Communication and learning at computers: an overview

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The article highlights key findings from a research literature overview within the field of learning and communication, for face-to-face small group settings in which pupils use a computer. The overview surveys articles with a general learning approach and articles from the field of mathematics education. The purpose of the overview is to locate the most significant literature of the field and qualitatively summarize these articles by identifying the issues that are their focus. In addition, the article presents some of the sceptical arguments presented in the literature, and finally some important issues for future work are singled out.

There has been an enormous growth in the accessibility and usage of computers over the last decade. Loveless (2003) argues that information and communication technologies (ICT) have a considerable influence on our social, cultural and economic lives, as well as on education. Hoyles and Noss (2003) observe that, due to the growth of research on the use of ICT in education, it is no longer feasible to conduct an exhaustive review covering the whole field of computers in, for instance, mathematics education. Thus, although an extensive survey process has been conducted, this overview does not claim to be exhaustive.

A systematic overview of the research literature on a specific field illuminates what is known and, often indirectly, what is not known. The reflexivity of meta analyses structures the knowledge within a field and is important in establishing a mutual point of departure for further research, as Blomhøj and Valero (2009) argue. Overviews are of special importance in an area which involves such a dynamic and complex

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challenge as the implementation of computers in education. Despite the fact that the widespread use of computers in education has only occurred during the last one or two decades, a massive amount of school and research projects, journals, and new or revisited learning theories have rapidly emerged.

This article overviews only one branch of ICT in education: research on collaborative small group settings with a pronounced emphasis on the relations between communication and learning. The topic is situated in the computer-supported collaborative learning (CSCL) paradigm. According to Koschmann (1996b), the CSCL paradigm appeared in the early 1990s and succeeds the *computer-assisted instruction* of the 60s, the *intelligent tutoring systems* of the 70s and the *Logo-as-latin* paradigm of the 80s.

Crook (1994) outlines four different social configurations whereby computers enter into learning activities: collaborative interaction *with* computers (a computer-based tutor), collaborative interaction *around* and *through* computers (interaction can be asynchronous and participants not co-present), collaborative interaction *in relation to* computers (collaborators able to refer to previous computer experience), and collaborative interaction *at* computers. This overview deals with the latter and focuses on how computers can support learning within peer interaction when pupils, usually pairs, "[...] work on the same computer-based problem at the same time" (Crook, 1994, p. 148).

There are several reviews dealing with more general topics, such as ICT and learning, ICT and attainment, ICT and pedagogy, and the impact of ICT in schools (e.g. the annual BECTA reviews, Cox and Abbott (2004), Cox and Webb (2004), and Condie and Munro (2007)). An informative historical perspective on computer-supported collaborative learning is written by Stahl, Koschmann, and Suthers (2006). A review with a more narrow focus on how technology can support collaborative learning is conducted by Resta and Laferrière (2007). Lagrange, Artigue, Laborde, and Trouche (2001) make a meta study of the integration of ICT in mathematics education, which reveals the huge amount of literature in this field. An interesting review on handheld calculators in the learning of algebra is conducted by Persson (2009). All in all, there is an acknowledgment of a general improvement in attainment, but with certain reservations. A common choice of words in many publications is: "The use of ICT can enhance pupils' learning *if* [...]" Cox and Marshall (2007) and Baron and Bruillard (2007) state strongly that there are in fact hardly any conclusive results associated with ICT, education, and pupils' learning outcomes. Many large-scale studies, Cox and Marshall (2007) argue, only reveal in depth cause-and-effect mechanisms to a certain degree. On the other hand, there are a number of small-scale experiments, Baron and Bruillard (2007) claim, which involve only a few students and teachers and which have a strong contextual dependency. A variety of assumptions are made and thus the results generated have great limitations. Meta studies which aim to synthesize micro-level studies with a more narrow focus on communication and learning in a computer context are few and far between. This overview study synthesizes the knowledge of the deep structure effects of teaching and learning and is one way of overcoming some of the limitations pointed out by Baron and Bruillard and by Cox and Marshall.

This overview is written from a theoretical perspective based on a dialogic (Bakhtin & Holquist, 1981; Linell, 1998; Rommetveit, 1992), distributed, and situated (Lave & Wenger, 1991) view of learning. Collaborative meaning-making and negotiation, the group as the unit of analysis, meaning not attributable to one individual, and the "attunement to the attunement of the other" (Rommetveit, 1992) are key aspects. Pupils' learning is viewed as interplay between social interaction and the pupils' own construction. Language is viewed as the foundation of the acquiring of understanding – the process of understanding is actuated by linguistic utterances. As Habermas (1991) argues, shared understanding is constructed through language. Gadamer and Wittgenstein hold a similar point of view: "[L]anguage is the universal medium in which understanding occurs" (Gadamer, 2004, p. 390) and "[l]anguage is the vehicle of thought" (Wittgenstein, 1953, p. 329).

On the basis of this view of learning, an overview which emphasizes the communication and learning when pupils work in small groups using a computer has been conducted. The following question guided the literature search and analysis: What are the important aspects in promoting pupils' talk and reflections in small group settings using a computer? The aim of the text is to provide an overview of a complex research area and to identify important research aspects and challenges. And, as one of few overview texts, this article can make an important contribution to the knowledge base of a rapidly evolving research area.

Method

The overview surveys empirically-based articles in computer-supported collaborative learning that focus particularly on communicative aspects. A time period of the last ten years is chosen as to ensure enough diversity, to make in depth reflections possible and to achieve an up to date overview of the current situation. However, the most influential and pioneering articles of the 90s have also been included, as they provide information about the issue, give the overview an historical perspective, and they show the first steps of the field.

