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Computer-supported collaborative learning: The Basics

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Abstract. This article provides a summary of research and developments in the field of computer-supported collaborative learning (CSCL). We argue that the contribution of CSCL to vocational training comprises a set of ideas that actually prove relevant beyond CSCL to encompass the whole field of training technologies. Collaborative learning, with or without computers, is not a recipe that automatically leads to expected learning outcomes. Rather, CSCL researchers have explored the types of interaction which are necessary in a team in order to produce positive learning outcomes: argumentation, explanation, conflict resolution etc. In a next step, environments have been designed which scaffold these interactions. This contribution reports on the way in which technologies can be used in designing interactions: by placing student in a situation in which they need to engage in effortful interactions in order to build a shared understanding; by selecting a task representation that will shape their language; by directly prompting specific types of utterances using semi-structured interfaces; by structuring collaboration with scripts; by capturing interactions and either simply mirroring them to the group members or conducting deeper analyses. Collaborative activities are now integrated in pedagogical scenarios that include individual and class-wide activities occurring in a variety of settings (classroom, workplace, fieldtrip etc.) and in a variety of modes (face-to-face/remote; synchronous or non-synchronous etc.)

Keywords: learning technologies, collaborative learning

1 Introduction

In the discussion on how to establish more learner-centered methods of instruction in the classroom, approaches to collaborative learning play an increasingly prominent role. In addition, learning technologies are considered as potential aids in realizing instructional scenarios in which learners engage in meaningful activities without completely being left to their own devices. Computer-supported collaborative learning (CSCL) combines both lines of thinking in order to improve learning and instruction in various areas of education. After a period of laying the conceptual, methodological, and technological foundations, CSCL approaches and technologies are now ready to be systematically employed in the classroom. CSCL applications cover a wide spectrum, spanning from two users solving a well-defined problem in 20 minutes within a school context to large communities that emerge spontaneously and comprise thousands of users sharing their informal knowledge over as period of years. CSCL environments include synchronous and asynchronous software, text-based, audio-based or video-based communication tools, as well shared workspaces (for instance shared diagram editors). Part of the research on CSCL has been conducted with standard tools (chat, email, forum, …) while an other looks to design specific tools to support specific collaborative processes (e.g. argumentation). Recent research extends beyond standard computers; investigating collaborative learning can be enhanced using mobile phones, PDAs, as well as a variety of technologies embedded in furniture, walls, ceilings or clothes.

This variety of scales (e.g., group size, time span) and contexts probably explains the co-existence of multiple theories of learning and instruction within CSCL. Theories that best apply to small group learning have emerged from cognitive science and instructional psychology. These theories have been 'scaled up' by the promoters of distributed cognition (Salomon, 1993; Pea, 1993; Hutchins, 1995). At the other end of the spectrum, theories that are more frequently applied to learning in large groups have been derived from socio-cultural theories. Some "down-scaled" versions address not only the social level but also the interface with the individual cognitive level (Kaptelinin & Cole, 2002; Engeström, 1999). In addition, theories from other fields (such as social psychology, and psycho-linguistics) have contributed to the multiple perspectives involved in CSCL research. Corresponding to these multiple theoretical perspectives, a broad variety of research methods find application, ranging from ethnographic field studies to controlled laboratory experiments. We argue that the multiplicity of theories and methods involved in CSCL should be perceived as a sign of maturity, in stark contrast to the long-standing fruitless struggle between schools of thoughts which mutually ignore one another (e.g. LOGO versus CBT) within learning technologies. We speculate that this maturity could have been facilitated by the technological evolution that now enables the integration of heterogeneous software components such as simulation, communication tools and databases within a single environment.

One flavour of CSCL which has proved unique in comparison to other computer-supported learning approaches is the attention paid to non-institutionalized education approaches such as life long learning and learning communities. CSCL has been investigated and applied within a variety of educational contents with the precondition that these contents could be elicited and verbally elaborated. Compared to other learning technologies, CSCL has focused less on basic skills (such as reading, calculating) and more on high-order skills and competencies (e.g., argumentation, self-regulation, media literacy) and the sharing of informal knowledge (e.g. how to cope with difficult clients).

Research on computer-supported collaborative learning (CSCL) began in the late eighties and now constitutes the main stream of research on learning technologies. However, in vocational schools, CSCL approaches have hardly been used or systematically explored. This contrasts sharply with the increasing importance of collaboration skills and media literacy in coping with everyday work demands in many if not most professional groups. Will CSCL go on to have a larger impact on vocational training? On account of its obsolete nature, we will not address this question. As this contribution will demonstrate, the distinction between collaborative learning and other learning activities is actually fading under the umbrella of integrated learning activities. Moreover, the distinction between activities with and without computers has become trivial. For instance, many apprentices carry 3 computers with them for the entire duration of their working day (a phone, a watch and MP3 player). Hence, the goal of the present contribution is not to review which CSCL-labelled tools or methods could potentially be used within vocational training. Our stance is rather that many of the concepts, ideas, approaches or controversies emerging within or around the CSCL community will now percolate through the educational system. Ten of these ideas will be presented and an attempt will be made to articulate them within the 'integrated learning' vision.

