De Vries, E., Lund, K. & Baker, M.J. (2002). Computer-mediated epistemic dialogue: Explanation and argumentation as vehicles for understanding scientific notions. *The Journal of the Learning Sciences*, 11(1), 63—103.

Computer-mediated epistemic dialogue: Explanation and argumentation as vehicles for understanding scientific notions

Erica de Vries
Laboratory of Educational Sciences, University of Grenoble II
BP 47, F-38040 Grenoble cedex 9, France
Tel: +33 4 76 82 57 09, fax: +33 4 76 82 78 11
Email: Erica.deVries@upmf-grenoble.fr

Kristine Lund and Michael Baker
GRIC Laboratory, CNRS & University of Lyon 2
5 avenue Pierre Mendès-France, F-69676 Bron cedex 11, France
Tel. +33 4 78 77 31 17, fax. +33 4 78 77 31 15
Email: Kristine.Lund@univ-lyon2.fr, Michael.Baker@univ-lyon2.fr

ABSTRACT

Epistemic dialogues, involving explanation and argumentation, have been recognized as potential vehicles for conceptual understanding. Although the role of dialogue in learning has received much attention, the problem of creating situations in which students engage in epistemic dialogue has only begun to be addressed. This article highlights the set of factors that must be taken into account in designing a computer-supported collaborative learning situation that encourages students to discuss scientific notions. These factors include the choice of the domain issue, the activities proposed to students, and the role of technology. We describe the design of CONNECT, an integrated environment and task sequence for the collaborative confrontation, negotiation, and construction of text. Results are then presented from a study in which students individually wrote an interpretation of a sound phenomenon, were matched in dyads so as to maximize semantic differences between their texts, and then collaboratively discussed and wrote common texts across the network using CONNECT. We show how careful engineering of the CONNECT environment favors the occurrence of epistemic dialogue and creates opportunities for conceptual understanding. The discussion centers on why these opportunities might be missed, as well as on the conditions required for students to exploit them.

INTRODUCTION

An important goal of teaching is for students not only to be able to solve specific problems, but also for them to understand the concepts and principles that underlie problem solving. Learning is often assessed by giving examination problems; when students succeed in solving them, the question as to whether they have acquired the underlying concepts as well is rarely addressed. Such conceptual understanding is an important prerequisite for interpreting new situations, predicting future states of affairs, and solving types of problems that have not already been practiced (Tiberghien, 1994). However, successful problem solving does not necessarily imply understanding, nor is extensive practice a sure way of acquiring conceptual understanding. A number of researchers studied situations involving peer interaction (Amigues, 1990) and collaboration between students (Roschelle, 1992) for their potential in promoting conceptual understanding. These studies stress the role of discourse and dialogue in learning domain concepts. More specifically, *epistemic activities*, such as argumentation and explanation, have been designated as potentially powerful mechanisms by which students can collaboratively construct new meanings (Roschelle, 1992; Ohlsson, 1995). According to Ohlsson, this is conceivable because reflection is the *process*, and discourse is the *medium* through which one may acquire conceptual understanding. Epistemic activities are important for the study of conceptual understanding since, in comparison with problem-solving activities, they embody a much smaller gap between performance and competence. In other words, the occurrence of explanatory and argumentative discourse (performance) about concepts effectively reveals degree of understanding (competence) of those concepts. Epistemic activities are therefore discursive activities (e.g. text writing, verbal interaction or presentation) that operate primarily on knowledge and understanding, rather than on procedures.

Our problem is thus to design situations that encourage students to engage in a specific type of epistemic activity, that we designate as *epistemic dialogue*. Epistemic dialogue in our definition meets three criteria, 1) it takes place in a collaborative problem solving situation, 2) it can be characterized as explanation or argumentation, and 3) it is concerned with the knowledge and the concepts underlying problem solving rather than the execution of problem solving actions. Creating such situations is difficult since specific conditions are required for students to spontaneously engage in explanation and argumentation about scientific notions (Baker, 1996; Golder, 1996). These conditions include differences in prior knowledge of the domain of discourse, ability to generate suitable arguments (Voss & Means, 1991), linguistic knowledge, interpersonal factors (overt disagreement constitutes a threat to facework), social-institutional factors (what views can legitimately be expressed) and factors relating to ease of use of the communication channel (Clark & Brennan, 1991). For example, students are often unaware of differences in their views, and simply avoid them by changing topic, or by adopting superficial compromises as a way of avoiding the issue (Baker, 1991, 1996, 1999; Baker & Lund, 1997). Whereas it is relatively easy to provoke and organize argumentation about contentious social topics such as nuclear power or capital punishment (see e.g., Kuhn, Shaw, & Felton, 1997; Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993), it is difficult to favor epistemic dialogue with respect to scientific notions that are taught in school and still being co-constructed (Nonnon, 1996).

We claim that in order to stimulate epistemic discussion, engineering of the whole learning situation is needed (see also Pea, 1994), i.e. the issue, the procedure and the computer support. The use of a computer allows for careful design of the task interface and the communication channel thereby providing ways of constraining students to certain types of activities. Our multidisciplinary approach draws on research in didactics, educational psychology, psychology of communication, computer science and on philosophical and linguistic studies of explanatory and argumentative dialogues.

We report a study in the domain of learning about sound in physics. Sound provides good opportunities for epistemic dialogue given the diversity of students' conceptions. The problem given to the students involves them discussing their interpretations of an experimental situation concerning two tambourines in the CONNECT environment

(Confrontation, Negotiation and Construction of Text). In analyzing students' interactions, we aim to enhance our knowledge of explanation and argumentation as vehicles for understanding scientific notions. Moreover, the amount and type of dialogue will be established, as well as the extent to which it addresses domain concepts.

The paper presents the theoretical background followed by a description of the sound domain and the CONNECT environment. We then proceed by a detailed description of our methodology and analysis. Finally, we present a qualitative analysis of an entire session of one dyad and a quantitative analysis of six dyads of students working together in this situation.

THEORETICAL BACKGROUND

The theoretical background to our work draws upon three areas of research. Firstly, research in science education provides characterizations of students' difficulties in learning both science concepts in general and particular concepts, such as sound in physics. Secondly, we review research addressing the relation between epistemic activities and the understanding of domain concepts. Finally, interface design research provides the background for developing a new computer-supported collaborative learning (CSCL) environment, to be used at a distance across a network. This section presents the main contributions in each of these areas.

Conceptual learning difficulties

This section presents some of the barriers to learning science concepts that could be overcome by epistemic dialogue. Comprehending students' difficulties in understanding sound in particular is crucial for subsequently getting a grasp of their discourse.

Prior knowledge constitutes the first barrier to learning science concepts. Physics learning involves an articulation between the student’s knowledge about the material world and domain knowledge as it is taught in schools (Driver, Guesne, & Tiberghien, 1985; McCloskey, 1983). Students' knowledge is constructed from experience with concrete objects and events in everyday life and from prior schooling. Instruction aims at an adaptation towards scientifically accepted theories in the domain of physics. This process, called conceptual change, may take place by adding notions to existing notions or by changing existing notions, cf. enrichment and revision (Chi, Slotta, & de Leeuw, 1994, Vosniadou, 1994). A number of studies showed that students have a variety of different potentially conflicting conceptions about sound. These conceptions are often shown to be persistent even after teaching (DiSessa, 1982). For example, Maurines (1998) found that both before and after teaching, high school students described sound as a material object created and put into motion by a source. He concluded that these naive conceptions show a high resistance to teaching. In fact, as this example and the examples in the next paragraph show, knowledge about sound is highly subject to what DiSessa has called phenomenological primitives (p-prims), in particular to the idea that force causes motion and that motion naturally fades away (DiSessa, 1996).

An extra barrier to learning science concepts is their level of description. Linder and Erickson (1989) found four different categories of description of sound phenomena by tertiary physics students (see Table 1). These categories are qualitatively different ways in which people make sense of part of the world. Two main perspectives were found, microscopic and macroscopic, differing in terms of levels of description: explanations focus either on the actions of discrete molecules or on the global properties of the medium such as pressure and density. The microscopic perspective includes conceptions of sound as an entity that is carried by individual molecules through a medium. Molecules are seen as initially stationary, or moving around randomly, and sound provides them with a forward linear or somewhat jerky movement. The microscopic perspective also includes a conception of sound as an entity that is transferred from one molecule to another in a medium. Sound is seen as a more abstract entity, e.g. a vibration. This conception may lead to domino-effect descriptions in which molecules push other molecules and so forth.