A search strategy was developed to locate potentially relevant articles. A very extensive electronic full-text access provided by the University of Bergen was of great help. Initially, general search engines were used to locate relevant conferences, research projects, associations, and websites, and the reference lists of relevant articles were scrutinised. This served as an important approach in order to gain an overview of the field. Key terms were then developed and refined for both manual searching and for search engines as ERIC, Science Direct, MathEduc, ProQuest, and Web of Science. Developing criteria for including or excluding articles was an important part of the survey process.

Inclusion and exclusion criteria, quality assessment

Communication and ICT are two generic terms in this overview. The communication part is face-to-face communication *at* computers involving pupil dyads or triads and occasionally the teacher. The ICT part is concentrated on how computers influence pupils' learning and communication. The articles about how computers can stimulate talk on a particular subject matter are of special interest, and the articles reflecting upon and identifying connections between communication and pupils' learning are the cornerstone articles in this overview.

There are two main challenges involved in conducting a meta-study on computer and communication in education. First, if one types terms like ICT, computer, or technology into search engines there will be a massive amount of hits. Second, in the field of ICT and education, a conglomerate of terms is used. The latter is illustrated by all the different terms researchers use when they write about communication (see the last row of table 1). The key terms listed in table 1 are used in search engines one by one and in many different AND-OR-NOT combinations. However, due to the two challenges mentioned, manual searching was required throughout the survey process.

Surveying articles can be described as a three-step process. Step one was an initial screening to locate relevant articles. The first screening resulted in a massive amount of articles, many of which were published in journals with some sort of emphasis on computers and learning. In addition, there were relevant articles in other journals, some of which were published in special issues. Step two was an extensive reading process, in which very many articles were excluded due to a lack of thematic relevance. The articles that made it through the third step were on topic and entailed a transparent methodological approach, in depth reflections, excerpts of verbal communication, and an analysis of

Table 1. *Criteria and key terms for inclusion and exclusion of articles*

Criteria	**Include articles if they are**	**Exclude articles if they are**
Level	Focusing on primary to upper secondary (grades 1-12)	From kindergarten and university
Design	Based on a qualitative or a mixed method design	Based on a pure quantitative design
Data	From micro-level, in-depth studies	From macro- and meso-studies
Learning perspective	Sociocultural, emphasizing the importance of language and communication for pupils' learning, regarding learning as participation	Focusing on instruction, drill, memorizing, individuality

Key terms	**Including searching terms**	**Excluding searching terms**
ICT	Computer, technology, software, digital	Hardware, informatics education, handheld device, whiteboard
Communi-cation	Collaboration, cooperation, co-work, talk, discussion, conversation, dialogue, interaction, reasoning, meaning-making, peer, pupil-pupil, shared, joint, verbal	Written, long distance, e-learning, asynchronous or web-based communication (blogs, wikis, asynchronous communication)

communication. The survey process was very much a cyclic and iterative process and not as linear as described here. The key search terms were continuously refined in order to locate the articles that were eventually included in the overview.

The selection process culminates in a quality assessment based on a co-reading- and discussion process with colleagues. Articles pass the in/exclusion criteria if they are regarded as (1) well written and reflective – the conclusions/results are not bombastic but reasonable and in line with the data, 2) transparent with regard to methodology and theoretical grounding, and 3) published in well recognized peer-refereed journals. The included articles are given one, two or three stars according to thematic relevance to indicate their "relevance factor", see tables 2 and 3. Achieving three stars requires a thorough analysis of communication versus learning.

In the following, the key issues from the articles are presented and sorted in what Lagrange et al. (2001) call "problématiques". The problématiques are generated through a "code-and-retrieve" process in which the articles are iteratively sorted and labelled according to the questions they address. Eventually, four problématiques stood out as dominant throughout the material. Many of the articles address issues within more than one problématique and some even address all four of the problématiques. Thus, these problématiques are not mutually exclusive. The next