2 Ten basic ideas of CSCL

2.1 More interaction balances less individualisation

For two decades, individualisation constituted the main principle of computer-based instruction: courseware was expected to be effective because the level of explanation, the quantity of exercises or even the didactic strategy could be adapted to the individual needs of the learner. National surveys on how information technology spread into schools used the "student per computer ratio" as their key indicator (Alspaugh, 1999). Accordingly, when teachers were forced to allocate two students to a single computer (due to an insufficient number of computers), the individual mechanisms should have broken down, leading to lower learning gains. Yet empirical studies showed the opposite results: side-by-side use of the computer if often more effective than using it alone (Dickson & Vereen, 1983). The added value comes from the social interaction in engaging with peers who, for example, explain computation results to each other, question the actions of the other on the interface, disagree on decisions, argue or negotiate and regulate one another (the student without the mouse reflects on the actions of the other). Collaboratively using courseware triggers twofold interactions, with the system and with the co-learner. These beneficial outcomes were first observed for courseware designed for individual users. The question which naturally followed - would these social interactions prove more effective if the system was purposely designed for collaborative use- gave rise to the field of CSCL.

Despite the growing interest in social interactions surrounding computers, individualisation remains a key concept. For instance, the delivery of personalized information on personal devices (Bull & Reid, 2003) is still a key concept in mobile learning. We do not argue that the principle of individualisation has lost its intrinsic value, but rather that designers must consider the individual/interaction balance as a parameter. The optimal value of this parameter varies in accordance with the nature of learning objectives and contents: social interaction is weighted more heavily, for example, if the content can be elaborated verbally, if there is room for multiple viewpoints, and so forth.

Moreover, the ideas of individualisation and interaction have been integrated (instead of placed in opposition) within CSCL environments, which are adaptable to groups of learners. This cannot be properly called 'individualisation' but instead 'group adaptation'. Individual adaptations rely on the so-called 'student model' (Self, 1977), i.e. the information about the student that the system possesses and uses in making decisions. Analogously, group adaptations require the maintenance of a representation of the group or 'group model' (Paiva, 1997). The group model may be constructed from the individual student model. For instance, Hoppe and Ploetzner (1999) developed an environment that identifies individual skills during individual problem solving and then selects the group task in such a way that none of the students are able to solve it alone, whereas the 'sum' of their knowledge enables them to reach a solution together. This mechanism corresponds to the JIGSAW 'script' used for structuring collaborative learning (see section 2.6). The group model may also be constructed from an analysis of on-line interactions (measuring participation, identifying conflicts etc.). CSCL environments use the group model in different ways (Jermann, Soller & Muehlenbrock, 2001): so-called 'group mirrors' (section 2.8) simply display a graphical representation of the model to the group while more elaborated systems 'coach' the group, for instance by suggesting a new task (Ayala & Yano, 1998) or a new strategy (Tedesco & Self, 2000) or by prompting a team member to participate more actively (Constantino-Gonzales & Suthers, 2000).

In summary, social interaction has become the main focus of CSCL and the adaptation to individuals has been reconceptualised around their role in group.

2.2 Media effectiveness is a myth

Each time a new media enters the educational sphere, it generates over-expectations with respect to its intrinsic effects on learning. Since the eighties, meta-analyses surveying several hundreds of studies on computer-based learning have failed to establish that computers per se constitute effective educational tools (Kulik, Kulik & Bangert-Drowns, 1985) In accordance with the so-called media debate (Clark; 2006), researchers of technology-enhanced learning have increasingly become aware of the possibility that the media might rarely have a direct effect on *what* people learn when using it. Rather, it is *how* learning takes place that is influenced by media characteristics. From this perspective, the various media forms are differentially suited to supporting different forms of instruction, though it is the instructional approach that makes the difference. We found, for instance, (Zeller & Dillenbourg, 1997) that the same hypertext used by two class halves with different instructional methods (different sets of questions) led to differences in learning outcomes.

The myth of media effectiveness seems to be less salient within CSCL research. We might speculate about the reasons for this evolution from previous technologies. One reason surely lies in the disillusion caused by over-expectations placed on previous software generations (e.g., microworlds, hypermedia). A second reason is that the very same CSCL tools led to very controversial results at an early stage of research. The best example is the use of online asynchronous communication tools (forums), that led to great learning outcomes under certain conditions (Schellens & Valcke, 2005) but failed to sustain students engagement in most studies (Hammond, 1999; Goodyear, 2004). The third and probably main reason is that CSCL benefited from a long tradition of research on cooperative learning, where some analogies to the media myth were to be found. Research on cooperative learning repeatedly and robustly showed that it is not cooperation per se which affects learning. It is rather a question of the appropriate instructional conditions (e.g., Slavin, 1996), and, even more importantly, of the emergence and support of productive interactions (Dillenbourg, Baker, Blaye & O'Malley, 1996), which in turn stimulate the cognitive and metacognitive processes necessary for learning. It is to be stressed that findings revealing that technology does not guarantee particular learning outcomes do not imply the end of CSCL, but instead encourage us to gain a deeper understanding of how technology features affect social interactions and - mediated by these - learning outcomes.