Table 1
Student conceptions of sound

Perspective	Conception of sound
Microscopic	1. Carried by individual molecules 2. Transferred from one molecule to another
Macroscopic	1. Traveling substance with impetus 2. Substance in the form of traveling pattern

The macroscopic perspective includes conceptions of sound as a traveling bounded substance with impetus, usually in the form of flowing air. Sound is described as a substance that has a moving force of its own, like a type of wind. It is strongly associated with a naive impetus theory (DiSessa, 1982, McCloskey, 1983) according to which an object set in motion obtains an internal force that serves to maintain the motion, and that gradually dissipates. Another conception within the macroscopic perspective describes sound as a bounded substance in the form of some traveling pattern. This view incorporates learned physics terminology, for example, sound as a disturbance propagating through a medium. This variety of conceptions shows how the concept of sound can occupy different places in an ontological tree (Chi, Slotta, & de Leeuw, 1994): as a characteristic of molecules, as matter, or as a process. The place of a concept in an ontological tree may be a barrier to learning in itself, but in our view constitutes an interesting opportunity for the occurrence of epistemic dialogue. In order to reach mutual understanding, ontological differences and differences in level of description need to be rendered explicit and discussed.

A final barrier to learning science concepts is the ambiguous nature of language in school science (Linder & Erickson, 1989). Many scientific terms are an integral part of ordinary language but have a different set of linguistic functions and meanings, e.g., the terms force and wave. Everyday meanings of words may facilitate or impair their understanding in a scientific context (Collet, 1994). Such differences in the use of words between students may constitute a starting point for epistemic dialogue and lead to conceptual differentiation. Students have to agree on the meaning of the words they employ.

These barriers are not addressed by regular science teaching. The question is then how to design a teaching situation that in fact *exploits* the diversity of student conceptions and the variety of meanings of scientific terms by encouraging students to mutually question these conceptions and meanings. The next section provides arguments for the claim that such situations involve epistemic dialogue.

The role of epistemic dialogue

If problem solving performance is not necessarily related to understanding, neither as a training mechanism nor as a testing device, then what types of tasks do exercise understanding? In comparison with skill acquisition, the process for acquiring understanding would be *reflection* as opposed to practice, and the medium would be *discourse* as opposed to (essentially non-discursive) action (Ohlsson, 1995). Ohlsson proposes a list of epistemic activities or types of discourse relevant for understanding, such as describing, explaining, predicting, and arguing. Two have received more attention in learning research — explanation and argumentation — and are at the core of this article.

Explanation

In order to explain, students have to externalize, but also to clarify, organize, and restructure their knowledge presenting many opportunities for learning. The learner giving explanations might detect and repair gaps in his or her own knowledge, find discrepancies between prior and taught knowledge, or discover the need for extra information. When their partners do not understand an initial explanation, explainers might try to use more familiar words, generate examples, or link examples to prior knowledge (Webb, 1989), all of which activities can stimulate the explainer's understanding. Webb (1989) examined a number of studies on peer interaction in the domain of mathematics and computer science in order to establish the relation between giving or receiving explanations and individual achievement. The results indicated that, even when corrected for ability, giving elaborate explanations was positively related to individual achievement (mostly tests involving problem solving). However, receiving elaborate explanations showed only a few significant positive relationships with individual achievement.

Studies on the self-explanation effect constitute another line of research into learning through explanation. Chi, Bassok, Lewis, Reimann, and Glaser (1989) found that good students spontaneously generate more self-explanations than poor students while studying worked-out examples of mechanics problems. In another study, students were explicitly asked to self-explain while studying a text on the human circulatory system. The prompted group showed a larger gain from pre-test to post-test, and within this group, the high explainers showed greater understanding of the circulatory system than low explainers (Chi, de Leeuw, Chiu, & Lavancher, 1994). Self-explanation thus has been shown to bear a relation to both learning a procedural skill (solving mechanics problems) and understanding in a declarative domain (acquiring a correct mental model of the human circulatory system).

Argumentation

Whilst both argumentation and explanation involve the foundations of knowledge, the basic difference lies in the fact that in explanation, the main focus of discussion (what is to be explained) is not called into question (although explanations may be), whereas in argumentation, it precisely is disputed. Thus, in an argumentation dialogue, explanations may take on the pragmatic value of argumentative defenses or supports.

Argumentation, as a form of dialogue, may lead to knowledge co-construction in a number of ways (Baker, 1996, 1999). One possibility involves an interactive version of the self-explanation effect. Argumentation obliges students to render their understanding explicit, reflect upon it, and eventually revise it. However, argumentation may also involve *a posteriori* reconstruction of new arguments and the active search for knowledge in the problem-solving environment in order to produce convincing arguments. A second possibility relates to restructuring knowledge as a result of argumentation outcomes, i.e. refutation or successful defense. Thus, the loser of the argument might adopt the winner's proposal and restructure his or her knowledge to eliminate the refuted proposal. However, argument often leads to dropping flawed proposals irrespective of argumentation outcomes. Once a proposal has at least one mutually recognized counter-argument, it can not become part of the *collectively valid* in Miller's (1987) terms. Moreover, argumentation outcomes are often the result of a negotiated compromise that combines elements of different proposals, although not necessarily in a convergent way. Finally, the benefits of argumentation may lie in its power to stimulate conceptual differentiation (Baker, 1999). Argumentation obliges the participants to be more precise (see, e.g. Perelman & Obrechts-Tyteca, 1988; Walton, 1992) — e.g. "but what do you mean by punishment?" This may involve a reconceptualization of the domain of discourse and a differentiation of the concepts underlying the debate.

Argumentation requires specific conditions in order to be produced in the first place. As Golder (1996) pointed out, one does not argue with anyone, about anything, in any situation. The topic needs to be debatable, the participants need sufficient knowledge of it, and the social situation must permit relatively free expression of views. These stringent conditions may explain why, in some research carried out within the socio-cognitive conflict paradigm (Doise & Mugny, 1981), the resolution of verbal conflict was not found to be a determining factor of cognitive progress. The types of tasks studied — e.g., matrix classification (Blaye, 1990) — were not sufficiently knowledge-rich and provided little opportunity for extended argumentation to even occur. More specific conditions for argumentation can be derived from pragma-dialectical research (Barth & Krabbe, 1982; van Eemeren & Grootendorst, 1984). In particular, the participants must have some common ground relating to the topic and the way in which the dialogue can be carried out (e.g., you must not simply ignore attacks, you can not argue around in circles, etc.), and they must have explicitly expressed, relatively stable and opposed attitudes.

Two aspects of the approach to learning involving epistemic dialogue have received attention in a broader context. The first aspect is that learning is intimately related to discourse and talking. Rather than just hearing about scientific concepts, students should be able to talk about them (Lemke, 1990). In addition to understanding the concepts, they are supposed to learn how to present and criticize ideas, i.e. act like scientists (Scardamalia & Bereiter, 1994), and thus become members of a community of practitioners (Lave, 1988). The second aspect is the fact that epistemic dialogue takes place in collaborative learning situations involving at least two participants. In this view, the products of collaboration are the emergent conceptions jointly constructed by two students (Roschelle, 1992). We postulate that the benefits of collaborative learning could well reside in explanation and argumentation activities undertaken by students.

So how do we encourage students to explain and argue about a scientific topic? The next section deals with how to exploit computer-supported collaborative learning (CSCL) environments for facilitating, augmenting, and redefining interactions (Baker & Lund, 1997, Koschmann, 1994).

Computer-supported collaborative learning

Amongst numerous CSCL environments, we restrict ourselves to those that focus on learning about science concepts through reflection and discussion in face-to-face and network situations. We review some of the special roles that the computer can fulfill by virtue of its distinctive features. The following receive special attention:

- the computer as a collective memory of what has been constructed;
- the computer as the focusing point of discourse and action;
- the computer as a means of representing elements in a discussion;
- the computer as a medium for communication.