Table 2. *Overview of articles – Education in general*

Nr.	Year	Author	Title	Relevance	Learning perspect.	Context, method	Content: Pair	Comm.	Comp.	Topic	Focus
1	1993	Fisher	Characteristics of children's talk at the computer ...	***	Sociocultural	10 schools, 15 teachers, 50 pupils 5-13 y, video rec., observation and interviews	Yes	Yes	Yes	Games	2, 3, 4
2	1993	Teasley, Roschelle	Constructing a Joint Problem Space: The Computer as ...	***	Learning as a social activity. Participation, share meaning	2 pupils, 15 y, 3 sessions, micro-analysis: pragmatics, conversation- and protocol analysis	Yes	Yes	Yes	Physics: velocity, acceleration	1, 2, 3
3	1994	Mercer	The quality of talk in children's joint activity at the ...	*	Sociocultural	10 schools, 15 teachers, 50 pupils 5-13 y, video rec., identify talk patterns	Yes	Yes	Yes	Games, writing, maths, art	2, 3, 4
4	1996	Wegerif	Using computers to help coach exploratory talk across the ...	*	Sociocultural exploratory talk, thinking skills	2 schools, 50+ pupils, 9-10 y, control groups, pre/post tests, discourse analysis, qualitative and quantitative	Triad	Yes	Yes	Science, citizenship	1, 2, 3, 4
5	1998	Wegerif, Mercer, Dawes	Software design to support discussion in the primary ...	**	Collaboration, talk	Findings from SLANT project, pupils 9-10 y, identifies comm. factors	Dyad triad	Yes	Yes	Science: friction	3, 4
6	1999	Anderson et al.	The effect of software type on the quality of talk	***	Sociocultural Talk	1 secondary school, 10 dyads, videotaping, coding of interaction	Yes	Yes	Yes	English and mathematics	2, 4
7	2003	Wegerif, Littleton, Jones	Stand-alone computers supporting ...	*	Dialogic, exploratory talk	Primary schools, series of design studies, control groups, comm. analysis	Yes	Yes	Yes	Co-ordinates, friction	4
8	2004	Wegerif	The role of educational software as a ...	**	Sociocultural	Primary schools, 119 pupils, 129 in control group, comm. analysis	Dyad triad	Yes	Yes	Science, moral issues	3
9	2005	Stahl	Group cognition in computer-assisted collaborative ...	**	Vygotsky, Lave/Wenger	K-12, F2F and online, discourse analysis, locate examples	Small group	Yes	Yes	Mathematics	1
10	2005	Wegerif	Reason and creativity in classrooms ...	*	Dialogic	7-10 years, reanalyses earlier case studies, communication analysis	Dyad, triad	Yes	Yes, mainly	Logics, philosophy	2
11	2008	Rojas-Dr., Albarrán, Littleton	Collaboration, creativity and the co-construction ...	**	Sociocultural	2 classes, 56 4th grade pupils, 12 sessions à 90 min, communi. analysis	Triad	Yes	Yes	Construct texts/stories	2
12	2009	Nussbaum et al.	Technology as small group face-to-face collaborative ...	**	Sociocultural collaborative scaffolding	3 schools in UK grade 6, 2 schools in Chile, 1 month, observation	Indiv, triad, full cl	Yes	Yes	Math, science and art	1, 3
13	2009	Mavrou, Lewis, Douglas	Researching computer-based collaborative ...	***	Sociocultural social constructivism	1 school, 20 dyads (1 disabled in each dyad), 7-11 years, discourse analysis	Yes	Yes	Yes	Writing activities	3
14	In press	Panselinas, Komis	Using educational software to support collective ...	*	Collective thinking and learning	1 upper sec. school, 3 groups, 7 pupils, video rec., discourse analysis	Dyad triad	Yes	Yes	Computer science	2, 3, 4

section summarises the findings, presents some of the common critiques, and raises some important issues for further research.

Extracted results

The first main result that has been extracted from the articles is the importance of establishing a shared language and communicative understanding, a common ground to stand on. The second result concerns communication characteristics and the third focuses on different aspects of the roles that pupils, teachers and computers can play in this educational setting. The fourth result concerns the implications of software design and task structure.

Eventually, 27 articles were included in the overview. There are 14 articles with a general learning approach, as presented in table 2, and 13 articles on mathematics education, as presented in table 3. The tables also include a brief analysis to indicate their research context. The numbers in the column on the right indicate the problématiques of the articles: 1: common ground, 2: communication characteristics, 3: roles, and 4: software design.

Table 3. *Overview of articles – Mathematics education*

Nr.	Year	Author	Title	Relevance	Learning perspect.	Context, method	Content				
							Pair	Comm.	Comp.	Topic	Focus
1	1995	Healy, Pozzi, Hoyles	Making Sense of Groups, Computers, and Mathematics	*	Social construction	Case study, 7 classes, 8 groups a 6 pupils, 9-12 y, quanti- and qualitative	3 pairs together	Yes	Yes	Programming and angles	1, 2
2	2000	Ainley, Nardi, Pratt	The construction of meaning for trend in active graphing	**	Social perspective	4 pairs, 8-9 y, 4 weeks, qualitative analysis, categorisation	Yes	Yes	Yes Excel	Graphing	4
3	2000	Jones	Providing a foundation for ...	*	Sociocultural, Van Hiele	1 class, 7 pairs, 12y, 9 month, analyses pupils' explanations	Yes, mainly	Yes	Yes DGE	Geometry	2
4	2001	Kieran	The mathematical discourse of 13-year-old partnered ...	***	Language, discourse, communication	6 pairs, 13 y, qualitative, a tool for interaction analysis	Yes	Yes	Yes	Functions, graphs	2
5	2003	Goos et al.	Perspectives on technology mediated learning ...	**	Sociocultural, cultural tools	3 years, 2 schools, 5 classes, ethnographic techniques + cases	Yes, mainly	Yes	Yes Excel	Functions (algebra)	3
6	2004	Lavy, Leron	The emergence of mathematical collaboration in ...	***	Sociocultural	Junior HS, 2 pupils, case study, interaction analysis	Yes	Yes	Yes	Number theory	1, 2, 3
7	2005	Sinclair	Peer interaction in a computer lab: reflections on ...	***	Peer learning collaboration	2 schools, 3 classes, grade 12, 11 sessions, case study, coding, categories	Yes	Yes	Yes DG	Geometry	2, 3
8	2005	Monaghan	'Don't think in your head, think aloud': ICT and ...	**	'The thinking together' approach	4 schools, 6 classes, 12 lessons, 9-10 y, locate key words and episodes	Yes	Yes	Yes	Mathematical games	1, 2, 3
9	2006	Åberg-Bengtsson	"Then you take half ... almost" – Elementary students ...	*	Sociocultural, situated	3 schools, 40 pupils, 7-12 y, 6 lessons, locate interesting sections	Yes	Yes	Yes + paper/pencil	Graphing	4
10	2006	Lavy	A case study of different types of arguments emerging ...	***	Sociocultural Argumentation theory	1 school, grade 7, case study 2 pupils, inductive and interaction analysis	Yes	Yes	Yes Logo	Geometry, number theory	2, 3
11	2007	Pijls et al.	Reconstruction of a collaborative mathematical ...	**	Van Hiele, collaboration	Montessori, 2 pupils, 16 y, 10 lessons, 'locate episodes'-analysis	Yes	Yes	Yes	Probability	2
12	2009	Lantz-Andersson	The power of natural frameworks: Technology and ...	**	Sociocultural, cultural tools, CSCL	Case study, 1 school, 34 pupils, 16-18 y, interaction analysis	Yes	Yes	Yes	Percentage	2
13	2009	Wyndhamn, Säljö	Meaning-making and the appropriation of ...	*	Sociocultural, Cultural tools Appropriation	18 pupils, 12 y, 1 lesson à 30 min., categorising transcriptions	Yes	Yes	Yes, mainly	Geometry, area and perimeter	2