Nonetheless, a myth never dies. Indeed, in the current excitement surrounding mobile learning, the myth shows signs of revival. Again, what can be measured is not the effectiveness of mobile tools but the effectiveness of scenarios based on networked handheld devices. Research on mobile learning raises the question as to the kinds of peer interaction which are more likely to occur through in technology-supported instructional scenarios.

2.3 What matters is the effort required to construct shared knowledge

From its early beginnings, CSCL research has focused on concepts that reach beyond the individual learner's mind to address "collective" phenomena. In this respect, an important conceptual and empirical focus of research has been the question pertaining to how learners build a shared understanding of a task or a learning environment. Influenced by approaches from situated cognition (Resnick, Teasley & Levine, 1993), Roschelle and Teasley (1995) investigated the way in which two individuals co-construct a shared understanding of a task in dialogue during manipulation of a physics simulation environment. They found that external representations in the environment were not used as an epistemic source but rather as a way of disambiguating verbal interactions in order to progressively construct a shared understanding. This led them to propose that collaborative learning is, in essence, the co-construction of shared understanding. Although restricting CSCL to a rather narrow scope of phenomena related to collaboration, this broader definition subsequently became one of the key references within the community. The psycholinguist concept of "grounding" (how communicators identify that their partners understand what they mean, and repair potential misunderstandings) has been introduced as a central idea in addressing phenomena of shared understanding development. Clark and Brennan (1991) associated grounding costs with different communication scenarios (e.g., with asynchronous vs. face-to-face communication). During the past decade, a wide range of more specific concepts have been suggested for addressing different aspects of the broad phenomenon of constructing shared understanding. Schwartz (1995) proposed the hypothesis that it is the effort towards shared understanding that constitutes the real motor of collaborative learning: the intrinsic effort of an individual to understand what the other means drives cognitive and dialogic activities which, in turn, enable cognitive changes in this individual. The importance of the 'effort towards a shared understanding' is reflected in the design of CSCL scripts (see section 2.6): for instance, a script that forms pairs of students with conflicting opinions or a script that forms teams in which each student receives only a subset of the required knowledge, both increase the difficulty level for acquiring a shared understanding and thereby increase the interactions necessary to reach the goal in spite of the given situation. The effort to be asked from students is of course limited: It is clear, however, that beyond a certain threshold, students will not feel confident that their goal can be attained.

Whereas the above mentioned approaches focus on *processes* of building a shared understanding, a further strand of research deals with the question, to what extent learners really share knowledge after having collaborated for some time. A number of years before the initiation of CSCL, Miyake (1986) investigated the extent to which collaborators had really developed a shared perspective on a task during collaboration. Subsequent testing revealed that individuals were hardly able to accurately state what the others might know or believe about the task they had worked on. In the same line of research, Jeong and Chi (1999) measured shared knowledge as the similarity of responses in an individual knowledge post-test following collaboration. They found that former collaborative learners shared only a very low proportion of the knowledge that they had discussed. Fischer and Mandl (2005) suggested that knowledge convergence be analyzed with respect to both processes and outcomes. They found a strong tendency for collaborative learners to converge in the process (e.g., by increasingly focusing in on the same concepts or by progressively using rather similar linguistic forms to express their views). Their findings also show, however, that former collaborators neither learn to an equal extent, nor do they show considerable overlap with respect to the concepts learned during convergent collaboration processes.

2.4 A greater resemblance to face-to-face interactions is not necessarily better.

The field of CSCL has, in the same way as the entire domain of learning technologies, fallen victim to the *imitation bias* (Hollan & Stornetta, 1992). This bias centers on the belief that the more a given medium resembles face-to-face interactions, the better. As a corollary, medium richness or even bandwidth is erroneously considered to represent the key to effectiveness, despite the fact that empirical research provides counter-evidence: video-supported collaborative work is not necessarily better than audio-only situations (Olson, Olson & Meader; 1995; Anderson et al., 1997; Fussel et al., 2000;); text-based communication offers affordances (e.g. the ability to maintain parallel conversation threads) that voice conversations do not (Herring,1999); an asynchronous communication tool enables more reflection than synchronous tools (Benbunan-Fich & Hiltz (1999). The 'richer is not better' lessons holds for mobile technologies: while SMS communication is a very 'poor' medium, billions of SMS messages are exchanged daily, WAP technologies (web browsing on mobile devices), a much richer medium, did not enjoy wide public success. The consequence of this widespread belief in face-to face interaction is not simply that it generates unfounded expectations, but also that it leads to the neglect of alternative technology benefits. Fortunately, the large body of empirical studies progressively led CSCL designers to distance themselves from this imitation bias: the question driving research is no longer "how to compensate the loss of not being face-to-face" but rather "how technology can fulfill collaborative functionalities that are not available in face-to-face situations".

This evolution is further related to the development of integrated learning. Since learning technologies are not only used in the context of distance situations but also in enhancing co-present collaborative learning, it is no longer the way in which computer-mediated communication imitates face-to-face interaction which is of relevance, but rather the way in which it differs. While 'augmented reality' (Azuma, 1993) refers to overlapping direct world experience with digital information increasing the user's perceptive potential, 'augmenting interactions' (Dillenbourg, 2005) refer to the way in which digital technologies provide additional features within co-present social interactions.

