially learnt dispositions, skills and ways of acting. At the same time, genres are also the source for change. The articulation between individual activity (style) and collective activity (genre)

Fig. 4 Rabardel's concept of instrument



can be understood in the following way. In collective activity each individual develops his own style. This style can be seen by the co-workers. “If it is convincing and effective” co-workers can imitate it (Lorino 2006). They can integrate this style in their activity, finally resulting in a variation of the genre. When creating a style, the individual must distance himself from the genre and transgress it. The subject has also to distance himself from his own history, his former styles, and to transgress those. Clot and Faïta observe that “at the crossing of these two lines creation is conflict” (Clot and Faïta 2000). Two opposite movements can be observed when creating a style: either it can lead to the development of the genre or the individual style is adapted to the genre: “activity is a permanent theatre of the movement between two opposite directions: stylization of genres and variation of oneself” (Clot and Faïta 2000). But if the agent does not master the genre he cannot elaborate different styles. Styles continually transform genres. Concerning the creation of styles it is crucial that the subject should have access to a repertory of variations of the genre or even a repertory of different genres. To look at a genre with the lens of another genre, being able to act in a genre with the resources of another genre is essential for the creation of styles (Clot 1999). In terms of Rabardel’s theory, the concept of genre can be considered a shared artifact expressing a “social utilization scheme.” Instrumentation of a genre, through the complex processes of “stylistic innovation” described above, produces a style, which is an individual “utilization scheme”. A “collective activity scheme” is a specific kind of “social utilization scheme” that is relative to a collective activity. Table 1, adapted from (Kern 2008), summarizes the relationships between the concepts proposed by Vygotsky, Rabardel and Clot for dealing with the individual and social dimensions.

An instrumental view of CSCL systems

Analyzing CSCL systems in terms of the instrumental approach is not straightforward for three main reasons: complexity, duality, and group-orientation.

Complexity In most cases, a CSCL system is a large collection of complementary and partly redundant instruments that Rabardel and Bourmaud (2003) call an “instrument system”. Several instruments can be associated with each service that is provided including, but not restricted to, interpersonal communication, collaborative knowledge building, collaborative process management, and awareness of what others are doing and thinking. Collaborative knowledge building is generally supported by shared workspaces that give access to various representational instruments such as texts, drawings, semi-formal or formal models. Working with these representational instruments enable learners to externalize their own knowledge and make it available to others. Ideas can be connected, reinterpreted, and expanded. Contradictions and opposing views may be revealed, discussed, and used for

Q20 **Table 1** The collective and the individual

Author	Tool	Prescribed scheme by the collective	Individual scheme
Vygotsky	Material or psychological tool	Cultural-historical context	Individual tool-use
Rabardel	Artifact	Social utilization scheme (including the concept of collective activity scheme)	Utilization scheme
Clot	Task description	Activity genre	Activity style

constructing new knowledge. The complexity stems not only from the number of instruments, but also from the fact that each instrument can perform one or more functions anticipated by the designers as well as other functions developed by learner-users, and the fact that the choice of a given instrument among all those that share the same functional value depends on "the particular characteristics of situations" (Rabardel and Bourmaud 2003).

Duality Like all educational tools, CSCL systems are instruments both for learner-users and teachers. This duality of influences increases the complexity and unpredictability of instrumental genesis. For learners, tools strongly influence the way knowledge is constructed and the conceptualization processes, through their properties (constraints and potentialities). For teachers, tools can be considered "variables that can be acted upon for designing and controlling the pedagogical situations" (Rabardel 1995a). Drijvers and Trouche (2008) analyze the instrumental genesis process for teachers: (1) "Teachers, when experimenting with resources in their classes, modify these resources, incorporating in them their own experiences. This is the instrumentalization side." (2) "Resources, when implemented by teachers in their classes, contribute to modify their practices. This is the instrumentation side."

Group-orientation Unlike for most educational tools, in the case of CSCL artifacts a community of user-learners is involved. Rabardel's approach has mainly considered instrumental genesis at an individual level, where a subject selects the most familiar tool, in order to avoid the efforts required to learn a less familiar one ("economy principle"), and uses it, sometimes in unanticipated ways, for achieving the goals that are considered important ("search for efficiency principle") (Docq and Daele 2001). The collective case has been conceptualized through the already evoked concepts of "genre" (Clot 1999), and through the concept of "use framework" (Flichy 1995), which corresponds to the construction "at one time and by a community of users of a social representation about the possible uses of a new tool." These social representations "have to be negotiated between the community users so that everyone shares those representations" (Fazzini-Feneyrol 1995). The collective instrumental genesis process is equivalent, at least for its instrumentation side, to the shared building of a "use framework". This process "is oriented by the activity to achieve and not by the wish to use the tool in accordance to the instructions of use" (Docq and Daele 2001).

Many issues arise from these considerations. This article specifically addresses two of them that can be stated as follows:

(1) How the complex collective instrumental genesis process of CSCL systems is structured and what are the respective contributions of teachers and learners?
(2) To what extent a CSCL system can mediate its own collective development process?

A multi-staged collective instrumental genesis process

The development of CSCL instruments can be broadly conceptualized as emerging from dialectics between institutional designers, teachers and learners. In contrast to work situations in the Computer-Supported Collaborative Work field, instrumented learning situations in the CSCL field are intentionally constructed for specific pedagogical purposes by designers and teachers. The initial design stage and the possible redesign stages of the artifact by its institutional designers are not discussed thoroughly here. The focus is on the core part of the process when the CSCL artifact becomes an instrument for a specific learning situation. It is understood in this work as involving two different phases as shown in Fig. 5.