Establishing a common ground

In order to facilitate communication, to stimulate an inquiring and ongoing dialogue, Stahl (2005) argues that establishing a *common ground* is of vital importance. It is a shared frame of reference, and as Teasley and Roschelle (1993) argue, a body of shared knowledge. A common focus of attention (Crook, 1994) and the importance of a common group goal (Healy, Pozzi & Hoyles, 1995) are relevant common ground aspects. The computer itself is, literally speaking, providing a common ground for pupils' interaction when pupil dyads work at a computer. Monaghan (2005) claims that the computer frames the pupils' interaction and provides "[a] focal point of attention for the two participants" (Lavy & Leron, 2004, p. 21).

Teasley and Roschelle's (1993) *Joint problem space* concerns aspects such as the mutual understanding of goals and problem-solving actions, and builds on the concept of common ground. Several authors emphasize that collaboration does not yield learning in itself (e.g. Healy, et al., 1995; Nussbaum et al., 2009; Sfard & Kieran, 2001). Being able to explain, to justify, and rephrase ideas is not common behaviour among learners (e.g. Lavy, 2006; Pijls, Dekker & Hout-Wolters, 2007). Within CSCL, the generation of collaborative understanding is explained by the common ground theory developed by Clark and Brennan (1991). "Grounding" is the important collective process in which common ground is maintained and developed. Equivalently, Teasley and Roschelle (1993) point out that collaboration entails two concurrent activities: solving a task and building a joint problem space.

Many articles in this field of research derive from or relate to the *Thinking together project* in the UK. Thinking together is a programme that is designed to increase pupils' awareness and use of spoken language in small groups. There is a focus (e.g. Monaghan, 2005; Nussbaum, et al., 2009; Wegerif, 1996b) on the common ground related development of ground rules for how to talk and interact in the classroom. Series of off-computer talk lessons (e.g. Monaghan, 2005; Wegerif, 2004) are conducted in order to talk about talking, agreeing on ground rules and practising the ground rules of exploratory talk. The view that communication- and thinking skills are not innate is central to this approach, and up to date research like that of Nussbaum et al. (2009) confirms the view that it is necessary to teach pupils how to work together to negotiate meaning.

Communication characteristics

Stahl (2005) takes a critical look at the concept of *shared meaning*. Meaning is viewed as something that is created collaboratively by a group as a whole. It is the interplay between group and individual learning, between group and individual processes. Stahl argues that it is not shared group meaning *or* individual interpretations but *both*, a combination of the two. Teasley and Roschelle (1993) find that group knowledge is achieved in discourse and cannot be attributed as originating from any particular individual. Stahl raises the question of whether knowledge constructed in community contexts can exceed the individual knowledge of the group's members. The answer *yes* to this question is taken by Stahl as the hallmark for collaborative learning.

Barnes and Todd (1978) identify three different types of talk in small groups: explorative, cumulative and disputational. This categorisation of talk is used to a large extent by Mercer and Wegerif in dealing with small groups in computer-based activities in school (e.g. Mercer, 1994; Wegerif, 1996b). Disputational talk is characterized by disagreement and individualism. In cumulative talk, pupils build on each other's utterances, but in an uncritical manner. Within explorative talk there is no immediate acceptance of views, as in uncritical acceptance. Nor is there an immediate rejection as a quick defence of one's own knowledge or viewpoints. On the contrary, in explorative talk there are challenges and disagreement within a collaborative environment.

Monaghan (2005) is one of the researchers who has worked with the concept of explorative talk more recently, while Staarman, Krol, and Meijden's (2005) term, *elaborative interaction*, represents an almost identical meaning. Both Monaghan and Staarman et al. emphasize the importance of posing higher-order questions, providing elaborated explanations, referring to earlier knowledge, summarizing, and developing common ground in order to enhance pupils' learning. Nussbaum et al. (2009) stress, as do all the abovementioned authors, the role of language as a fundamental tool. Language makes elaboration, explanation, evaluation, exploration, and clarification possible – sharing and explaining ideas, negotiating. It all sums up as verbalisation. The importance of thinking aloud and making thinking public, with respect to learning, is explicitly emphasized by Monaghan (2005) and Kieran (2001), for example.

Wegerif (2005, 2007) introduces a fourth type of talk, *playful reflective talk*, both off- and on-task. He argues that although exploratory talk is a useful pedagogical tool, there is another useful way of talking that is more typified by verbal creativity than explicit reasoning. Wegerif situates playful talk within the dialogical paradigm of Rommetveit (1992) and Linell (1998). Wegerif argues that playful reflective talk can expand the concept of exploratory talk into a broader dialogical model of reason.