One augmentation provided by CSCL tools is to provide users with the history of interactions in a chat, email or forum or in a group mirror (see section 2.8). We observed that communication tools with a persistent display of messages provide teams with an external shared memory (Dillenbourg & Traum, 2006). A further example of 'augmentation' is the possibility of storing the context of an utterance: in the Sticky Chat (Churchill et al., 2000) for example, a chat session that fits on desktop sticky notes is attached to an anchor in the text which is jointly edited by the users. This note moves up or down or disappears as users scroll the document. Similar CSCL tools visually maintain links between the verbal utterances in a chat and the graphical object referred to in a shared space (Haake, 2006). Context-aware technologies have begun to augment interactions by transmitting externally collected information such as geographical information or measures of temperature, altitude, humidity, location, etc. together with the message. The program STAMPS (figure 1) for instance enables users to associate a message with either their current position or the place to which they refer in their message. It would be possible to expand context storage to encompass social context (e.g., FoF networks), physiological information (pulse rate etc.) and many other informational contexts..

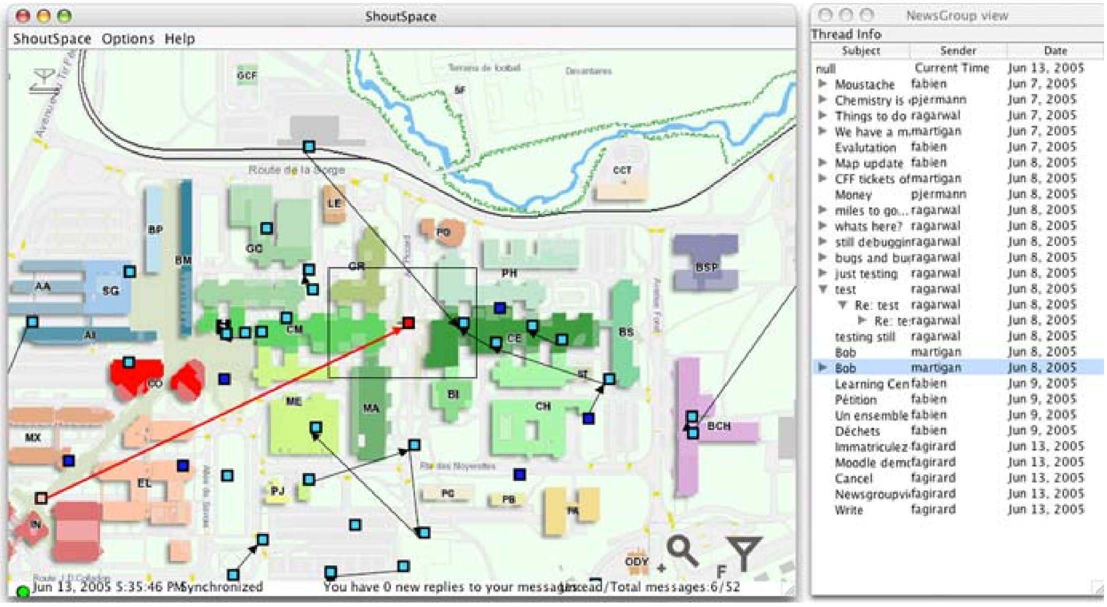

Figure 1. Storing geographical context together with messages in STAMPS (http://craft.epfl.ch)

Based on the fact that they have managed to escape from the limiting grip of the imitation bias, CSCL and other related fields are producing tools that often do not resemble educational objects at all, such as interactive lamps, tables, carpets, walls or plants. Let us turn to consider modern-day teachers. Many buy their airline tickets as well as other purchases over the internet, jog with their MP3-player, take pictures with their phone and go trekking using their GPS and yet they remain somewhat reluctant to use educational technologies. One interpretation of this fact is that technology per se does not create resistance, but rather the fact that this technology is defined as "educational". Hence, an exploration of the impact of applications which do not necessarily appear to carry an educational purpose at first glance is not as absurd as it may appear.

2.5 Task representations mediate verbal interactions

Let us return to the question raised in section 2.1: should the design of educational software be different given that we know there will be 2 users in front of the machine? Early insights came from the previously reported work of Roschelle (1992) based on a physics microworld. Roschelle observed was task representations within collaboration tools shape the social interactions which arise, a principle which he summarized as "designing for conversations". Another prominent example of this mediation of interaction is the synchronous argumentation tool Belvedere[1] (Suthers, Weiner, Connelly & Paolucci, 1995). Two students, working side-by-side or on-line, construct a graphical representation of a scientific debate. They share a graphical editor with which they connect text boxes. The palette of boxes defines the argumentation grammar: to add an element to the workspace, the student has to select the 'hypothesis' box, the 'data' box to present evidence, and so forth. The set of links for connecting boxes ("X supports Y", "X contradicts Y",…) defines the dialogue structure. The way in which a task representation shapes social interaction is referred to by Suthers & Hundhausen (2003) as **"representational guidance"**. Both examples illustrate a subtle way of shaping social interaction. As we will see in section 5, CSCL has developed more direct or more intrusive methods such as scripts and semi-structure interfaces.