Firstly, the computer can take up the function of a *collective memory* of what has been constructed. This type of database function is exploited in Computer-Supported Intentional Learning Environments (CSILE). Activities of scientists are taken as a model for students' learning activities. Students can evolve in knowledge building communities in the same way as scientists (Scardamalia & Bereiter, 1994). Students build a database of notes and elaborate on their own and peers' notes. Thus, the database becomes a locus of peer review that is considered important for student's motivation and intentional learning.

Secondly, the computer can be the *focusing point of discourse and action*. For example, the Envisioning Machine (EM; Roschelle, 1992) offers a direct-manipulation graphical simulation of the concepts of velocity and acceleration. Collaboration between students using the EM is studied as a process that gradually leads to convergent conceptual change. Conceptual change is analyzed as it emerges from the combination of utterances and gestures in relation to the EM. The computer display in this respect is viewed as a social tool for achieving common meaning in discourse. In another study, involving the same environment, collaboration was studied as a process of constructing and maintaining a shared conception of a problem (Roschelle & Teasley, 1995). In addition to showing how coordinated production of talk and action enabled this process, collaborative learning was not always taking place smoothly but required a conscious, continued effort from both students.

Thirdly, the computer can be used to *represent the knowledge elements currently under discussion* and the relations between them. For example, Belvedere (Suthers, 1998; Suthers & Weiner, 1995) represents the logical and rhetorical relations within a debate. Belvedere is designed for supporting students learning to engage in critical discussion of competing scientific theories. It allows the assembly of components (principles, theories, hypotheses, claims) into a graphical configuration that reflects the current debate (supports, explains, conflicts etc.). Abstract components and relationships can be represented using the concrete forms of the graphical language. The representation allows students to jointly focus on and discuss the same claim. Formative evaluations showed some cases where students seemed to change their conceptions as a result of dialogues around Belvedere. Problems mainly concerned turn-taking and students' understanding of the task posed to them. In addition, many ideas and relationships discussed were not captured in the diagrams.

Fourthly, technology can not only be used as a memory, an instrument, or a display, but also as the *medium* for communication. The characteristics of a medium are thought to considerably influence the nature of interactions and the use of grounding mechanisms (Blaye, Light, & Rubtsov, 1992; Clark & Brennan, 1991). Some types of collaborative interactions could be obstructed or on the contrary be facilitated by using the computer as a communication medium. In previous research, we used a flexible structuring approach to collaborative learning interactions (Baker & Lund, 1997). An interface with a number of dedicated communication buttons (dealing with task actions, interaction management, and reaching agreement) was designed with a view to encourage specific types of interaction. The task involved students' construction of energy chains modeling small physics experiments (e.g. a bulb that lights up when connected to a battery) using the CSCL environment C-CHENE. A preliminary study showed that, in comparison to a free text interface, students using the dedicated interface produced a greater proportion of domain-related communicative acts relating to explanation and argumentation, such as verifications, explanations, justifications and evaluations (Baker & Lund, 1997). In addition to the design of the interface, the nature of the task may also be an important factor influencing the nature of collaborative interactions. The energy chain building task, for example, was initially designed for students collaborating side-by-side, and required both discussing and constructing a solution. However, a comparison of the side-by-side and the network situation showed that students collaborating side-by-side spent considerable time discussing a solution before constructing it. In the network situation, students proceeded by a rapid construction of parts of the solution followed by a relatively small number of dialogue turns (Tiberghien & de Vries, 1997). These results show that the design of both the task and the interface can be capitalized on for facilitating certain types of collaborative interactions.

The CONNECT environment was designed to incorporate in a specific way these four points: providing a memory, a locus of action and discourse, a display of opinions, and a medium for communication. The next section presents the features of the sound task that are related to the goal of favoring epistemic dialogues.

THE SOUND TASK

Conceptual understanding in the domain of physics involves the ability to interpret and predict the physical world. Students use their own theories and models when interpreting a new situation, much like a physicist who uses a scientifically accepted physics theory (Tiberghien, 1994). An interesting teaching sequence consists in giving students the elements of a scientific theory and asking them to use it in interpreting or modeling a new situation (Tiberghien & Megalakaki, 1995). Students working in pairs are thus led to confront their individual interpretations of the new situation and to construct a meaning of it in terms of the physics to be learned. The sound task was designed within such a modeling framework. It involved an introduction of the particle model of sound, student's individual interpretations of a new situation, and a confrontation between two students with conflicting interpretations.

The particle model of sound

The particle model of sound was introduced to the students by showing them a video[1] explaining the propagation of sound using a microscopic representation. It shows a simulation in which small cylinders represent gas molecules. The spoken text of the video provides a way of talking about the behavior of gas molecules (text translated from French):

> Just like some musical instruments, a tuning fork produces a sound when hit. The sound propagates from the fork to our ears. Physicists explain this propagation in air with a particular representation of matter. For physicists, air is a gas composed of molecules in permanent motion; this molecular restlessness is represented by the motion of these small entities on the screen. If the air molecules around the tuning fork could be seen, we would see this when there is no sound. The fork's vibrations disturb the motion of the molecules just as our blade disturbs the motion of the small cylinders. Let's observe one of these vibrations in detail. Let's observe it again. A last time. In slow motion, propagation of the perturbation is observable. The red line follows the progression of the perturbation. The tuning fork's vibration disturbs

[1] The video was developed by Robles and Le Maréchal (1996)

the motion of the molecules. This perturbation propagates until it gets to our eardrum.

Students can use both the images and the text of the video to interpret future situations.

The two-tambourine situation

We designed a new situation for eliciting students' interpretations of sound phenomena provoking the use of the terms introduced by the video, such as perturbation, vibration, propagation, and movement of entities. Students were shown Figure 1 accompanied by the following description and questions:

> There are two identical tambourines. We delicately put a little ball hanging from a string in contact with the skin of the second tambourine. When tambourine 1 is hit with a stick, it emits a sound. Directly afterwards, the little ball in contact with tambourine 2 starts bouncing. Use your own knowledge and the knowledge you gained from the video to explain what happens in the air so that the little ball in contact with the second tambourine starts to bounce. What happens to the molecules near tambourine 1, the molecules in between the two tambourines, and the molecules near tambourine 2 (A, B, and C in the figure)? What changes in the behavior of the little ball when tambourine 1 is hit harder with the stick? Using two tambourines with a lower sound having a skin that is stretched much less tightly, what changes in the behavior of the skin of the second tambourine after hitting the first?

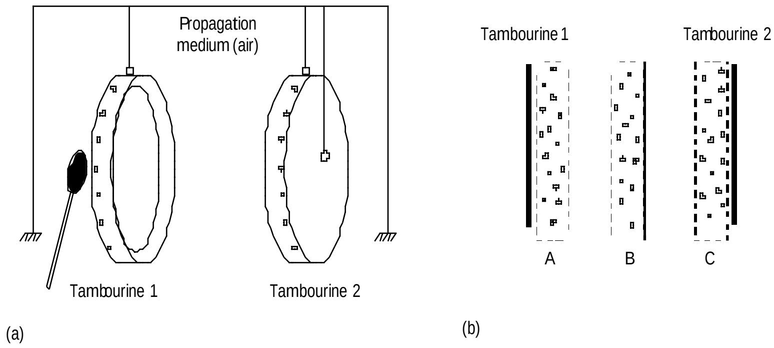

Figure 1 The two-tambourine situation (a) and diagram (b)

In writing their interpretation of the two-tambourine situation, students are supposed to construct a mental model of sound (Vosniadou, 1994) that should provide an explanation of the described phenomenon and allow them to predict phenomena in other situations. The description in terms of the A, B, and C molecules forces students to give a more precise description of the situation thus allowing researchers to categorize the students’ texts into different types of models. Two main ways of describing the two-tambourines situation can be distinguished beforehand (see Figure 2): initial and synthetic models. Initial models correspond to a naive framework of physics. Students with this type of model believe that all molecules (A, B, C) will move to tambourine 2. The initial model corresponds to the first microscopic perspective in Table 1. Synthetic models incorporate some physics knowledge, but do not yet correspond to the accepted scientific model. Students with this type of model do realize that sound is not a permanent displacement of molecules from left to right. Similar to the second microscopic perspective (Table 1), they describe the process as molecules hitting other molecules, that eventually hit tambourine 2. A variety of verbs can be used for describing the behavior of the molecules: molecules move, drag, are ejected, or alternatively, molecules hit, push, or mix. The third type of description depicted in Figure 2 is one in which students specify what happens once the molecules hit tambourine 2 (added on to a synthetic model description).