During the "preparation phase" the CSCL artifact is customized by the teacher who prescribes its use, possibly with the help of educational and engineering technologists. Hakkarainen (2009) speaks of "shaping, adapting, and tailoring the artifact according to the local needs and requirements of activity". The verb "customize" is used to designate any kind of technical change to the artifact. As explained previously, instrumentalization is a broader concept that includes also selection, regrouping, institution of functions, deviations and catachreses, attribution of properties, etc. This "preparation phase" is based on didactic and domain knowledge, together with contextual factors such as learners' traits. It may be quite simple for elementary tools (e.g., description of a discussion topic and registration of the authorized users), or very complex for deeply customizable systems (e.g., parameterizing/selecting/integrating components, designing/coding/verifying enactable process models, specifying groups and assigning roles, etc.).

During the "use phase" teachers, playing the role of tutors, and the community of learners collaborate through the instrument system. Instrumentalization can continue at the initiative of either learners or tutors, in parallel with instrumentation that "focuses on developing and cultivating personal and collective practices needed for productively using the artifact as an instrument in knowledge-building activity" (Hakkarainen 2009). A three-stage model of instrumentation in collaborative learning settings (Overdijk et al. 2008) has already been described in a previous subsection. Instrumentalization by learners can modify not only their personal parameters, but also the global functioning of the whole system. Thus, it should be a part of the overall collaborative activity. It should also match teachers' didactic choices. Haspekian (2005) speaks of the "didactic accompaniment of instrumental genesis".

It is argued in what follows that the relative importance of teachers and learners during the instrumentalization process of the "use phase" is the essential discriminating characteristic of CSCL systems.

The multifaceted mediating role of CSCL systems

At a very abstract level, Rabardel (2000) has characterized any educational setting by the following properties. (1) Teacher and learners are the subjects; (2) The instrument-mediated activity is oriented towards knowledge and competencies that learners need to develop; (3) The learning instrument mediates subject to subject relations, subject to object relations (epistemic and pragmatic forms of mediation), and the reflexive relations from each subject

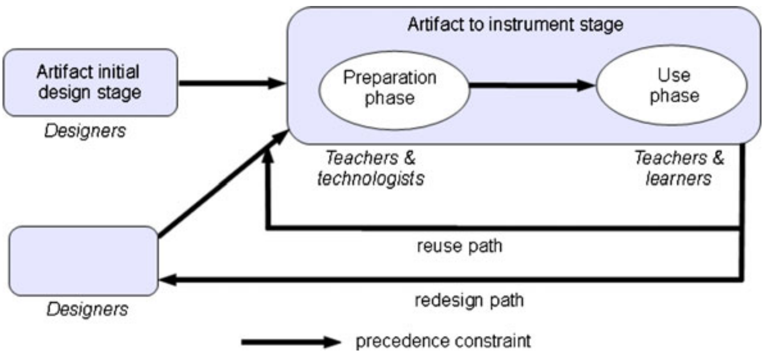


Fig. 5 Genesis of a CSCL instrument

(teacher or learner) to him/herself, as depicted in Fig. 6. This subsection characterizes, at a greater level of detail, instrumental mediations that take place during the two above-defined "preparation phase" and "use phase".

During the "preparation phase" teachers and technologists are the subjects. The instrument-mediated activity is oriented towards the initial instrumentalization of the CSCL artifact by the subjects in accordance with didactic and domain knowledge (target knowledge and competencies, collaborative task to be performed, roles and interaction rules, etc.). Learners are not directly involved in that phase. They will participate in the instrumentalization process later, during the "use phase," as discussed in the next subsection. In theory, the instrument system should mediate all the relationships shown in Fig. 7. (1) At the epistemic level, for accessing didactic knowledge (e.g., process models describing how collaborative learning processes may be organized, repository of components and associated usage scenarios) and domain knowledge (e.g., domain ontologies). (2) At the pragmatic level, for performing CSCL artifact customization. (3) At the interpersonal level, for supporting interactions between teachers and technologists. (4) At the reflexive level, for reflecting on the way the system has been actually used by different groups of learners in different configurations, for example, through post-mortem analysis of previous collaborative learning sessions. In practice, most of these activities can be detached from the CSCL system, with the obvious exception of those directly related to the system customization. An interesting research direction is to design a dedicated web environment that provides high-value services to a virtual community of practice (Wenger 1998) for all the other activities, such as the collaborative design of learning situations, the selection of the most appropriate instruments for a given situation, the evaluation and improvement of instruments on the basis of experience reports from teachers –see the "reuse path" in Fig. 5, etc. (e.g., Guin et al. 2008; Lonchamp 2007a, b, c). Q24

The dissemination of ideas among a larger community of interest could also be supported by such a dedicated web environment. It is thought to be used by a wide and geographically distributed audience that collaborates asynchronously for a long period of time. On the