This concept of mediation has been for a long time developed with socio-cultural theories, namely through the notion of cognitive tools (Kuutti & Kaptelinin, 1997). Mediation extends, however, beyond the simple shaping of interactions. Following Vygostsky (1986), individual reasoning is to be understood as the internalization of dialogues conducted with more knowledgeable persons (adults for children, experts for novices). The dialogues are mediated by tools, language itself being a tool for communication. Therefore, the design of CSCL environments is not simply intended to mediate communication among students, but, also to shape the way in which students reason about the content to be learned.

2.6 Collaborative learning needs to be structured

The issue of instructional support for groups in CSCL environments has been subject to a wide variety of approaches across the history of the field. Whereas the ideal of an instructionally unconstrained collaboration would appear to have at least implicitly dominated the early days, it has become increasingly evident that some form of additional structuring is required in order to facilitate learning and interaction. There is convincing evidence that fully self-directed learning is beneficial neither for individuals nor for groups, regardless of whether with or without technological support (e.g., Dillon & Gabbard, 1998; Fabos & Young, 1999).

A comprehension of the mediating role of CSCL tools led to the design of *semi-structured communication tools*. By instructionally constraining the space of possible actions to those that are seen as productive in a given context, such tools scaffold social interaction within collaborative learning. With synchronous and asynchronous text-based communication tools, communication acts such as "Please explain this in more detail:" or "I do not agree with respect to…" are included as buttons or sentence openers that can be selected from a pop-up menu. Some discussion forums ask collaborative learners to classify each message, for example according to its function in a discussion (e.g., "counter-argument", "example"). While semi-structured interaction tools have some positive effects on interaction, results regarding the effects on learning outcomes are mixed (e.g., Baker & Lund, 1997; Veerman and Treasure-Jones, 1999).

Collaboration script approaches are a more promising approach to providing instructional support (O'Donnell & Dansereau, 1992; King, in press). Their goal is to foster productive interaction among collaborative learners. They structure interactions by defining activities and sequences of activities, clustering activities to roles and assigning roles to individual learners (Kollar et al., in press). Scripts moreover can include role switches. It is important to note that activity is used here in a very broad sense and includes coarse-grained steps in an instructional plan (e.g., a small-group discussion) as well as fine-grained activities that are hierarchically nested in larger ones (e.g., formulating a counter-argument in an online discussion). The notions of micro-script and macro-script (Dillenbourg & Jermann, in press) reflect the different grain-sized activities that are addressed by collaboration scripts. We will present examples of both a micro-script and a macro-script below. Collaboration scripts can be scaffolded by the computer in a variety of ways (Kollar et al., in press).

The ArgueGraph script is an example of a macro-script and is described by Dillenbourg and Jermann (2006). This computer-based script begins by asking individual students to fill out a questionnaire with respect to their opinion on controversial topics. The computer then assigns students with opposing opinions into pairs. These pairs are then asked to jointly complete the same questionnaire with the task of agreeing on a joint position. Subsequently, the teacher discusses all answers and arguments with the whole class and organizes these from a theoretical perspective. Finally, individuals are asked to write a short essay on the topic under consideration. Note that the script does not provide support with respect to *how* the pairs should discuss and agree on a joint position. Macro-scripts such as the ArgueGraph script assume that learners are already able to engage in argumentation in a self-guided manner.

An example that also includes micro-scripting is the "social script" described by Weinberger et al. (2005). Here, three university freshmen collaborated online to analyze text cases under application of a theory of their study domain. The computer sequences interaction by assigning a specific activity (e.g., writing an analysis of a specific case) to students and setting and controlling a time limit following which students are assigned the activity of criticizing the analysis of one of their collaborators. Following this, students receive the critique of their initial analysis and are assigned the activity of replying to the criticism and finally revising their analysis. The various activities are further supported by different prompts ("Please write a criticism of your learning partner’s analysis!") or sentence starters ("I do not agree with your analysis with respect to…!"). In this script example, the computer not only provided affordances for the activities but also supported sequencing, timing, and role switches.

2.7 Interaction analysis can be partly automated

A broad consensus among CSCL researchers is that the key to successful collaborative learning lies in the productive interaction of the collaborators. On these grounds, CSCL researchers have, over the last decade or so, adopted and developed sophisticated methods for analyzing on-line group interactions, in order to identify productive interactions and compare the effects of different variants of a CSCL environment. The approaches vary from qualitative analyses of interactions within a single dyad or group (Koschman & LeBaron, 2002) to the coding of approaches by segmenting the stream of interactions into units and categorizing these according to a theory-based coding scheme. Interaction analyses, however, do not merely represent methods by which researchers are able to gain a better understanding of CSCL-related processes. Coding scheme approaches are of particular interest from an application perspective on account of their potential development into a computerized, automatic procedure. Over the last few years, a large number of coding schemes have been developed (for an overview of current coding systems, see Schellens et Valcke, 2005). Technologies are evolving which enable automated interaction analyses with even higher dynamics (Mühlenbrock & Hoppe,1999; Lavie & Rosé, 2004). Coding approaches combined with these new technologies are now beginning to form the basis of automated analyses of interaction. This development carries the potential of facilitating the computer-assisted (the system suggests codes for segments and the human coder makes the final decision) or even fully automatic analysis of large sets of data. This can drastically speed up the research process, and additionally foster measurement reliability and validity by increasing the portion of the interaction stream subject to analysis.