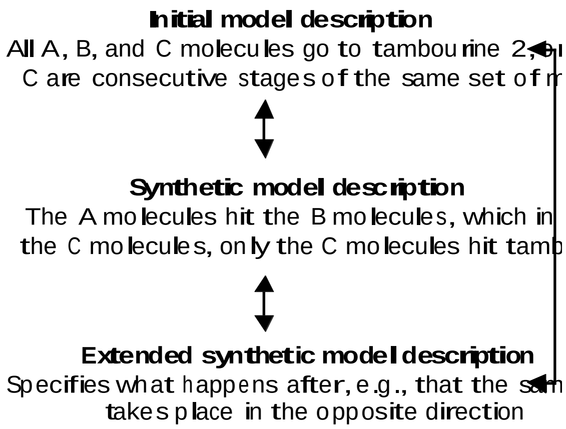

Figure 2 Three different descriptions of the behavior of the molecules

THE CONNECT TASK SEQUENCE AND ENVIRONMENT

A CSCL environment CONNECT was designed to create conditions for epistemic dialogue and used within a global task sequence (Table 2). CONNECT was programmed in HyperCard™ and Timbuktu Pro™ was used as a distance technology enabling full screen sharing across the network. The sequence involved two task phases: a confrontation between two students regarding their individual interpretation and the collaborative construction of a common interpretation. The main screen consisted of two parts (see Figure 3): a communication interface (top half) and a task-specific interface (bottom half). The design took into account both the general roles of CSCL and the necessary conditions for argumentation described earlier. In particular, attention was paid to provide:

- *Preparation for discussion*. Students need to have previously performed a task that enables them to individually construct an initial conceptual viewpoint.
- *Conditions for discussion*. Students need to gain understanding of their partner's views, to compare them with their own, and to form clear opinions with respect to them.
- *Guidance for discussion*. On the basis of a comparison between opinions, students need to have some idea of the appropriate way of going about discussing their views.

Table 2
Global task sequence used with the CONNECT interface

Phase	Students	Situation	Task	Rationale
0	Individuals	Classroom	Write text	Preparation for discussion
	Researchers analyze student texts and create dyads			Conditions for discussion
1	Dyads	Laboratory CONNECT 1	Study and discuss texts	Conditions and guidance for discussion
2	Dyads	Laboratory CONNECT 2	Write common text	Goal for discussion

The communication interface

The text-based communication interface provided three separate participant areas, one for each student and one for a teacher (see top half of Figure 3). Each of the participant areas contained a chat box (free text) and a dedicated (button) interface. The chat box appeared upon clicking on the empty text balloon (see Figure 3) so that a free text message could be typed and sent. The dedicated interface consisted of a number of pre-defined communication buttons dealing with interaction management: Yes, No, OK?, I don't agree, I'll do it, You do it, Hello?, and Are we done? Clicking on a communication button sent the corresponding message. The communication buttons were based on former research on structuring interactions in CSCL environments (Baker & Lund, 1997). The research reported in this article only used the student areas for communication (fourth role of CSCL). The teacher area was added to allow for a tutoring session after the discussion and construction activities (see Lund, Baker & de Vries, 1997).

The communication interface also contained a dialogue history. A scrollbar permitted students to look back at their own dialogue thereby providing a collective memory of what was discussed before (first role of CSCL). Finally, buttons were provided for changing between phases and for showing the two-tambourine situation (Figure 1).

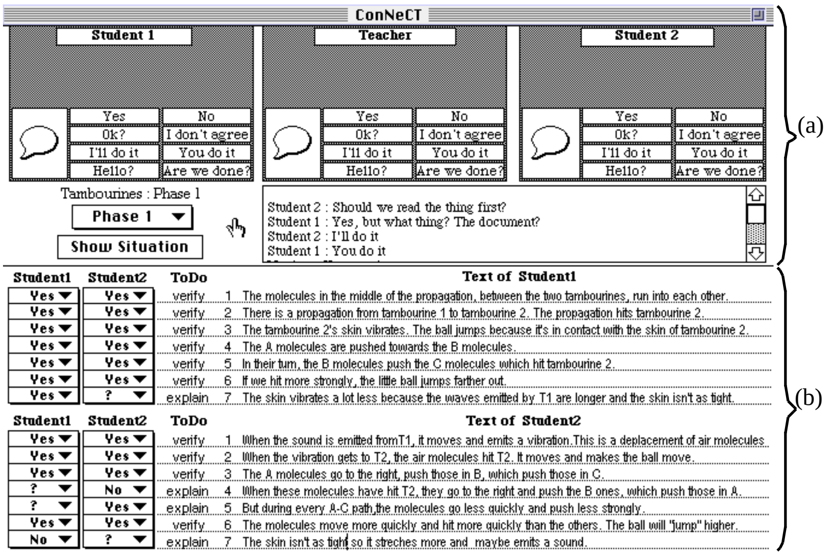

Figure 3 The CONNECT interface for discussing individual interpretations consisting of a communication (a) and a task (b) interface (translated from French)

Task interface for phase 1: Discussing individual interpretations

The task interface for phase 1 consisted of spaces for individual student texts, choice boxes for expressing opinions, and instruction labels (see bottom half of Figure 3). It displays two individual texts as a list of seven sentences with choice boxes for expressing one of three opinions: Yes (Yes, I agree with that), No (No, I don't agree with that), or ? (I don't understand, I don't know, or I don't have an opinion). Students were asked to judge both their partner's and their own text. Judging their own text allowed them to express a possible change of opinion that might have occurred since the moment of writing it. At this point, the task interface has the function of representing the elements under discussion and the positions of both participants (third role of CSCL).

Depending on the particular combination of opinions, one of four instruction labels was dynamically generated and displayed next to each sentence: verify, discuss, explain or to be seen (see also Table 3). *Verify* encourages students to check whether they have the same understanding of a sentence. *Discuss* prompts the students to discuss the sentence, address their difference in opinion, and try to come to an agreement. *Explain* suggests that one of the students explain the sentence to the other. Finally, *To be seen* appears when the students both don't understand, don't know, or don't have an opinion, and advises students to try to see what is meant by the sentence. The meaning of these four labels was explained prior to working with CONNECT. Students were told to follow the instructions next to each sentence, preferably starting with the sentences marked *Discuss.* In addition, they were informed that in such a complex topic, there is no right or wrong answer, but that any opinion contributes to the discussion. The task interface allowed students to reflect changes in their judgment as a result of discussion by modifying the opinion marks.

Table 3
Instruction and expected dialogue type as a function of opinion pair

Opinion pair	Description	Instruction	Exp. dialogue type
Yes-No, No-Yes	Conflict	*Discuss*	Argumentation
Yes-Yes, No-No	Agreement	*Verify*	Verification
?-?	Both students don't know	*To be seen*	Enquiry
Yes-?, No-?, ?-Yes, ?-No	One student doesn't know	*Explain*	Explanation

The lists of sentences, opinions, and instruction labels were designed so as to function as a focusing point of students' discourse (second role of CSCL). The goal was to make students carry out a concrete action concerning all sentences (read and express an opinion) thereby stimulating and rendering explicit the potentially conflicting points between their interpretations. Furthermore, the goal of the instructions was to encourage explanation and argumentation types of interactions as a way of co-constructing mutual understanding.

Task interface for phase 2: Collaborative construction of a common interpretation

The task-specific interface for this phase displays the individual student texts and has a space for editing the common text (see Figure 4). The original individual texts were shown and clicking on a sentence copied it into the text editing space. The sentences on which both students put Yes in phase 1 can be seen as the joint collection of propositions on which the students agree. However, both agreed and non-agreed sentences could be chosen for copying into the common text. The text editing space allowed a number of operations such as adding, changing, and deleting text. The goal of this collaborative text production phase is to produce a common text that gives an interpretation of the situation as well as to provide a final goal towards which the students' previous discussion of their texts can be directed..