Explorative and playful talk has many similarities with Alrø and Skovsmose's (2002) *Inquiry co-operation model*. Like Wegerif and Mercer, they aim at illuminating the relationship between talking and learning. Alrø and Skovsmose point out several key factors for successful inquiring talk: to verbalize and express one's thoughts, to pay attention to each other's perspectives, and to justify, challenge and evaluate these perspectives. Communicative characteristics, such as sharing information, negotiation, synthesizing perspectives, shared decision making and maintaining channels of communication, are accentuated as important in pupils' learning by Healy, et al. (1995) and Rojas-Drummond, Albarrán, and Littleton (2008). Teasley and Roschelle (1993) share this focus on verbalization. They identify several communicative qualities that enhance pupils' learning: asking questions and framing statements as questions, restating the other's utterance, and making communicative "repairs" through which pupils can resolve problems or misunderstandings. As a part of the emphasis on mutuality, both Sinclair (2005), Kieran (2001), and Teasley and Roschelle (1993) find that pupils sometimes complete each another's sentences. Consistent findings are made by Pijls, et al. (2007), and their research also shows that pupils who regularly explain and criticize themselves are more likely to lift their level of mathematical performance.

Fisher (1993) and Crook (1994) relate to the work by Sinclair and Coulthard (1975) when they identify IRF communication structures (*Initiative*, *Response* and *Feed-back*) in children's talk at the computer. Fisher finds that highly structured software more often leads to IRF structured talk while open-ended software leads to more varied talk that goes beyond the IRF model. The former is associated with the transmission model of learning and the latter with learning through discovery and constructivist approaches. Another significant finding by Fisher is that when using highly structured software, the computer generally takes on both the Initiative and the Feed-back part. In more open-ended software the pupils are much more likely to take the Initiative and provide any Feed-back. Lantz-Andersson (2009) identifies a challenge for software in which the only feedback pupils get is whether they are right or wrong; when pupils get the response "incorrect", they sometimes think there is something wrong with the software or they think the computer wants the answer in a different format. Rather than examining their own mathematical reasoning the pupils try to please the technology.

Wegerif (e.g. 1996a; 2004) adapts and modifies the IRF structure into an IDRF structure (*Initiative*, *Discussion*, *Response* and *Feed-back*). In the IDRF structure the pupils spend time discussing an issue, rather than giving an immediate response to the computer's initiative. The IRF part is pupil-computer interaction, while the D part is purely pupil-pupil spoken interaction. Wegerif's research shows that highly structured or directive software can also facilitate discussion and explorative talk, not only talk confined to the IRF model. Panselinas and Komis' (in press) findings reinforce the view that directive software cannot be equated with the transmission model of learning.

Wyndhamn and Säljö (2009) and Lavy (2006) extract four categories of utterances or a four-step continuum of pupils' communication at the computer. At one end there is the type of communication that is totally dependent on screen images and entails little mathematical reasoning. At the other end, mathematical concepts and considerations constitute a large part of the communication and discussion has moved beyond strong dependence on the computer screen. Lavy and Leron (2004) and Jones (2000) also discover how pupils' communication gradually changes from being mainly computer-related to being mathematically focused.

The quality of the computer's communicative support depends on the communicative characteristics of the software and, as Panselinas and Komis (in press) and Wegerif, Littleton, and Jones (2003) stress, the technological pedagogical framework provided by the teacher. In addition to the computer and teacher variables, Mercer (1994) calls attention to the pupil variables, particularly their interpretation of the aims and ground rules for collaboration. The roles of teachers, computers and pupils are closely related to the quality of communication and the communication characteristics. In the next section, the role of the pupil, teacher, and computer will be further elaborated upon.

The roles of teachers, computers, and pupils

In the *Thinking together project* the pupils are explicitly taught about exploratory talk and they do exercises designed to develop their communicative awareness and abilities. According to Wegerif, Mercer, and Dawes (1998) and Monaghan (2005), for example, the teacher guides and models the pupils' use of explorative talk. They find that the quality of pupils' talk can be enhanced by off-computer talk lessons and coaching. The role of motivator (e.g. Nussbaum, et al., 2009; Panselinas & Komis, in press), to encourage the pupils to explain and verbalize their opinions and thoughts, is another function assigned to the teacher. Furthermore, the teacher has a "crucial role to play in orchestrating fruitful collaboration" (Nussbaum, et al., 2009, p. 150). According to this literature, the teacher can take on the role of a role model, a facilitator, a motivator, and a conductor in order to stimulate pupils to think aloud, to justify reasoning, to ask questions, to come up with alternatives and so forth. All in all, there is a profound acknowledgement of the importance of the teacher's role, also in computer settings. Panselinas and Komis (in press) find that the teachers' role is particularly important when open-ended software with little feed-back is used.

The computer or the software design can support pupils' talk (Wegerif, et al., 1998). In fact, Teasley and Roschelle (1993) and Lavy and Leron (2004) claim that the computer provides language when pupils lack a technical vocabulary. Typically this involves non-verbal communication and the computer display serves as a shared frame of reference. Wyndhamn and Säljö (2009) use the term *deictic* and Lavy (2006) the term *basic* for this type of utterances, ones that are very much based on screen images. The activities or objects on the screen become an important and integrated part of pupils' arguments and turn into a type of reasoning which is impossible to understand without screen access. Mavrou, Lewis, and Douglas (in press) find that the computer releases pupils' language and provides scaffolding for the verbal interaction between the pupils. The scaffolding function of technology is also emphasized by Nussbaum et al. (2009). Løvlie (2006) stresses that one has to leave behind the classical opposition between man and machine. It is not pupils on the one hand and the computer on the other. It is interplay between pupils and the subject matter and between pupils and the machine. Säljö (1998) views learning as the use of tools and computers as artefacts which strengthen the pupils' embedded skills. Learning is not only connected to the pupil, but to the unit consisting of the pupil and the tool.