While (semi-)automatic coding is the researcher's dream, teachers and learners might benefit more directly from a further potential of real time analyses. Real-time analyses of interactions provide the teacher with information as to which small groups in the classroom most require his or her help and what kind of support is required. This could lead to more adaptive instructional support (e.g., the teacher fading out the script of a group when the system indicates that sustained productive interaction has taken place in the given group; see section 2.6) as well as feedback for self-regulating groups (e.g., in displaying the results of the system’s discourse analysis to the whole group; see section 2.8 on group mirrors).

An example of such a development will follow. In the late nineties of the last century, a coding scheme was developed for the analysis of collaborative knowledge construction in discourse (Fischer et al., 2002) and later adapted to the context of case-based online discussions, with the current version of the coding scheme including 3 main dimensions (Weinberger & Fischer, 2006): an epistemic dimension which analyzes how the knowledge construction task is being carried out, an argumentation dimension which analyzes the formal structure and sequence of arguments and counterarguments in a discussion, and a transactivity dimension which analyzes the extent, to which learning partners refer to each other and use the learning partner as resource for the knowledge construction task. These dimensions include different numbers of categories (i.e., codes). Over the years, a series of experiments have been conducted and the data of more than 300 groups (about 14000 segments) coded "by hand" by members of the research group. Since 2004, computer linguists have been using parts of these data to train different algorithms used in the TagHelper tool (Rosé, 2004). Some of these algorithms have been shown to meet the reliability level of human coders (Dönmez et al., 2005). This analysis technology has been built into the experimental case-based online learning environment and is now able for the evaluation of single text messages as well as entire discussions with respect to their epistemic quality, argumentation, and transactivity (Wecker, Stegmann, Weinberger, Fischer & Rosé, 2006).

While approaches to real time analysis of interaction are currently in their early stages, we see considerable potential in these approaches, especially with respect to supporting facilitators, teachers, and learners with automated process analyses running in the background.

2.8 Interaction is a substance

The previous section reviewed the way in which computers are able to analyze group interactions in order to support or even make pedagogical decisions (forming groups, selecting tasks, prompting specific interactions etc.). A simple yet interesting way of using outcomes of such interaction analyses is to display these to the group members. We refer to these tools as "group mirrors", since they reflect some form of external interpretation of the interactions to the users. The pedagogical purpose of group mirrors is to scaffold reflection upon the interaction process itself, and in doing so stimulate the group to regulate the quality of its interaction. Figures 2 and 3 illustrate two examples of group mirrors. The first (Jermann, 2004) is based on a normative model of interaction and provides the group with an indication of what is expected of the members in order to ensure effective collaboration. In pre-experiments, Jermann established that effective pairs show a higher ratio between the number of utterances between the users and the number of user actions on the interface ("tuning" the simulation parameters). This talk/tune ratio, although very simple, was significantly related to group effectiveness and hence used as group mirror.

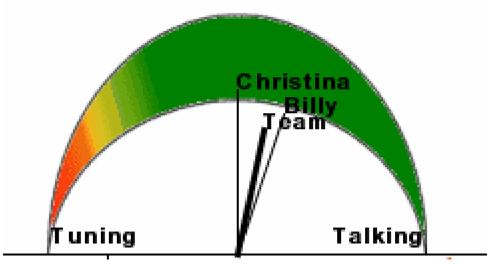

Figure 2. Normative group mirror (Jermann, 2004)

The second example of a group mirror (figure 4) is more neutral: a matrix of LEDs reflects the participation patterns without explicitly revealing which patterns are good or bad (Haué & Dillenbourg, to appear). A good group of 4 students is not necessarily a group where each member speaks for 25% of the time during the whole process. The mirror displays the amount of speech both over the last few minutes and over a longer time period. Participation is measured by the noise captured by microphones, without any natural language analysis. This indicator is thus very simple. The noise-sensitive table bears resemblance to a real mirror: it does not tell you whether you are beautiful or ugly, it simply reflects light. The difference with a standard mirror is that the group mirror has a memory and is able to reflect phenomena that are perceived and aggregated over long periods of time. In figure 3, this mirror can be seen to be embedded in a table (instead of in a screen display), a design choice that illustrates the computing evolution towards physical artifacts (section 2.9).

Figure 3. The noise-sensitive table embeds LEDs that reflect interaction patterns

Beyond these concrete examples, the general idea emerging from CSCL is that social interactions constitutes a 'new substance' (Dillenbourg, 2005). In this context, instructional designers are seen in the role of sculptors who discover a new kind of clay: social interactions. We may anticipate a rapid evolution with regard to how to capture interactions (e.g., voice/text dialogues, task actions, body movements, location etc.), how to analyze and display them (e.g., how to visualize them, where to display them). We believe that these developments will strongly stimulate CSCL research and increasingly become part of CSCL environments in practice.

2.9 Computing is more than computers

Figure 3 illustrates an evolution of computer science that has impacted CSCL but will certainly go on to have a more global impact on learning technologies. While computers have long been seen as rectangular boxes placed on a table with peripherals such as keyboards, mice and monitors, they are now becoming embedded in multiple objects of our daily environments (phones, cars, TVs, watches etc.). Expressions such as "the invisible computer" (Norman, 1998) or the 'disappearing computer' (Russell, Streitz & Winograd, 2005) stress the fact that these embedded computers are less salient and rather present in the background. The idea that technology may augment social interactions without being the focus of attention has of course raised interest within CSCL circles. This interest has covered three different lines of development.