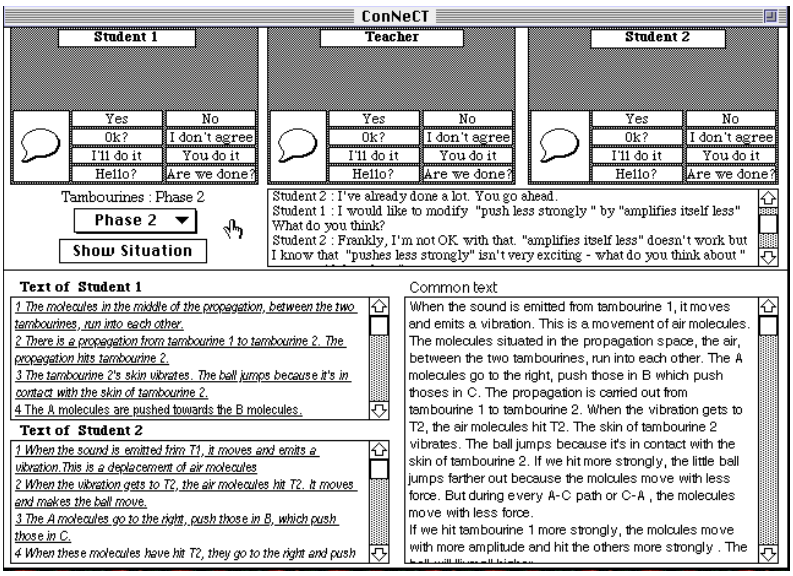

Figure 4 The CONNECT interface for writing the common text (see text for explanation)

AN EMPIRICAL STUDY WITH CONNECT

An empirical study with CONNECT was carried out involving several steps, namely data collection, constitution of the dyads, development of an analysis scheme for epistemic dialogue, and finally qualitative and quantitative analysis of the dialogue produced within the CONNECT task sequence and environment.

Data collection

At the outset, 15 subjects volunteered to participate in the study. The subjects were students of one class at the high school level who had not yet had a course on sound as part of their normal curriculum (11th grade, age 16-17 years). The procedure consisted of one group session in the classroom and, for each dyad, an individual session in the laboratory.

The aim of the group session was to collect students' individual texts. Students were shown the sound video and they individually wrote an interpretation of the two-tambourine situation. They also wrote a small text on the topic of censorship on television, which served as a practice text for the CONNECT environment. The individual texts (two-tambourine situation) were analyzed in order to constitute seven dyads (see next subsection).

The dyads were invited to come to the laboratory at different times. The two students of a dyad were seated in front of a computer in two different rooms in the laboratory. Each session started with a practice period using CONNECT on the censorship texts. The individual texts dealing with the two-tambourine situation were slightly adapted and then displayed on the CONNECT interface showing the author's first name. The students then marked their opinions and discussed their individual texts (phase 1) and produced a common text (phase 2). All dialogue interventions and task actions (dialogue, text typed and buttons clicked) were written to logfiles. The dialogues were examined using the analysis scheme for epistemic dialogue described below.

Constitution of the dyads

In order to augment the chances of occurrence of epistemic dialogue, the texts were analyzed with a view to creating dyads with maximum semantic differences between texts and different mental models underlying the texts. However, the dyads should also present about the <u>same</u> degree of difference between texts (instead of dyads with small and dyads with large differences between texts). Mean length of the texts was 135 words (min. 83, max. 174). The answers to the four questions of the two-tambourine situation (Figure 1) were rated. Four aspects were identified for the first question, and one aspect for each of the remaining three questions, making a total of seven aspects.

The four aspects rated for the question "What happens in the air that makes the little ball bounce?" were 1) the description of the main cause, 2) the traveling substance, 3) the nature of the traveling, and 4) the effect produced (forming a chronological description). For example, the answer categories for the traveling substance were the molecules, the air, the sound, or the propagation (that went from tambourine 1 to tambourine 2). These terms can be seen as a manifestation of a conception of sound, e.g. the term molecules is viewed as evidence for a microscopic perspective, whereas the term propagation implies a macroscopic perspective.

The three authors jointly rated all 15 texts on the seven aspects by scoring occurrences of the (non-exclusive) answer categories for each aspect. A text was attributed a 1 if it contained a category, e.g. molecules as the traveling substance, and a 0 if it didn't. As a result, a table was obtained with a score on each text for each answer category (29 categories for seven aspects). The matrix with the cumulated differences between student texts allowed determining for each text the most distant text amongst those remaining. The text showing the lowest maximum distance with any other text (9 points) was excluded. The second lowest maximum distance was 13 points and 26 out of the 105 possible pairs showed a distance equal to or higher than 13 points (highest maximum distance was 19 points). The distances of the selected dyads were 13 (4 pairs), 14 (1 pair), and 15 points (2 pairs).

In addition to the wording of the texts, the texts were checked for evidence of different underlying mental models (Figure 2) as assessed by the second question (see Figure 1b). The answer categories for this aspect were "All molecules go to tambourine 2", "The A molecules go to B, the B molecules go to C, the C molecules hit tambourine 2", and statements asserting that "The same movement occurs in the opposite direction". All seven pairs constituted by the distance procedure showed a different combination of these three answer categories. Six of the seven dyads worked with CONNECT and one dyad was used for a side-by-side pilot session.

An analysis scheme for epistemic dialogue

Our goal in analyzing the dialogues was to determine the amount and the type of epistemic dialogue as a function of the differences in individual texts and opinion marks of the two students of each dyad. The logfiles were made up of task and dialogue interventions. The dialogue interventions were segmented into semantic units, approximately corresponding to phrases. In doing so, we took into account the punctuation marks used by the students themselves. We distinguished four main categories (see Figure 5 and Table 4): Explanation, Argumentation, Problem resolution and Management.

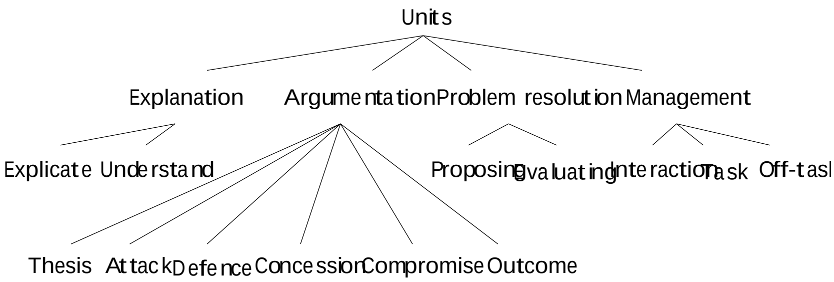

Figure 5 Coding scheme for analysis of the dialogues

Table 4
Category definitions with examples (originally in French) from the corpus

Explanation	Explicate	To express one's understanding of the meaning of a concept or why an event happened, in order to enable understanding of it by one's partner. Ex.: *Often you can say that sound is like the wind*
	Understand	To ask the partner whether he or she understood something or to express one's own (mis)understanding. Ex.: *Is that clear?* or *I don't get it*
Argumentation	Thesis	To make a proposal in an argumentative context (explicit conflict), i.e. that becomes a subject of debate. Ex.: *This skin thus "fits" the form of the ball,* (partner: *I don't agree*)
	Attack	To state reasons against a particular position. Ex.: *If the molecules always went as fast and as hard, the ball would never stop jumping!*
	Defense	To state reasons for a particular position Ex.: *Believe in my experience as a percussionist, a snare drum that has a very tight skin vibrates much less than a bass drum*
	Concession	To give in, i.e. admit the partner is right. Ex.: *Yes, you must be right* or *Okay, you've convinced me*
	Compromise	To propose an idea that unifies two conflicting interpretations. Ex.: *Another explanation: take a cord that isn't tightly stretched When you touch it, it will move a lot but vibrate a little*
	Outcome	To discuss the outcome of an argumentative sequence. Ex.: *In case you've noticed, we agree*
Problem resolution	Proposing	To present a new element to be incorporated in the text. Ex.: *We carried out an experiment with two tambourines. We observed: (and then we'll put in our sentences)*
	Evaluating	To judge an element in the text either positively or negatively. Ex.: *Yes; sorry for that, but you put T2 instead of T1*
Management	Interaction	To manage the interaction (perceive each other's actions and dialogue) and turn-taking (without reference to specific task elements). Ex.: *What's happening here?*
	Task	To manage the problem-solving task (with explicit mention of a task element). Ex.: *I have to explain my line 5 to you*
	Off-task	To make off-task (i.e. problem-solving) or social relational remarks. Ex.: *You're smart!*

The distinction between explanation and argumentation requires an examination of the surrounding context of a unit. Units were categorized as argumentation only if they appeared in an argumentative sequence, i.e. only if a clear disagreement could be identified either in the opinion marks on the interface (Yes - No opinion marks) or in the dialogue itself. Proposing or evaluating a solution element, e.g., a sentence to be included in the common text (phase 2) fell into the problem resolution category. The management category contained units dealing with the coordination of the interaction, of the task, as well as units falling into a social off-task subcategory. The three authors jointly analyzed the whole corpus (a total of 492 collective decisions in six dialogues).