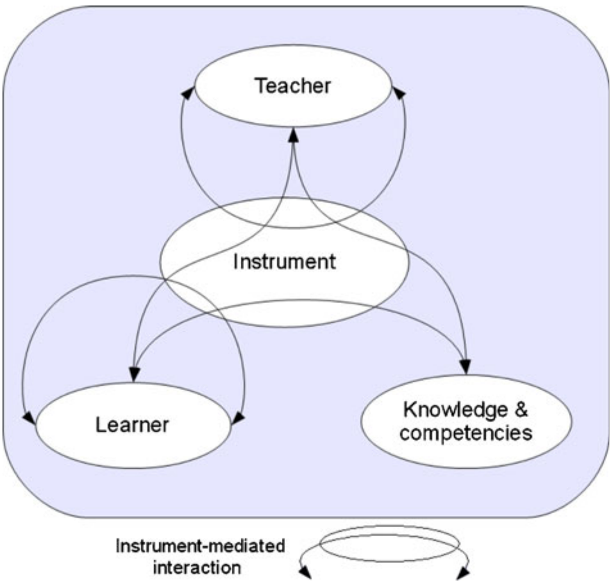


Fig. 6 Instrumental mediations in the educational field (Rabardel 2000)

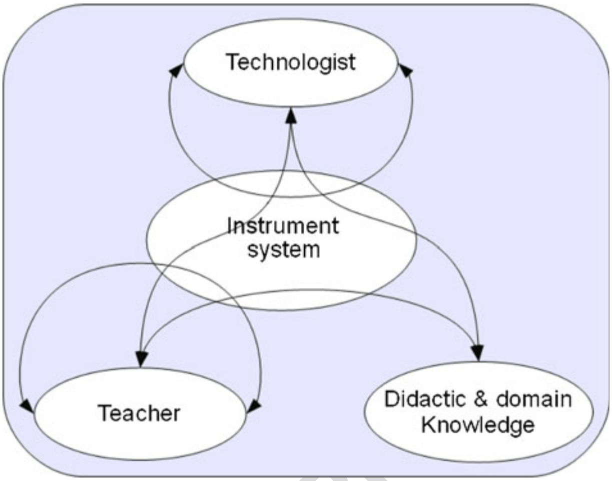


Fig. 7 Instrumental mediations during the "preparation phase"

opposite, system customization is performed by a few people who collaborate synchronously during a short period of time, or even by a single person.

During the "use phase," learners, peers, and tutors are the subjects. The instrument-mediated activity is oriented towards the collaborative development of knowledge and competencies and the continuation of instrumental genesis. The instrument system should mediate all the relationships shown in Fig. 8. (1) At the epistemic level, for understanding the situation (shared knowledge objects, collaborative knowledge building process, etc.). CSCL puts a specific emphasis on instruments for flexible linking of all information related to knowledge objects, processes, and people. (2) At the pragmatic level, for performing learning activities (building and organizing knowledge objects, managing the collaborative process, etc.) and continuing instrumental genesis. This last point, which implies that CSCL systems can mediate their own instrumentalization during the "use phase" is important and will be explored with more detail later. (3) At the interpersonal level, for managing social relations and linking people. (4) At the reflexive level, for reflecting on learning and tutoring processes.

Artigue (2002) suggests that epistemic mediation dominates in the case of educational instruments while pragmatic mediation is central for instruments in the workplace. The

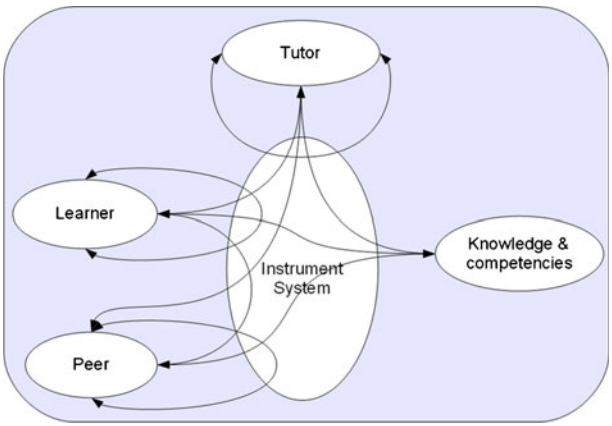


Fig. 8 Instrumental mediations during the "use phase"

review in the next section reveals a more complex picture for CSCL systems that either support all forms of mediation or privilege one form over the others. Instrumentalization during the "use phase," also called "dynamic instrumentalization" in this work, is a complex process that can go through different stages: discovery and selection of the more relevant functions, institution of new functions, and transformation of the artifact sometimes in directions unplanned by the designer. According to Rabardel (1995a, b), the first solution to support dynamic instrumentalization is to design flexible systems that users can adapt, by selection or transformation, to their needs while they use them. It is possible as "contemporary systems are perhaps, more so than those born of traditional technologies, unfinished in a sense and thus open to a range of possibilities in terms of functionalities". Changing the constraints that the system enforces during its usage may require more or less complex techniques supported by specific "functionalities facilitating the instrumental adaptation" (Rabardel 1995a, b). The next section will analyze how this is currently implemented in CSCL systems. Beyond technical aspects, dynamic instrumentalization is also difficult because the nature of the potential modifications may be hard to envisage (Béguin and Rabardel 2000): subjects must have a clear vision of the task to accomplish and a deep understanding of the system, its usage, and the way it works. This could be difficult to achieve for most teachers, who should be on the look-out for the constituted functions and new practices of learners. The second way to support dynamic instrumentalization is to alternate formal design phases and utilization phases (Rabardel 1995a, b). It is only possible if institutional designers are aware of the actual operating modes used by the subjects. Instruments that aim at supporting the community of practice, previously evoked, could be the right place for direct and indirect communication between users and institutional designers, for instance, by means of experience reports and trace analysis—see the "redesign path" in Fig. 5. In the particular case of open source CSCL systems, the term "institutional designer" may refer to all interested developers around the world. Jones et al. (2006) reach similar conclusions when they characterize (1) "a flexible approach to design in which designed artifacts are thought of as shells, plastic forms that incline users to some uses in particular but are available to be taken up in a variety of ways and for which the enactment of preferred forms depends upon the relationships developed in relation to learning" and (2) user-centered design approaches "where designers and users collaborate closely in the design process."