(1) The first is the creation of new input/output devices, called 'tangibles', that support a physical interaction with computers (Stanton et al, 2002): students interact with a simulation for example by moving different objects on a table, moving a brush on the screen, or moving sand in a box.

(2) The second line, 'ubiquitous computing' (Weiser, 1993), refers to the multiplication of computational devices that are carried around by students most of the time. These include MP3 players, phones, watches etc. The slogan 'learn anytime, anywhere' (Rogers et al, 2004) corresponds to what could be termed 'ubiquitous learning': students are either expected to use useless time slots (e.g., waiting for the bus) to learn general topics or to receive information specific to their learning needs. Specificity is achieved by 'context-aware' technologies: the information/learning needs of students are often inferred from the geographical context (if the student is standing in front of the painting X, tell him more about the painter – Hsi, 2003) or

from the social context (e.g. the social distance between two Japanese speakers; Ogata & Yano, 2004). Mobile artifacts not only provide access to online information in any location, but more interestingly also enable data collection. Multiple input devices are integrated into or connected to the phone: camera, microphone, GPS, thermometer, sound meter, altimeter, accelerometer (to capture paths or gestures) etc. For instance, ImagiProbe enables the measurement of the PH value of water, which can then be read from a PDA (Imagiworks, 2006).

(3) The third line is the embedding of digital technologies in local environments. The interactive table presented in Figure 3 is an example of 'roomware' (Prante, Streitz. & Tandler, 2004); more elaborated tables include displays and software aimed at sustaining collaborative work. Interactivity was also introduced in carpets used as an input device, or in walls used as displays.

A real life application of this concept was implemented by Lingnau, Hoppe and Mannhaupt (2003) in a first year classroom of a primary school. Technology played a key role in the learning-to-read method, at the same time as being very discrete, such that social interactions were not obstructed as is the case with monitors in standard computer rooms. This evolution extends far beyond CSCL. In new CSCL environments, both software and hardware disappear in the sense of the 'disappearing computer': they expand to multiple learning planes including non-collaborative activities; they expand to multiple objects and not only standard computers; they expand to multiple places - inside and outside. Let us repeat what we said earlier concerning the myth of media effectiveness: the new tools described in this section are not presented because we expect them to be intrinsically effective. Rather, we want to stress that within the concepts of 'computer-supported collaborative learning' or 'computer-based learning', it is not merely computers which are referred to, but a variety of devices that process digital information. These devices might inspire new pedagogical approaches, which in turn may show pedagogical effects.

2.10 Some virtual communities effectively share knowledge

Inspired by socio-cultural approaches, the idea emerged to transform classrooms and schools into learning communities (e.g. Collins et al., 1989; Bielaczyk & Collins, 1998). At a very early stage, CSCL researchers emphasized the great potential of the internet and the World Wide Web when it comes to changing education in this direction, e.g. with concepts of technology-supported knowledge-building communities (Scardamalia & Bereiter, 1994). The basic idea of such concepts is that a larger technology-supported group of people who may be distributed in space and/or time build and refine new knowledge together and individually internalize this newly generated knowledge. With the CSILE approach, Scardamalia and Bereiter (1994) set up communities of school students within and across classrooms around an instructionally designed shared database. Here, learners were to develop and contribute their *own* ideas with respect to a given domain and improve these ideas with the help of questions and criticism from their peers. In formulating ideas, questions, criticisms etc., learners are supported by different kinds of scaffolds. The growing database is seen as reflecting the knowledge (in a sociological sense) jointly constructed by the group. Key research questions are: how can these communities of learners be scaffolded in such a way as to experience conceptual growth on a collective as well as an individual level? How do such communities contribute to a new learning culture, where knowledge building and idea refinement constitute major goals? Many educators and researchers consider CSCL to have great potential in helping to establish a culture of collaborative knowledge building and idea transformation at the expense of the traditional "knowledge re-telling" culture of learning (Bereiter & Scardamalia , 1994.

One approach representing this perspective is "Learning-by-Design" (Kolodner, in press). Here, learners are supported in developing a knowledge community based on technology-supported cycles of inquiry (to identify and generate knowledge) and design (to apply the knowledge and identify new challenges for follow-up inquiry).

Compared to other learning technologies, CSCL has emphasized the potential of knowledge communities for informal learning. Most learning occurs out of schools, universities or corporate training. With millions of people becoming increasingly familiar with digital technologies, there is scarcely a topic for which no community or news group is to be found on the Web. Within these communities, the focus is often more on sharing and pooling the existing knowledge of individual members of a community who are distributed over the whole world, than on creating and refining new ideas.