QUALITATIVE ANALYSIS

We begin our discussion of analysis results by a blow-by-blow illustrative analysis of the whole sequence for dyad 5: Andy and Jerry (not their actual names). The analysis concerns their individual texts, all task actions and dialogue interventions of phase 1 and most of the task actions and dialogue interventions of phase 2. The excerpts are presented in chronological order. The analysis aims at revealing how the elements of the design of the CONNECT environment lead the students to explain and argue about domain concepts and to describe how knowledge and conceptions evolve in such dialogue. We then will discuss excerpts from two other dialogues that show how students, in spite of favorable conditions, may engage in a type of dialogue that does not address their domain notions.

Andy and Jerry: Conceptual differentiation

Table 5 shows the individual texts. Andy's text was classified as a synthetic model and

Jerry's text as an extended synthetic model description (Figure 2). Lines 1 to 3 concern the students' initial spontaneous descriptions of what happens between the two tambourines. Lines 4 and 5 reflect their response to the diagram with the A, B, and C molecules (triggered microscopic description). Line 6 deals with what happens if one hits harder and line 7 deals with what happens when one takes tambourines with less tightly stretched skins.

Both spontaneous descriptions contain evidence for a macroscopic type 2 conception (see Table 1): sound as a substance in the form of a traveling pattern. Andy's text mentions vibrations and displacements and Jerry's text mentions a stretching of molecules. Jerry's text in addition specifies that the air molecules will position themselves as before. This addition distinguishes an extended synthetic from a synthetic model and constituted one of the grounds for putting Andy and Jerry together to form a dyad.

Table 5
The individual texts of dyad 5 on the CONNECT interface

Andy	Jerry	Assignment	Andy's text
Yes	Yes	Verify	1. When hitting tambourine 1, it emits a sound. This sound propagates itself in the form of vibrations.
Yes	Yes	Verify	2. These vibrations reach tambourine 2, by creating displacements of molecules in the air.
Yes	Yes	Verify	3. The tambourine 2 starts to shake, dragging the little ball along.
Yes	Yes	Verify	4. There is a chain reaction. The vibrations emitted by the sound push the molecules from A to B.
Yes	Yes	Verify	5. The A molecules push the B molecules towards C. The B molecules push the C's towards T2.
Yes	Yes	Verify	6. (hitting harder) It moves more, since the displacement of molecules is more important.
Yes	Yes	Verify	7. The skin less tightly stretched of tambourine 2 absorbs the vibrations more, and thus vibrates less itself.
Andy	**Jerry**		**Jerry's text**
No	Yes	Discuss	1. It disturbs the air molecules contained between t1 and t2. These move away from each other .
Yes	Yes	Verify	2. The stretching of molecules arrives at t2, those near strike it, provoking the movement of the ball.
Yes	Yes	Verify	3. Then the air molecules, between t1 and t2 position themselves as before.
Yes	Yes	Verify	4. The A molecules hit the B molecules, that on their turn hit the C, that subsequently hit T2.
Yes	Yes	Verify	5. Then those groupings go back to their place, like before.
Yes	Yes	Verify	6. (hitting harder) The molecules stretch more violently, thus strike t2 harder. The ball moves more, jumps farther.
Yes	Yes	Verify	7. The skin less tightly stretched, it is easier for the molecules to make it move but the ball moves less.

Forging opinions

The two students started by marking their opinions taking a total of thirty-one actions (twenty-eight are minimally necessary), i.e., clicks on choice boxes. In addition, they viewed the two-tambourine situation (picture and assignment shown in Figure 1) three times. The existence of changes of opinion during this opinion forging phase suggests that it led to genuine reflection on the part of the students. Andy and Jerry predominantly marked their own and partner's text lines with a "Yes" (see Table 5). It seems that Andy was neither surprised nor intrigued by Jerry's remark about the molecules going back to their initial place. The interface nevertheless shows one "No"; Jerry's first line, that needed discussion. The apparent agreement between the two students was a rather disappointing outcome and showed that the dyad matching procedure is not a sufficient condition for pinpointing debatable topics (see final section). The dialogue about the texts started only after completion of all opinions.

Guided discussion

The interface showed one line to discuss (see Table 5): "It disturbs the air molecules contained between t1 and t2. These move away from each other". The first episode shows how Andy and Jerry immediately focus on the controversial line (as indeed they were requested to).

1 A:	They don't move away from each other, they all go towards t2	A - Attack
2 J:	My 1 We saw in the movie that the air molecules that were positioned in a certain way, spread ahead, here t2, thus creating more spacing between the molecules than before. / OK? YES OR NO	A - Defense A - Concession
3 A:	yes	A - Concession

Note: In the excerpts throughout the results section, units are separated by slashes and main categories are abbreviated (E = Explanation, A = Argumentation, P = Problem resolution, M = Management).

The episode is very short, only three turns. The unambiguous "Yes" versus "No" on the interface led us to categorize the interventions as argumentation. Andy immediately objects to Jerry's line by stating that all molecules go towards the second tambourine. Jerry defends the idea of spreading molecules, but at the same time concedes that they move ahead. They then converge to an interpretation that combines the two ideas: molecules both move away from each other and move towards the second tambourine. Note how the students do not need to explicitly discuss management of their interaction or the task in this episode. Since there is only one controversial line, Andy does not even bother explaining what he is talking about. The salience of the instruction label "Discuss" alone seems to give rise to their discussion.

Multiple meanings

The remaining lines received the label "Verify": the students supposedly agreed on them. However, Andy discovers a point that needs clarification. He signals this by changing the opinion mark from a Yes into a ? on Jerry's text line 7 "With a skin less tightly stretched, it's easier for the molecules to make it move, but the little ball will move less".

	Andy changes his Yes on Jerry's 7th line into a ?.	
4 A:	If the skin moves more why does the little ball moves less?	E - Explicate
5 J:	The skin moves more because it is less tightly stretched but the pressure exerted by the air is the same. This skin thus "fits" the form of the little ball.	E - Explicate A - Thesis
6 A:	Don't agree. In my opinion the skin of T2 moves less (see my 7).	A - Attack

Andy proceeds by explicitly asking for an explanation. Following Jerry's explanation, a conflict arises about whether the skin moves more or less, a conflict also occurring in another dialogue.

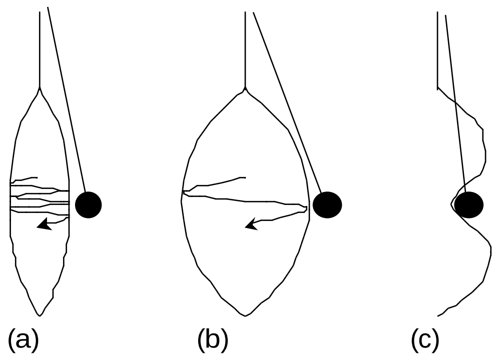

Figure 6 Mental models of a tightly (a) or a less tightly stretched (b, c) skin

We found in fact several ways of describing what happens when you have less tightly stretched skins. Some students predict a change in frequency (the skin will vibrate less), whereas others predict a change in the amplitude (the skin will go farther out). The descriptions are not incompatible, but due to their imprecise nature, they actually denote the same interpretation (see Figure 6a and b). For example, the skin in Figure 6b can be said to move less (referring to its frequency: less movements per second) or to move more (referring to its amplitude: it goes farther out). In other words, to move a lot can either mean that something has a high frequency or that it has high amplitude. These opposite meanings are a source of conflict in two of the six dialogues. In the Andy and Jerry dialogue, both students use the verb "to move", but Jerry means to say that the skin goes further out (moves more), whereas Andy means to say that it does not vibrate as much (moves less). In the last turn of this episode, Andy maintains that the skin will move less and refers to his line 7 that says that the skin will *vibrate* less, a clear example of a conflict related to the ambiguous nature of language. In order to sort it out, the students will need to differentiate between the two opposite meanings of the expression "moving a lot".