Learner- versus teacher-instrumentalizable systems

Rabardel's theory emphasizes the importance of instrumental genesis as a two-way process. There is dialectic between the subject acting on his/her personal instrument (instrumentalization) and the instrument acting on the subject's thinking (instrumentation). In the case of CSCL systems, the process is highly complex due to its dual (teacher/learner) and collective nature (community of learners). Two radically different conceptions can be clearly distinguished in the CSCL domain. (1) In the first conception, instrumentalization by learners during the "use phase" is considered a fundamental ingredient of collaborative learning directed to competencies and meta-skills development. In general, this view is implemented by large instrument systems (learning spaces) that aim primarily at opening a wide range of possibilities. Learners collectively select the instruments (into the "range of possibilities" evoked by Rabardel) and practices, which are the most adapted to the complex problem they deal with during sustained asynchronous collaborative learning processes. In other terms, they build their own contingent "places" from general "spaces" (Harrison and Dourish 1996). In the following, systems in this first category are called "learner-instrumentalizable systems". (2) For the second conception, instrumentalization by teachers dominates, both during the "preparation phase" for adapting the system to the learning situation they define, and during the “use phase” for reacting to the contextual characteristics that differentiate each learning context from the others. Systems in that second category, called “teacher-instrumentalizable systems,” generally enforce a predefined way of learning that learners are expected to follow and internalize. They mainly support short-term synchronous processes during which learners are constrained and guided (“scaffolded”) by the customized instruments.

That distinction can be related to the classical dichotomy between (1) technology as predefined “embodied structures” that determine the use, and (2) “emergent structures” (or “enacted structures”) that are constituted in the actual use (Orlikowski 2000; Widjaja and Balbo 2006). In the case of “teacher-instrumentalizable systems,” designers and teachers define the embodied structures which are appropriated by users during their use of the technology. The interest of the previous analysis of instrumental genesis of CSCL systems is to make explicit by whom and when these embodied structures are defined. This work highlights the tendency to complement the work of institutional designers during the initial design phase by additional contributions from the teachers during the preparation phase and more and more noticeable contributions from teachers during the use phase. In the case of “learner-instrumentalizable systems,” structures emerge during the “use phase” through learners’ activity.

The next section gives an overview of recent developments in the two categories of systems and specifically addresses the question about the degree to which they can mediate their own instrumentalization.

A classification of CSCL systems

Learner-instrumentalizable systems

Learner-instrumentalizable systems offer a wide range of possibilities through a set of complementary and possibly redundant instruments. The group of learners is encouraged to perform the kind of instrumental adaptation they feel useful during the “use phase” for reaching their common goal. Adaptation is mainly performed by selecting progressively the most relevant instruments and self-elaborating their collaborative practices. Instruments and practices are interdependent and both evolve in the course of social activity. Collective instrumental adaptation is considered a central element of the learning process. Beyond domain-related knowledge, learners will also develop meta-level skills for working together and self-organizing. “The end results of inquiry processes are not only the artifacts, but also the transformed personal and collective practices” (Hakkarainen 2009). Meaningful adaptation by learners takes time to develop. This kind of approach requires both a complex and preferably authentic problem to grasp, and a sustained effort that generally lasts weeks or months, with users contributing from time to time in an asynchronous way.

The Knowledge Practices Environment (KPE) is a recently-developed representative example of learner-instrumentalizable system (Lakkala et al. 2009). Its underlying approach is “trialogical learning.” According to Dondi et al. (2011), learning is trialogical if (1) it is learner-centred, (2) it involves a community of learners, (3) it is long-term work on open-ended “real-life” tasks, (4) it is centred around the creation of reusable artefacts that enhance the knowledge of the whole group, (5) the process of collaborative knowledge-creation is made explicit, (6) it is supported by technology. KPE is described by its designers as a web-based application “which is designed to provide specific affordances for joint development of concrete epistemic objects, as well as for planning, organizing and reflecting on related tasks and user networks. With KPE, users are able to build collaborative environments by creating and configuring the means, as opposed to operating in predefined structures, of the common practice." This predominant role of learners does not mean that teachers do not play an important role: as a "learner facilitator" teachers may, among other things, facilitate emerging knowledge creation processes, help learners explicate their tacit knowledge, ensure their knowledge artifacts are created for re-use, and foster boundary crossing collaboration (Dondi et al. 2011).

KPE is a large collection of partly redundant instruments that support all forms of mediations. Learners can select and combine them for building their own "place" from a general "space," in order to reach their common objectives. Table 2 relates the most important instruments in KPE with the dominant mediation they can be associated with.

Synergeia (Stahl 2004) and FLE3 (Leinonen et al. 2003) are two precursors of KPE that also offer a set of complementary and possibly redundant instruments (such as threaded discussions, thinking types, concept mapping, or document sharing). Learners can select and appropriate them for self-elaborating their collaborative knowledge construction practices. However, as a difference from KPE, they include a few elements that aim at constraining learners' actions and interactions, which are defined by teachers. These elements could blur the distinction between learner-instrumentalizable systems and teacher-instrumentalizable systems. But, they have a limited scope, and learners' self-organization remains the fundamental rule. In Synergeia, when a new knowledge building area is created (during the "preparation phase"), the teacher can select which set of "thinking type" categories will be used: "knowledge building," "scientific theory," "negotiation," "debate," "discussion" or "brainstorming." In FLE3, similar "knowledge type sets" are fully editable by teachers and it is possible to export and import them from one FLE3 to another. Default sets, such as "progressive inquiry" and "design thinking," are provided. KPE takes a different direction following Web 2.0 principles. Instead of locking down taxonomies, a tagging system allows a folksonomy to emerge from the idiosyncratic choices of learners during the "use phase." This reflects both (1) the evolution from user-contributed content to user-contributed metadata, through annotations, tags, bookmarks or ratings, and (2) the technical evolution of user-contributed "place structuring" from "heavy tools" to small pluggable components.