On the one hand, extremely productive knowledge communities such as Wikipedia (www.wikipedia.org), or some news groups can be considered to provide evidence that - given the right conditions, large-scale knowledge sharing can work. On the other hand, however, there are many more examples of well-meant initiations of knowledge communities which very quickly died following their launch. Cress & Hesse (in press) emphasize that there is very little scientific knowledge regarding the question as to *why* virtual communities are formed. Potential reasons might be the need for information exchange, the search for emotional peer support, or the desire to come into contact with people sharing common interests. What is clear is that common interest stimulates individuals to form or join a virtual community and electronically interact. But what are beneficial conditions for such knowledge communities? This question is of great relevance, even beyond educational contexts of formal and informal learning. Indeed the construction of a new culture of knowledge-sharing also constitutes a central focus of approaches to organizational knowledge management: large organizations, nowadays commonly distributed across continents, try to establish shared databases which permit individuals and groups who do not regularly interact face-to-face or do not even know each other to share information on concepts, methods, experiences, or good practices. Many of the early approaches to creating organizational databases failed. The question thus remains as to which conditions are advantageous for the effective running of such knowledge management systems, i.e., those which are productively used for extended periods of time to store and exchange relevant informational resources.

It turned out to be a particularly productive perspective, to consider membership in knowledge communities as a motivational issue in light of a social dilemma situation (Cress, 2005): contributing to such a community (e.g., entering some information into a jointly used database) necessitates costs for the individual (e.g., time, effort). Participating individuals have a better cost-benefit ratio, if they use the information contributed by other community members without contributing anything themselves. If nobody contributes, the community is dead. There is an ongoing series of studies aiming to identify conditions that hinder, foster, or moderate individual contribution to a community database (see Cress, 2005). There are indications that the design of community technologies can substantially influence interaction and knowledge exchange. However, effects of the design of knowledge sharing technologies are often neither straightforward nor direct, but rather moderated by individual prerequisites. For example, the effects of associating member portraits with respective individual contributions in a shared database environment affected the individuals' contribution rate depending on the individual social value orientation. When portraits of other community members were present, prosocially orientated, as compared with individualistically orientated participants tended to reduce their contribution rates (Cress, 2005).

3 Conclusions: Orchestrating integrated learning environments

In this article, we provided a summary of ten central ideas within CSCL research. Simply stated, collaborative learning per se is not effective since productive social interactions often do not occur spontaneously. Hence, CSCL environments must purposely be designed to trigger interactions that produce positive learning outcomes. The reported ideas supply more detailed information about the way in which CSCL environments may trigger specific interactions: by placing students in a situation in which they need to engage in effortful interactions in order to build a shared understanding; by selecting a task representation that will shape the language used by students; by directly prompting specific types of utterances using semi-structured interfaces; by structuring collaboration by means of scripts; by capturing interactions and either simply mirroring these to the group members or conducting deeper analyses. As a brief conclusion: in small-scale collaborative learning, **interactions can be designed**. This conclusion does not apply, however, to larger, often informal, virtual communities. Thus far, a deeper understanding of the individual and collective processes of knowledge-building and knowledge-exchange has not been attained and the development of principles for designing virtual communities is therefore still in its early stages. Multiple disciplines have begun to investigate the processes of emergence, development and decay of virtual communities. CSCL research is a forum in which these disciplines exchange their findings and thus may aid the identification of fruitful interdisciplinary research issues.

A further aspect which becomes apparent from the 10 ideas presented is that collaborative learning is not treated in a narrow sense. For instance, the scripts presented do not simply include collaborative learning activities (explaining a phenomenon to the learning partner) but also individual activities (reading documents, reflective writing etc.) as well as collective activities (e.g. presentation by the teacher, debriefing with the whole class). In addition, these approaches include activities both with and without computers, distributed across multiple places, using diverse tools (e.g., roomware, mobile devices). Therefore, instead of speaking of CSCL in such a broadened sense of the concept, we tend to use the notion of **integrated learning**, i.e. integration within a coherent pedagogical scenario of activities that occur across multiple social planes (individual, group and class) and places, and can be supported with multiple tools. In formal and informal learning settings, CSCL activities are embedded in more comprehensive sets of activities.

This article reviewed many ways to provide instructional support during collaborative learning. Scaffolds can be provided by the teacher or by the software; they range from a single prompt to a long explanation and from flexible to a prescriptive instructions; they may target individual, small group or whole class activities, and so forth. Tabak (2004) recently suggested the term *synergistic scaffolding* to address the challenges of productively coordinating supportive interventions on different levels. We referred to this as **'orchestration'** (Fischer & Dillenbourg 2006) in order to stress the role of teachers when conducting CSCL activities in schools and universities. Teachers are central to integrated learning approaches. The frequently used slogan "From the sage on the stage to the guide on the side" conveys a misleading interpretation of constructivism as 'teacherless' education. Instead, integrated learning brings teachers back to the foreground, where they are required to manage complex multi-layered activities in real time. The orchestration refers to cognitive, pedagogical and practical dimensions of a distributed CSCL environment. At the cognitive level, teachers need to regulate the interplay between individual learning mechanisms (e.g. induction), small group interactions (e.g. pair argumentation) and class-wide activities (e.g., presentations). At the pedagogical level, teachers must in real time adapt the designed activities to what is actually taking place in the classrooms. The awareness of these processes across different levels will be increasingly supported with intelligent technologies (e.g., Dönmez et al., 2005). At the technological level, orchestration is used to refer to the dynamic management of transactions between software components. We expect this orchestration perspective of integrated learning environments to become a key issue within both technological and educational research on technology-enhanced learning.

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