Divergent mental models

Jerry also uses the verb "to fit" for describing the behavior of the skin. Further analysis lead to two different mental models for the behavior of the little ball as a result of the behavior of the skin: the little ball moves as much as the skin (Figure 6b) or the skin is very loose and goes around the little ball (Figure 6c). This latter model lead to statements such as "…the skin moves more, but the little ball moves less (than it would with a tightly stretched skin)". Note that the original question referred to the behavior of the skin only. It left aside the behavior of the little ball, which would be hard to predict from physics knowledge. Jerry's use of the verb "to fit" clearly refers to the second model. So in addition to a language problem, the students will have to sort out their differences related to what actually happens to the little ball.

Conceptual differentiation and use of analogy

One way of solving the language problem is to discriminate between different meanings by using analogy. The choice of a particular analogy reveals one's conception of the phenomenon at hand. In turn 7 and 8, Andy and Jerry use different analogies to defend their interpretations: a guitar cord that vibrates versus a piece of cloth that moves. Their analogies nicely disclose the two meanings of “to move” and reveal two slightly different macroscopic conceptions of sound: sound as a traveling pattern that will make something vibrate and sound as a substance with impetus that will make something move. Moreover, Andy tries to solve the language conflict by explicitly differentiating "to move" from "to vibrate".

7 J:	Difficult to know. When one looks at the skin one sees it move more than one that has a tightly stretched skin / When you hit something hard, that's stable in space, it will not move whereas a piece of cloth that isn’t tightly stretched, for example will	A - Defense A - Defense
8 A:	Another explanation: take a cord that isn’t tightly stretched. When you touch it, it will move a lot but vibrate a little / On the other hand, a tight cord like a guitar will move a little but vibrate a lot	A - Compromise A - Compromise
9 J:	I agree with your 7 / but I thought for a moment that you did not agree with mine. / For me the two lines are right they just don't explain the same thing (vibrations and movements).	A - Concession M - Interaction A - Compromise
10 A:	NO When a skin less tightly stretched vibrates less itm movesaivses more moves more so the little ball has to move more too. / Pardon me, / do you get it?	A - Attack M - Interaction E - Understand

Note: Some non-words in this excerpt show the occurrence of concurrent typing by the two students.

Andy's explanation has come across, Jerry's answer (line 9) shows that he picked up the difference between vibrations and movements. The language problem has been solved by a conceptual differentiation of meanings. Andy now focuses on the implication for the behavior of the little ball, the essence of their conflicting mental models (Figure 6b versus Figure 6c).

11 J:	Hypothesis: with the same force of the air exerted on T2: a tight skin vibrates more than a skin less tightly stretched but will move less than the latter	E - Understand
12 A:	Yes. Yes.	E - Understand M - Interaction
13 J:	For the little ball, I think it will move less with a less tightly stretched skin because it will vibrate less and thus less "transmit" the vibrations	A - Attack
14 J:	Okay?	A - Outcome
15 A:	Maybe	A - Outcome

Jerry once more shows his understanding of the vibration-movement issue (line 11), but in line 13, he attacks Andy's statement (ball moves more) saying that the skin transmits less (ball moves less). The final intervention shows that Andy is not really convinced. So whereas they sort out the frequency-amplitude confusion, the question about the little ball remains unanswered.

Addressing remaining differences

The main outcome of phase 1 was a conceptual differentiation on the frequency/amplitude, move more/move less, movement/vibration debate. However, Andy and Jerry were put together because they had a synthetic versus an extended synthetic model, i.e. Jerry in addition described what he thought would happen once the molecules hit the second tambourine. This issue did not show up in the first phase. In the second phase, the students were asked to write a common text describing the tambourine situation. This common text should reflect mutual understanding of the phenomenon and constrain students to identify and address remaining differences.

The analysis of the second phase begins when Andy and Jerry start adding original individual sentences to their common text. The second sentence added caused some discussion in the first phase ending in an agreement about the molecules both spreading and moving towards the second tambourine. Subsequently, Jerry thinks it is necessary to specify the behavior of the molecules after striking the tambourine, i.e. the distinguishing feature between their mental models (molecules go back)

	When hitting tambourine 1, it emits a sound. This sound propagates itself in the form of vibrations.	Andy's text line 1 added
	It disturbs the air molecules contained between t1 and t2. These move away from each other .	Jerry's text line 1 added
1. J:	Yes	M - Interaction
2. A	Yes	M - Interaction
3 J:	I don't know whether the molecules go back to their place or whether , because of the partial vacuum they create	P - Evaluate
4 A:	O	M - Interaction
5 J:	h becau what are you doing??? I did not finish my sentence	M - Interaction
6 A:	I got it, it's OK, hypothesis 2	E - Understand
7 J:	continued; …create, are replaced by others Thank you	P - Evaluate
8 A:	I got it, it's OK, hypesis 2	E - Understand

Note: Some non finished words in this excerpt show the occurrence of concurrent typing by the two students. The translation of the French excerpts shows the English equivalents of the students' original typing or spelling errors.

Andy seems to agree with an interpretation according to which the molecules get replaced by others (he refers to it as hypothesis 2), and the original ones do not go back to their place. It is difficult to interpret the episode because of problems in the communication. Several dialogue turns in fact reveal the burden represented by interaction management necessary in distance communication.

The burden of collaborative text writing at a distance

One of the disadvantages of the double task of discussing and writing at a distance is that writing may inhibit discussion. The following episode shows a number of interventions that aim at organizing the interaction and problem solving.

9 J:	I think everything is OK: let's reread together and write if something is not right	P - Evaluate M- Task
10 A:	t what?	M - Interaction

	When hitting tambourine 1, it emits a sound. This sound propagates itself in the form of vibrations.	Andy's text line 1 added
	~~*When hitting tambourine 1, it emits a sound. This sound propagates itself in the form of vibrations.*~~	Text deleted
11 J:	Your1:OK?	P - Propose
12 A:	Yes	P - Evaluate
13 J:	your2	P - Propose
14 A:	YOUR 2 OK.	P - Evaluate
15 J:	is that something is not right in the text, and then in mine. For me everything seems alrighte	P - Evaluate P - Evaluate
16 A:	There's no E at alright, FOR THE REST it's OK.	P - Evaluate
17 J:	and what about the ball that does not move? And about the air that maybe gets replaced by the one coming from outside the zone of the tambourines?	P - Propose P - Propose
	Some of them strike T2.	New text added
18 A:	OK?	P - Evaluate
19 J:	I'm thinking	M - Interaction
	~~*Some of them strike T2.*~~ *thus provoking a stretching of the air mass in question.*	Text deleted and new text added
20 A:	Are you sure	P - Evaluate
21 J:	We saw in the movie that the space was larger when there were vibrations	E - Explicate
22 A:	OK	M - Interaction
23 J:	continue the summary of the displacements of air in between T1 and T2	M - Task

Although Andy and Jerry are proposing and evaluating solution elements and executing task actions, the common text does not develop until after turn 17. In fact, the episode represents a status quo. Whereas Andy proposes a shortcut (some of the molecules strike the second tambourine), Jerry stays with the process itself, adds that the air mass gets stretched, and in turn 23 asks for still more precision about the behavior of the molecules. In a sense, both students are faithful to their initial individual model. The text writing task brings up the issue that distinguishes between their models, but the burden of problem solving action of adding and deleting propositions interferes with a discussion *about* those propositions.

Communicating through text writing

Andy and Jerry's models did agree about the initial behavior of the A, B and C molecules. After an episode with text changes and management turns, they include the following sentence on the subject: "Through a chain reaction, the A molecules hit the B molecules, which in their turn hit the C, which then hit T2." Jerry subsequently returns to the issue of what happens afterwards. In their text, the students leave room for two interpretations: molecules either reposition themselves as before or are chased by others. Writing the text does force the students to be precise in expressing the fact that the moving molecules leave an empty space. As the episode shows, the students communicate through their problem solving action rather than discussing the issue first. The action of adding or changing text in itself takes the function of proposing a solution element. The students oscillate between a vacuum, a partial vacuum, and finally the word space is introduced. The latter term seems to satisfy both, the word vacuum being too controversial.