Teacher-instrumentalizable systems

The initial design of a teacher-instrumentalizable system promotes a certain way of learning. This way of learning is supposed to be efficient and learners are expected to internalize its rules. For achieving the desired internalization process, learners are scaffolded and strongly

t2.1 **Table 2** KPE system of instruments

t2.2	Interpersonal mediation	Object-bound chat, object-bound forum, meeting management, user/group/role/competencies management…
t2.3	Epistemic mediation	Shared working spaces with visual arrangement in different views (content view, tailored views, process view, community view), personal working spaces, linking tool, semantic tagging, ontology management, metadata management, semantic search and filtering, free-text search, data import–export …
t2.4	Pragmatic mediation	Note editor, sketch pad, visual model editor, versioning tool, upload tool, wiki, commenting tool …
t2.5	Reflexive mediation	Reflection on individual's work (to-do list) and collective work (GANTT chart), real-time awareness, history-based awareness …

discouraged from performing opportunistic adaptations. Instrumentalization mainly stays under the control of teachers. During the "preparation phase," the teacher customizes the artifact for defining the specific learning situation and how learners will be supported and scaffolded. During the "use phase," instrumentalization is a way for the tutor to adapt the artifact-embodied structures (scaffolds) to the actual learning process. Most systems in that category support short-lived synchronous learning sessions, lasting less than a few hours.

Teacher-instrumentalizable systems are much more diverse than learner-instrumentalizable systems, because there exists a large variety of embodied structures that can be instrumentalized by teachers. For further analyzing and classifying these systems, the instrumental approach leads, as suggested by Kern (2008), to consider the primacy of one particular form of mediation (interpersonal, epistemic, pragmatic, or reflexive) over the others or their well-balanced coexistence ("multimediation") as meaningful criteria. Such a classification allows characterizing and analyzing the specific embodied structures associated with each form of mediation. In each resulting subcategory, the degree to which systems support their own instrumentalization is specifically addressed.

a) Interpersonal mediation primacy

Systems in the first category primarily support the social construction of knowledge through peer group discussion. Instrumentalization by teachers may concern several aspects of these interpersonal exchanges such as the channels, messages, and protocols.

A majority of these systems includes a single or a small set of communication tools adapted to a given task that cannot be deeply customized. For example, VMT Chat, which is based on ConcertChat (Mühlpfordt and Wessner 2005), is designed to support collaborative mathematical problem solving through the integration of a textual communication space (chat tool) and a graphical task space (shared whiteboard). The whiteboard allows learners to draw graphical representations of mathematical issues and the posting of ideas and equations in text boxes that remain on-screen while chat postings scroll away. For better integrating the two spaces, the system also includes a graphical referencing tool as well as social awareness and history features. VMT chat has been used in particular for investigating, on the instrumentation side, utilization schemes that learners elaborate for distributing and coordinating their actions over both spaces during mathematical problem solving tasks (Cakir et al. 2009). Q28

Some systems provide hard-coded mechanisms for scaffolding interactions among learners: predefined sentence openers or speech acts, like for example in BetterBlether (Robertson et al. 1998), and less frequently, predefined interaction protocols, including role types, message types, and message sequencing rules (Pfister and Mühlpfordt 2002).

When instrumentalization by teachers is supported, it generally means that they can modify and sometimes dynamically adapt the ontology of speech acts or dialog acts, like in ACT (Gogoulou et al. 2005). At a higher level of complexity, a few systems support teacher-defined interaction protocols definition and enactment (Whitehead and Stotts 2000; Lonchamp 2005).

b) Epistemic mediation primacy

Systems in the second category mainly support the social construction of knowledge through the mediation of diverse knowledge artifacts. Instrumentalization by teachers may affect the formalism in which the knowledge is expressed and the way artifacts are shared and constructed by learners.

For example, Synergo (Avouris et al. 2004) and its predecessor ModellingSpace (Avouris et al. 2004a) support synchronous collaborative building of knowledge representations by small groups of students. They propose a shared graphical workspace, used as persistent representation of a problem space, and a chat tool, which plays a supportive role in discussing and disambiguating activities in the workspace. Sticky notes may be used instead of chat messages for commenting and designating specific elements in the workspace. A coordination mechanism (token-passing floor control mechanism at the workspace level) can suppress the problem of tracking simultaneous actions, as a single learner holds the floor and can contribute at each moment. Interaction analysis indicators can be displayed for facilitating learners' self-regulation (Margaritis et al. 2006). Synergo and ModellingSpace mainly differ in the way they support instrumentalization, with predefined knowledge artifacts (like flowcharts, entity-relationship diagrams, concept maps, or data flow diagrams) in Synergo, and teacher-defined quantitative and semi quantitative models in ModellingSpace. Similarly, Digalo exemplifies the large class of systems in which the graphical workspace mediates the construction of a discourse structure (Lotan-Kochan 2006). Using Digalo consists of synchronously co-creating argumentative maps built of written notes inside different cards (represented by several geometrical shapes), as well as using different arrows to represent various types of connections between the cards or contributions. These "cards" and "arrows" represent the ontology or "grammar" of the discussion, which can be customized by teachers. The ontology constrains, but also facilitates, the discourse by guiding learners to use specific speech acts (or argumentative moves). Digalo can also be customized with different policies regarding floor control ("free for all" and "turn taking").