The computer can prompt, respond and frame the learning dialogue just as teachers can, but unlike teachers and peers they have infinite patience, they do not have expectations and are not judgemental (Monaghan, 2005). Monaghan argues that this enables a powerful space for the pupils' discussion. When one pays more attention to the role of the computer, an ambivalent ontological status occurs. Computers can act like subjects when they respond to inputs in such a manner that pupils get the feeling they have to justify their responses. On the other hand, computers are objects. They do not have feelings or expectations. Wegerif (2004) points out that this dual role of computers makes them able to play a unique part in stimulating pupils' learning talk. In Monaghan's study (2005) the computer is, to a large extent, considered by pupils to be a quasi human male agent. The pupils, when referring to the computer, used masculine pronouns such as *he* and *him*. In the study by Lavy and Leron (2004), the computer is regarded as a "third participant"; a pupil uses screen images to express himself and the other pupil uses the same screen images to interpret these utterances. Goos, Galbraith, Renshaw, and Geiger (2003) discuss four roles for the computer that add to the other findings presented here: computer as a *master* that is trusted blindly by the pupils, as a *servant* that can carry out tedious calculations (cf. Åberg-Bengtsson in the next paragraph), as a *partner* that mediates mathematical discussion (cf. Wegerif, Lavy & Leron, etc.), and as an *extension of* *self* where the computer is incorporated as a natural part of the pupils' competencies. Goos et al. point out that the teacher is very important in order to help pupils move from the computer as master metaphor on to the three other more fruitful applications of computers.

Pupils are regarded as *participants* in line with Skjervheim's (1996) disjunction of participant-spectator, as talkers and collaborators who make arguments, raise questions and explain their ideas (e.g. Nussbaum, et al., 2009; Wegerif, et al., 2003). Sinclair's (2005) research shows that the partner's role is more influential than the researcher expected. The pupils not only share information, they also attempt to affect their partner's knowledge. It is a form of peer-peer teaching and the pupils are inviting, modelling, correcting and informing each other. They adopt a teaching role. But when the teacher is not present, who is in control, the computer or the pupils? Are the computers "programming children" or are the children, as Papert (1981) wanted it, "programming computers"? Is the software a "tutor" or a "tool" (Crook, 1994)? This is closely related to the extent to which the software is open-ended and gives freedom to the pupils, or whether it is more directive and closed. In what follows, the effects of different software design and different task structures are identified and discussed.

Software design and task structure

Software design is in many respects the equivalent of task structure or, more precisely, one could say that task structure is embodied in the computer software. Many of the findings highlighted in this section are related to the early work of Fisher (1993) and Mercer (1994), especially the discussion of open and closed software. Many researchers focus on the software type and how the characteristics of the task affect the quality of the talk.

In a programme where the software is designed to support talk and to direct it to particular curriculum areas, the evaluation shows improved group cognition (e.g. Wegerif, 1996b). Wegerif et al. (1998) add to this when they identify several design features as being effective for supporting explorative talk: the elements on the screen that help pupils' reasoning are easy to point to, there are multiple choice options, and the problems are made sufficiently complex so that reflection and discussion are needed and mechanical turn-taking is avoided. Also competitive software can motivate reasoning. Competition is often associated with disputational talk. However, Wegerif et al. (2003) argue that if the pupils have developed productive ways of working and communicating together, then the competitive aspect can be fruitful.

Wegerif et al. (2003) show three distinct ways that software can support pupils' learning dialogues. First, a computer can stimulate and direct pupils' communication by using productive feedback. Second, a group strategy game combined with preparation for exploratory talking can enhance pupils' learning. Third, software like *Bubble dialogue* allows groups to externalize thoughts.

In mathematics education, the software design of dynamic geometry is one curricular resource. Many researchers, for example Ruthven, Hennessy, and Deaney (2008), focus on software that makes dynamic manipulation like *dragging* possible. Dragging provides opportunities to focus on continuous dynamic variation, which substantially moves mathematical activity beyond established norms. Spreadsheets with appropriate graphing functions offer another software opportunity. Åberg-Bengtsson (2006) finds that graphing software releases pupils from time-consuming and tiresome work and this makes the conditions favourable for pupils' subject matter discussions. Similarly, Ainley, Nardi and Pratt (2000) find that the spreadsheet's graphing possibilities facilitates pupils' interpretation and discussion. Ainley et al. argue that the pupils can focus their attention on mathematical connections rather than using most of their time and energy on technicalities and detailed time-consuming paper and pencil constructions.

In the earlier discussion about communication characteristics, the research by Fisher (1993), Crook (1994), and Wegerif (e.g. 2004) on the relationship between IRF communication structures and open-closed software was elaborated upon. Open and closed software is distinguished by the number of options, the degree of prompting and the granularity of the task. The open-closed distinction is more a continuum than a dichotomy. Software characterized as open has, according to Anderson, McAteer, Tolmie, and Demissie (1999), many options, few prompts and consists of larger chunks. They find that open software generates more question posing, more querying, more explaining, countering, and turning to the other, while closed software generates more assessing and informing. Thus, their research adds to Fisher's (1993) research, and they conclude: "[...] there is evidence that the structure of the computer task does indeed affect dialogue among users of the software [...]" (Anderson, et al., 1999, p. 39).