FreeStyler, which is an extension of Cool Modes (Pinkwart 2005), supports more complex instrumentalization processes by teachers. It is a collaborative modelling tool that combines different visual languages with handwritten input. Pages are used to structure a document and each page consists of layers in order to stratify different levels of input (e.g., graphical elements and handwriting). Pages can remain private (for preparing complex contributions) or be shared with other participants. The "plug-in" and "reference frame" concepts of Cool Modes allow for flexibly exchanging and extending the available visual languages. Teachers with programming skills can even define, from scratch, new visual languages with animation capabilities.

c) Pragmatic mediation primacy

Systems in the third category chiefly support the social construction of knowledge through problem-solving processes. Unlike with learner-instrumentalizable systems, learners are constrained to follow a specific process and cannot self-organize. The problem-solving tasks are more focused and short-lived. Instrumentalization by teachers may affect the process structure (task definition, task sequencing, resource attribution…) and the way learners are associated with different tasks, roles, and groups. The process is either predefined and hard-coded in the system, or explicitly specified by teachers through process models, often called "macro-scripts". These models are defined during the "preparation phase" and can, possibly, be changed on the fly, during the "use phase," for taking into account various unforeseen events. They are enacted by script engines which scaffold participants in carrying out their collaborative activities.

Non-customizable systems follow hard-coded scripts. For example, the ManyScripts web-based environment (Dillenbourg and Hong 2008) offers a set of predefined scripts. Adaptations are restricted to the association of specific learning materials by the teacher to a predefined script.

At the intermediate level of instrumentalization support, script-sensitive systems provide teachers with tools for designing, coding, and enacting macro scripts (Tchounikine 2008). At the coding level, some approaches rely on *ad hoc* scripting languages (e.g., Ronen et al. 2006; LAMS 2010). Others are built around the IMS Learning Design (LD) standard (Bote-Lorenzo et al. 2004; CopperCore 2010) or specific extensions to this standard (Turani and Calvo 2006). S-COL (Wecker et al. 2010) follows an original approach by implementing scripts and scaffolds at the level of the browser plug-in, allowing their transfer between different learning platforms. At the script design level, authoring tools such as MoCoLADe (Harrer and Malzahn 2006) allow teachers to manipulate graphical representations instead of the low-level IMS LD notation and to interactively simulate script execution. With Web Collage (Villasclaras-Fernandez 2010) teachers can reuse "Collaborative Flow Learning Patterns" (CFLPs), which specify classical collaborative learning techniques like "Jigsaw", "Pyramid", or "Think pair share" (Hernandes-Leo et al. 2006), and assessment patterns (Villasclaras-Fernandez et al. 2009).

At the highest level of instrumentalization support, a few systems support instrumentalization by teachers also during the "use phase." For example, CeLS controls how artifacts flow among the stages of a script and how they are offered for interaction to each group of learners. During script enactment, teachers can change stages and data flows, as well as social structures that define learners' grouping (Ronen and Kohen-Vacs 2009).

d) Reflexive mediation primacy

Systems in that fourth category assist users in improving their contribution to the collaborative knowledge construction activity. This goal can be achieved through a three steps process distributed over the subjects and the system: making relevant properties visible, reflecting on them for characterizing problems, and devising remedial solutions. Such reflexive mediation that could probably be better termed "reflective mediation," as proposed in Lakkala et al. (2009), is always associated with one or several other forms of mediation, through which social construction of knowledge takes place. Many CSCL systems that Jermann calls "mirroring tools" (Jermann et al. 2001), collect and display awareness indicators about the other participants, their actions, the artifacts they share, and so forth. A few systems that Jermann calls "metacognitive tools," display information about what the ideal values might be in addition to the current state of the indicators. With that help, learners and teachers can more easily diagnose the situation and decide what actions to take. Finally, some "guiding systems" automate all the regulation process by proposing remedial actions.

Most implementations are hard-coded and instrumentalization by teachers is generally restricted to the selection of the most relevant indicators. However, in a few cases teachers are provided with more advanced facilities for instrumentalizing reflexive mechanisms. For example, teachers can specify in a declarative way task-specific collaboration indicators directed to learners for self-assessment and regulation, and to tutors for coaching support (Lonchamp 2008). In another example, teachers can provide the ideal solution to a design problem for directing an automated advisory tool that provides both task-based and collaboration-based feedback (Baghaei and Mitrovic 2005).

e) Multimediation

Systems in that last category achieve a well-balanced coexistence of all mediation forms. Co-Lab (van Joolingen et al. 2005) is a representative example of a first category of "multi-mediators", which provides a predefined collection of highly specialized tools. Co-Lab is an integrated tool suite for inquiry learning, designed for learning in the natural sciences at the upper secondary level and the first years in university. Content is available for four domains: water management, greenhouse effect, mechanics and electricity. Table 3 summarizes the most important instruments with the dominant mediation they can be associated with. In Co-Lab, customization is only supported at the layout level through a setup tool. Deeper customization requires integrating new tools into the java-based implementation.

"Multimediators" that provide higher level instrumentalization support move the scripting approach into new directions. A first example is CoFFEE (De Chiara et al. 2007), a tailorable open-source environment that is designed for co-located problem-solving activities in the classroom. A collaborative script in CoFFEE consists of a sequence of steps, either "classroom steps" (for the whole class) or "group steps" (when the class is divided into subgroups). Several services can be enabled and customized differently for the different groups. A service is a tool with a specific configuration that modifies some of its functionalities. The main tools are a threaded chat (with configurable "contribution types") and a customizable graphical discussion tool. Additional specialized tools can be developed thanks to the underlying Eclipse RCP component-based architecture: whiteboard, streaming tool, etc. Each group uses the services as defined in the script, and learners can see only the artifacts created within their group. At the end of each step, the services are frozen, so that all the artifacts are then readable, but not modifiable. The collaborative process must be planned in advance during the "preparation phase." The CoFFEE Controller allows the teacher to load the lesson plan, configure the services, run the session step-by-step, manage groups and latecomers, block and unblock learners and, of course, access each group's tools –except private workspaces—in order to monitor, facilitate or participate in the activities. Scaffolding mechanisms are either provided at the run-time environment level (e.g., artifact and process history) or embedded into the services (e.g., presence awareness). A second example of "multimediator" is Omega+, a generic infrastructure on top of which customized dual interaction space environments can be built (Lonchamp 2006). Omega + is implemented as a reflective system, that is to say, a system that includes an explicit model of the supported activity. Teachers can customize the infrastructure during the "preparation phase" by providing a dedicated model. They can also evolve the system during the "use phase," because the behavior of a reflective system depends on the continuously queried model and changes as soon as the model is modified. Omega + associates four separate (sub-) models to the different facets of collaborative learning activities (Dillenbourg 1999): process model, interaction model, artifact model, and "effects model." The last one specifies how to monitor learning sessions for self-regulation and coaching purposes (Lonchamp 2008). Omega + kernel provides customizable tools and mechanisms. Some of them are just parameterized tools like the whiteboard, the shared text editor, the referencing tool (Lonchamp 2007a), and the session history browser (Lonchamp 2008). Others are model-based, and therefore deeply customizable, like the shared diagram editor, the chat tool, the floor control mechanism (Lonchamp 2007b), and the interaction monitoring tool (Lonchamp 2008). Table 4

Table 3 Co-Lab system of instruments

Pragmatic mediation (experimentation and data collection)	Remote labs (including web cam), simulations, databases, process coordinator, control tool…
Epistemic mediation (modelling for explaining the events in the experimental space)	Quantitative and qualitative dynamic modelling tool, graph tool, table tool, html viewer for background information access…
Interpersonal mediation	Chat tool, graphical whiteboard.
Reflexive mediation	Report tool.

t4.1 **Table 4** CoFFEE and Omega + instrument systems

	Mediation	CoFFEE	Omega+
t4.2	Mediation	CoFFEE	Omega+
t4.3	Pragmatic	Model-based process controller	Model-based process controller
t4.4	Epistemic	Customizable graphical discussion tool, streaming tool, co-editor tool…	Model-based diagram editor, shared text editor, explicit referencing mechanism…
t4.5	Inter-personal	Threaded chat, whiteboard…	Model-based textual interaction controller, whiteboard…
t4.6	Reflexive	History of past steps and artifacts, awareness tool…	Model-based interaction monitoring mechanism, collaborative session history browser, awareness mechanisms…

summarizes the most important instruments of CoFFEE and Omega + with the dominant mediation they can be associated with.

Discussion

The existence of a difference between intended and real usage of artifacts is widely recognized and has been studied thoroughly by ergonomists (e.g., De Montmollin 1986). In some domains this difference is interpreted negatively because it can create dangers and accidents (Faverge 1970). At the opposite extreme, Rabardel's theory of instrumental genesis analyzes this difference positively, as the fact that "users contribute to the design of artifact uses," and more generally "are actors of the overall design movement," which is "continued in usage" (Rabardel 1995a, b). Q31

By definition, a CSCL artifact conveys some pedagogical intent, which requires that learners use it more or less as anticipated by its designers. An inherent tension exists between learners who elaborate their own instruments, on the one side, and designers/teachers who wish to impose their pedagogical visions, on the other side. A first approach to deal with this dilemma is to avoid associating a particular way of using the artifact with the pedagogical intent. A "learner-instrumentalizable system" only provides means for reaching the objectives and lets the community of learners find its own path. Structures emerge over time from situated practice. As discussed in detail below, this orientation is highly demanding for both learners and institutions. In a second approach, a particular usage is prescribed by designers/teachers and more or less enforced. There are different ways of enforcing rules in such "teacher-instrumentalizable systems." At one extreme, it is done in a non-constraining way, for example with a human tutor who recalls the prescriptions and ensures, as much as possible, a disciplined usage of the system. An already well-established research stream aims at building intelligent agents for playing that role or, at least, for assisting human tutors (Magnisalis et al. 2011). At the other extreme, rules are automatically enforced. But, many users are reluctant to use such systems, and often find inventive ways to circumvent the rules (e.g., use a sentence opener with a contribution of a completely different nature). Therefore, researchers are looking for flexible rules and flexible enforcement mechanisms. For example, the overview in the previous section has revealed the growing importance of solutions that support the dynamic adaptation of the system to each specific learning process (dynamic instrumentalization). This kind of approach can be quite complex, not only at the technical level, but also at the organizational level, as it requires remaining to be on the look-out for the emerging practices of the community of learners.