To extend the open-closed debate one could talk about end-user tailorability. More open structured software gives the pupil the opportunity to adjust the task to his/her needs. One concept developed within the CSCL paradigm which has several features in common with the open-closed continuum is *scripting*. Scripting is "a story or scenario that the students and tutors play as actors play a movie script" (Dillenbourg, 2002, p. 71). Silverman (1995) emphasizes openness and minimal instructionism while what Dillenbourg (2002) terms as ”over-scripting” is the other end-point. A reasonable dosage of structure and openness might be situated somewhere in between these two extreme points.

Samuelsson (2006, 2007) observes that in many studies of mathematics learning, a common differentiation is made between tool and drill programmes. Drill programmes, which focus on memorizing and procedural training, belong to a behaviouristic paradigm. Tool programmes are often situated in a cognitive tradition. Most of the articles presented in this overview, however, emphasize collaborative learning with the predominant aim of making pupils able to participate in a learning community. Wyndhamn (2002) is an example of a researcher who focuses on organizing pupils in smaller groups in order to stimulate the pupils' joint discussion and investigation of mathematical phenomena. This is within the sociocultural learning paradigm. Koschmann (1996a) discusses more thoroughly the link between how computers are used in education in relation to views on learning.

Summary

What are the important aspects in promoting pupils' talk and reflection in small group settings using a computer? Analysis of the perspectives and results from the reviewed articles generated four main problématiques: (1) common ground, (2) communication characteristics, (3) roles, and (4) software design. These areas are all interconnected. For instance, how common the common ground is and how the software is constructed both influence pupils' communication and how pupils relate to each other. The foundation of this overview is the link between the quality of pupils' talk and reflection and the quality of pupils' learning outcomes. This link is indentified and illuminated by the research presented in this overview.

There are both pro and con arguments that emerge from the selected literature. However, there are four problématiques which are brought up as fundamental to pupils' talking and learning. Establishing *common ground* was stressed by many authors as a key issue. Pupils and teachers need to share a minimum amount of language and subject matter knowledge in order to be able to collaborate fruitfully. So, what does fruitful collaboration look like? Talking is *the* important collaborative factor and many articles focus on *communication characteristics*. Enhancing the pupils' ability to construct and verbalize explanations is accentuated. A special type of talk characterised as explorative, inquiring, creative, challenging, and argumentative in a collaborative framework is considered as especially valuable for pupils' learning. A great benefit of this kind of talk is that, as Dawes, Mercer, and Wegerif (2000) and Harré and Gillett (1994) point out, the process of talking and reasoning aloud can serve as a basis for succeeding individual thinking. The interplay between group and individual learning, combined with the view of collaboration as co-construction rather than pure individual learning which just "happens relatively close in time and space", is a key pillar of the sociocultural learning perspective.

The *roles* of teachers, computers, and pupils are at the centre of many discussions. The implementation of computers in the classroom does not reduce the teacher's great importance in pupils' learning, as a coach, a facilitator, a discussion partner, and linguistic role model. Based on the literature, the quality of communication can be improved by off-computer coaching and by software design which supports productive discussion and also curriculum learning. Researchers emphasize not only the pupils' verbal activity but also their development of meta-language. The extent to which the pupils are in control of their work depends on how the teacher arranges the lesson and on the *software design*. The computer can serve as a tool which pupils can adjust and use according to their needs, or it can be far more directive, leaving the pupils with few opportunities to influence the task structure. However, it is stressed by Wegerif, et al. (1998), for example, that it is not the software alone which defines the educational activity, but the software within a pedagogical context.

Sceptical voices

There are also sceptical voices with respect to how the use of ICT impacts on learning and attainment. Computer-based learning is too often assimilated into old traditions, both methodologically and content-wise. This is a well known challenge examined by Samuelsson (2006, 2007) in his studies. He points out that although many people think ICT tools have the potential to play an important role in pupils' learning, very little happens in everyday teaching. A great many computer-aided lessons focus on drill and procedural knowledge. Samuelssons's data show that linguistic interaction is constituted by one pupil posing a question and the other pupil giving an answer. Very little of the talk includes any use of or reflection upon scientific concepts. Corresponding findings are made in the ImpaCT2 project (BECTA, 2004). Cuban (e.g. 2001) has conducted several studies showing that the use of ICT in education is neither widespread nor consistent. The latest BECTA reports (2005, 2007), however, show a significant improvement with regard to motivation, collaboration, communication and learning, if there is a whole school commitment and if ICT is combined with what Mishra and Koehler (2006) term as technological pedagogical content knowledge. Wyndhamn (2002) point out that the teacher's support is often lacking when pupils collaborate when using a computer. Thus, Mishra and Koehler's emphasis on describing a framework for teacher knowledge for technology integration is highly relevant.

Somewhat less concrete is the fact that according to Hennessy, Ruthven, and Brindley (2005), there is a rhetoric about how technology is going to revolutionize teaching and learning. Warschauer (2007) points to a similar view: the myth of both autonomous and out-of-school learning with ICT. Also Haugsbakk and Nordkvelle (2007) examine the rhetoric of ICT with respect to learning, and the best example might be the frequent use of the concept "interactivity" during the 80s and 90s. Based on the literature in this overview, such rhetoric now seems to be more common amongst politicians than among scholars working with education.

Beauchamp and Kennewell (2008) claim that much ICT use is at a relatively superficial level of interaction. They go on by saying that when a deeper, reflective level is used, ICT based teaching is no better than teaching without ICT. Another issue that makes it increasingly difficult to exploit the potential of ICT is the fact that teachers often use ICT as an "add-on" rather than conducting ICT supported learning integrated with traditional, effective learning methods (e.g. Richards, 2005, 2006).