The overview also emphasizes the emergence of what can be called “rich instrument systems,” that is to say, systems that support all forms of mediation defined in Rabardel’s approach. They are classified according to the kind of genesis process they are designed for, either as learner-instrumentalizable systems or teacher-instrumentalizable “multimediators”. These systems were hardly classified in previous classification schemes based on the types of activities they support –“action-oriented,” “text-production-oriented,” “argument-oriented” (Dimitracopoulou and Petrou 2005) or the objectives they pursue—“domain-specific support,” “peer-interaction support,” “group-formation support” (Magnisalis et al. 2011).

Moreover, it can be noticed in the overview that solutions supporting the reflexive mediation are less mature than those supporting the other forms of mediation. Rich learner-instrumentalizable systems might require support for assisting learners in selecting and adapting the most appropriate instruments and practices. It is one of the requirements of the still-under-development “Science Created by You” project and its SCY-Lab system: “pedagogical agents will measure students’ progress and initiate, if appropriate, scaffolding by adapting tools and services” (Giemza et al. 2009). Rich teacher-instrumentalizable systems might require support for assisting teachers in tutoring multiple small groups working concurrently (e.g., Voyiatzaki et al. 2008) and performing the inherently complex dynamic instrumentalization activities. Further research is clearly needed in all these directions.

The instrumental perspective also helps us to understand why it is so difficult to analyze and evaluate rich CSCL systems. Researchers often report difficulties in performing global evaluation studies: “As Co-Lab is a large comprehensive system, evaluation studies have had to focus on specific aspects of it, rather than evaluating the whole system” (van Joolingen et al. 2005). Fundamentally, what can be evaluated is not the artifact, but an instrument, and “its significance to a particular user for a particular purpose” (White 2008). Q32 In Rabardel’s terminology, the objective of these studies would be to discern and characterize the activity schemes that learners elaborate for the collective utilization of the artifact. The complexity of understanding these cognitive schemes results not only from their invisibility, but also from the way their evolution (instrumentation) is interwoven with changes at the level of the supporting artifact (instrumentalization). “The two processes (instrumentation and instrumentalization) contribute jointly, and often in a dialectic manner, to the construction and evolution of the instrument” (Béguin and Rabardel 2000). Thus, analysts are in search of “cognitive trajectories” more than fixed cognitive schemes. Furthermore, a rich and flexible CSCL system can generate a quasi-infinite space of potential instruments in which these trajectories are difficult to discern. They result from many individual, social, technical and contextual influences. Finally, as emphasized in Overdijk et al. (2008), the schemes or trajectories are negotiated among the learners. The results of these negotiations are not easily reproducible. For all these reasons, most evaluation studies tend to reduce both the space size and the number of influencing factors. In the CSCL field, evaluated systems are generally simple in design, poorly customizable, and mainly support collaboration through textual interaction that makes negotiation processes explicit (e.g., Cakir et al. 2009). Similarly, studies that rely explicitly on Rabardel’s theory also consider simple artifacts, like electronic handheld calculators (Guin and Trouche 2002) and spreadsheets (Haspekian 2005), or focus on a single elementary task performed within a rich system, such as dragging in a dynamic-geometry software system (Restrepo 2008). It is very difficult to go further. Searching for regularities among the cognitive trajectories of users would require huge longitudinal studies of complex systems. Practically, researchers try to combine many evaluation techniques, like the developers of Beehive for example: “We followed a multi-faceted evaluation approach (…). This approach incorporates both quantitative and qualitative methods. These methods include interviews, surveys, focus groups, direct observation, system logs, and software usability analysis" (Turani and Calvo 2006). However, much research is still needed for defining strong methodological guidelines for evaluating rich CSCL systems.

At a more general level, Artigue (2002) emphasizes that the importance of instrumental genesis is underestimated by educational systems. This may affect both global institutional processes and local organizational processes. At the global level, Hakkarainen (2009) argues that technology-mediated knowledge building can enhance learning only through "transformed educational practices": "Whenever there is a mismatch between affordances provided by a technology-enhanced learning environment and the participants' actual activities, the process does not produce worthwhile results. When used in conjunction with traditional educational practices, the use of Knowledge Forum may actually lead to excessive copying of information" (Hakkarainen 2009). Such a deep transformation of the social practices of working with knowledge is of primary importance for learner-instrumentalizable systems with which learners are expected to build their own sustained collaborative-inquiry processes. Teacher-instrumentalizable systems probably have a lower impact on educational practices, as they generate only short- instrumented episodes that are less demanding. At the organizational level, the instrumental approach emphasizes the importance of the "preparation phase" when systems are initially instrumentalized by teachers. Even for simple handheld calculators, Guin and Trouche (2002) stress the importance of what they call "instrumental orchestration" that is defined as "the intentional and systematic organisation and use of the various artifacts available by the teacher" in a given learning situation, in order to "guide students' instrumental genesis. It is partially prepared beforehand ('preparation phase') and partially created 'on the spot' while teaching ('use phase')" (Drijvers et al. 2009). In the theoretical model of the "preparation phase," shown in Fig. 6, educational and engineering technologists assist teachers during that initial instrumentalization phase. In many countries teachers have never met a technologist. The concept of virtual community of practice, previously evoked, can be an effective substitute, where online participants (researchers, developers, early adopters) are likely to play a similar role. In particular, successful open source systems can benefit from a reactive community of developers for quickly solving most technical problems and implementing new ideas. The transferability of collaborative-learning situations and scenarios among the members of these communities and the transferability of a given learning situation and scenario into practice, possibly on different target systems, constitute two other fundamental issues that should also be addressed in the near future.

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