Most of the criticism of the use of computers in education is based on descriptive-analytic, non-intervention research. It is research *on* education and not an attempt to improve and develop teaching and learning *together* with teachers and pupils. This indicates that how computers are used in school today needs to be elaborated upon and further developed. It does not indicate, however, that ICT based teaching lacks the potential to enhance pupils' learning and development. In other words, the potential for ICT to support dialogic teaching-learning is noted, but descriptive-analytic research reveals that the field is changing and there remains a need for inquiry into many issues.

Important issues for future work

To gain more insight into pupils' learning in collaborative face-to-face settings using computers one must acknowledge that there is "[...] a pressing need for naturalistic studies more directly grounded in the actuality – and contingency – of teaching" (Ruthven & Hennessy, 2002, p. 51). However, it is well documented that a wide spectrum of research shows there is a propensity for teachers to talk and pupils to listen (Galton et al., 1999). Alseth, Breiteig, and Brekke (2003) found that in Norway the dominant teaching method in mathematics is pupils sitting one and one, the teacher making an introduction, and the pupils solving tasks individually; compare this to the concept of the exercise paradigm (Mellin-Olsen, 1991). Similar results in science education reveal that there is little time allocated for pupil talk (Newton, Driver & Osborne, 1999). Wegerif refers to several studies which indicate that children "[...] have very little opportunity to engage in intellectual enquiry through talk [...]" (1996b, p. 52). Similarly, Artigue's (2000) and Fuglestad's (2009) research shows scarce use of computers, especially in the learning of mathematics. These findings offer a convincing argument for conducting research that aims to develop both the amount and the quality of pupils' (1) talk in the learning of mathematics, as well as in other subjects, and (2) use of computers in educational settings.

The focus of this overview has been on talking and learning within face-to-face interaction. There are many studies of virtual interaction using means such as MSN, Skype, and LMS systems which generate results that are also highly relevant to face-to-face interaction. An interesting and important issue in future work will be to identify the knowledge which is transferrable from one area to the other. This overview also shows that there is primarily a focus on verbal interaction. The study by Wyndhamn and Säljö (2009) is an exception, as they also inquired into non-verbal aspects as the deictic level of communication. So, in addition to looking into the relationship between virtual and face-to-face communication, one should also investigate the relationship between verbal and non-verbal communication.

Sørensen, Danielsen, and Nielsen (2007) point to a key finding from the Danish project *ICT in new learning environments*. It is, according to this project, possible to use ICT regularly, alongside and integrated with traditional forms of teaching and learning. This makes it possible to create a holistic teaching and learning plan in order to prepare pupils for the knowledge society. A holistic approach could help to avoid the problem pointed out by Richard (2005, 2006), namely that the use of computers only turns into isolated happenings and add-ons. Säljö (1998) reminds us of a well-established benefit of computers; they make powerful visualizations possible. In the learning of mathematics, a well-documented domain where ICT has proved useful is the visual representation and dynamic effects in graphing and geometry (Hennessy, et al., 2005). Thus, when working with topics such as functions and geometry, it could be beneficial to take advantage of the possibilities offered by computers and then integrate these lessons with traditional teaching in a holistic teaching agenda.

Educational research with a focus on learning and talking would profit substantially if it is anchored in communicational or interactional theories. Ravencroft et al. (2007) and Wegerif (2008) have done this in their discussions of dialogue using the disjunctions of monologic versus dialogic and dialogic versus dialectic. Some of the most relevant philosophical theories which could be used as a foundation in this context are Buber's distinction between the two ground words I-You and I-It, Bakhtin's concept dialogism, Habermas' communicative rationality and his concept of the ideal speech situation, Skjervheim's triangular relationship, and Gadamer's fundamental acknowledgement of the question. Much of the research on common ground could be better reflected upon by using established theory, such as Rommetveit's (1974) concept *shared social world* and the concept *shared cultural horizon* (e.g. Gadamer, 2004). A philosophical foundation which focuses on the importance of a joint space of understanding is highly relevant when it comes to establishing common ground. However, it seems that it is only recently that the possibility of using this theory to enrich a discussion on common ground has been paid the attention it deserves, in the articles from Stahl (2005), Ravenscroft, Wegerif, and Hartley (2007) and Wegerif (2008).

Nussbaum et al. (2009) claim that *when* and *how* the teacher should intervene are two important issues for pupils' learning. However, there is not much research devoted to these aspects. Another issue concerns how tasks are presented. Software design and task structure are important, but how the introduction and organization of tasks influence pupils' communication and learning needs more research. One can argue that software can be used to develop individual mental representations if the pupils work individually and if their teacher encourages individual thinking and reflection. The same software can be used to develop the pupils' ability to participate in the class community if they work in groups and the teacher stresses the role of language, encouraging dialogue and critical argumentation. The same software can hence be used in two different learning stands. It is just a matter of how the task is presented and how the teaching-learning is conducted.

The dual approach of this overview towards education in general and mathematics education in particular has uncovered the opportunity for more interdisciplinary communication between two research communities with several concurrent research interests. This overview may contribute to more widespread cross-disciplinary knowledge and collaboration. Another important issue for future research will be, as Wegerif and Mercer, for instance, have done a great deal of, is to actually get involved in teachers' teaching and pupils' learning and pursue the joint aim of developing how computers are used in stimulating pupils' communication and learning at computers.

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