	Then the air molecules in between t1 and t2 reposition themselves as before	Text added
36 A:	We	M - Interaction
37 J:	would have Ito knowdidn't finish	M - Interaction
	, or are "chased" by others that come fill the vacuum, that is partial, that they produced.	Text added
38 J:	OK?	P - Evaluate
39 A:	almost	P - Evaluate
	fill the vacuum that they left behind	Text changed
40 A:	OK?	P - Evaluate
	fill the partial vacuum that they left behind	Text changed
41 A:	Yes	P - Evaluate
	fill the, partial, vacuum that they left behind	Text changed
42 J:	OK?	P - Evaluate
	fill the space that they left behind	Text changed
43 A:	OK?	P - Evaluate

44 J:	Are you sure!!!!!!!	P - Evaluate
45 J:	VACUUM would be better	A - Attack
46 A:	It is not a vacuum	A - Defense
47 J:	partial	A - Compromise
48 A:	as you like	A - Concession
49 J:	let's go on	M - Task
	When the molecules strike T2, the little ball moves.	Text added
50 A:	OK?	P - Evaluate
	because of the vibration provoked on the skin of the tambourine	Text added

The students' final common text is an elaborate description:

> When hitting tambourine 1, it emits a sound. This sound propagates itself in the form of vibrations. It disturbs the air molecules contained between t1 and t2. These move away from each other. Through a chain reaction, the A molecules hit the B molecules, which at their turn hit the C, which then hit T2. Then the air molecules in between t1 and t2 reposition themselves as before, or are "chased" by others that come fill the space that they left behind. When the molecules strike T2, the little ball moves, because of the vibration provoked on the skin of the tambourine.

Their text is a reformulation in comparison with both of the individual texts. They do not mention their answer to the question of the tambourines with less tightly stretched skins.

Carol and Ellen: Missed opportunities

The second dyad, Carol and Ellen, showed a dialogue with a poor outcome. At the outset, Carol's text says "The A molecules are disturbed by tambourine 1. They propagate right up to the B molecules. These last ones also propagate to the C molecules that strike tambourine 2. A ← B ← C" (synthetic model). Ellen's text says "The A and B molecules are pushed away towards tambourine 2. Next, the A, B and C molecules make the little ball in contact with T2 move by being smashed against the skin." (initial model). Ellen noticed the difference, since she put question marks on Carol's lines. In the corresponding excerpt, Ellen starts by asking Carol to explain her lines. This first turn (line 1) can be interpreted as a clear reference to the assignment shown on the interface that Carol in the beginning of the second turn acknowledges.

1. E:	You'll have to explain some of your lines to me?	M - Task
2. C:	I admit that some of my lines are difficult to understand. / About 3, / the A molecules are pushed over to the B molecules which in their turn push the C molecules. / The last ones will hit T2. / Then, the little ball that touches the tambourine will start jumping.	M - Interaction M - Task E - Explicate E - Explicate E - Explicate
3. E:	So you say that only the C molecules will touch the tambourine?	E - Understand
4. C:	It seems to me that the A, B, and C molecules are the same ones / but that they are the stages in order to arrive at tambourine 2	E - Explicate E - Explicate
5. E:	That's also what I think, / I badly understood the meaning of your sentences. / I'm going to change my answer for 3 and 4 / but we'll have to talk about the two last ones.	E - Understand E - Understand M - Task M - Task
	Ellen changes her ? on Carol's 3rd and 4th line into a Yes.	

In the remainder of this turn, Carol reformulates her lines into a description which again reveals her synthetic model: only the C molecules, "the last ones", will hit the second tambourine. Ellen notices the discrepancy with her own initial model since she then explicitly asks whether Ellen thinks that only the C molecules will touch the tambourine. This seems to be an excellent opportunity for both students to figure out which of the two models holds. The dialogue could even have turned into an argumentative sequence. However, the conflict does not really become explicit, neither in the opinion marks, nor in the dialogue between the two students. Instead of answering by a distinct confirmation that could have marked the beginning of a verbal conflict situation, Carol attempts another explanation but this time adapting her previous version in a way that is compatible with Ellen's initial model (see also Figure 2). She now describes A, B, and C as stages in the process. Ellen promptly accepts this adaptation, both in her answer and by changing her opinion marks.

Two related things can be observed from this excerpt. Firstly, the way in which the students refer to the assignment shows that both seem to be very aware of the expected type of behavior: some lines of text need to be explained. Secondly, although there is an attempt to clarify their conception of the behavior of the molecules, Carol merely paraphrases her lines until Ellen is satisfied. Carol and Ellen seem to think that they must have the same conception from the outset, and that it is just a matter of finding the formulation with which they will both agree. It is not clear from the dialogue whether Carol has a synthetic model (turn 2) which she badly formulates into an initial model (turn 4), whether it is the other way around, i.e. an initial model that was badly formulated at the outset, or whether she changes her mind in between.

Although there is good opportunity for argumentation, this type of dialogue seems to provide a very weak basis for learning. There is no conceptually-based argumentation and even the explanations are mere paraphrases. Their common text shows no real resolution of the conflict between the two interpretations (initial and synthetic model):

> Knowing that air consists of molecules in constant movement, we observe that after hitting tambourine 1, the A molecules are pushed away towards the B molecules. Those last ones also propagate towards the C molecules. They arrive at tambourine 2 and make the little ball in contact with it move.

In fact, the word "they" in the last sentence reflects the ambiguity because it can refer both to all or to only the C molecules. The dialogue and common text of this dyad show how a high opportunity for epistemic activities may not be exploited. Baker and Bielaczyc (1995) termed this type of situation a missed opportunity, demonstrating how students can only be led to consider their conceptual differences up to a certain point. The question arises as to how technology could help to further exploit such situations.

Daphne and Lydia: Learning needs revealed

The fourth dyad, Daphne and Lydia, presented another opportunity for addressing domain notions. Their texts contained seven lines in need of explanation and one line with two question marks (see Table 6 that displays only part of their texts).

Table 6
Part of the individual texts of dyad 4 on the CONNECT interface

Daphne	**Lydia**	**Assignment**	**Daphne's text**
Yes	Yes	Verify	3. When hitting T1, the A molecules of air are disturbed and sent to the side of T2.
Yes	?	Explain	4. In this way, they mix and drag along the B and C molecule groups. Thus there is a displacement of air.
Daphne	**Lydia**		**Lydia's text**
Yes	Yes	Verify	3. The T1 pushes the A molecules, that in turn push the B molecules, that themselves go push the C's.
Yes	Yes	Verify	4. There's a propagation of movement within the molecules.

The ensuing dialogue and common text focalize on the verbs *mix*, *drag*, and *push* for describing the behavior of the molecules. The excerpt shows an omission of a word in Daphne's intervention, noticed by Lydia, and solved immediately. The discussion then is suspended. It is impossible to decide from the dialogue whether the verbs to drag and to push carry different interpretations (respectively all or only the C molecules reach the second tambourine).

1 L:	… Ah yes, line 4: are you sure they mix?	A - Attack
	One of the students shows and hides the problem screen.	
2 D:	I don't know whether they the other molecules or whether they drag them.	E - Explicate
3 L:	Haven't you forgotten a word?	M - Task
4 D:	Whether they push them…	M - Task
	One of the students shows and hides the problem screen.	
:		
22 D:	The only problem left, is for my line 4 and your line 3.	M - Task
23 L:	Why?	M - Interaction

24 D:	Because we don't know whether it must be pushing or dragging.	M - Task
25 L:	That's right / we will have to ask Mrs. L.	M - Interaction M - Task
26 D:	You're still convinced that the A molecules are pushing the others?	A - Outcome
27 L:	Not convinced, I put that because it seemed to be the best answer. But it could very well be that the B molecules are dragged along by the A ones.	A - Outcome A - Outcome
28 D:	Are we done?	M - Interaction
29 L:	Yes, I think so	M - Interaction

The students seem to search for evidence outside their own judgment as they consult the assignment screen. It's only after eighteen turns, towards the end of the first phase that Daphne brings the issue up again. Neither of the students has an argument for one or the other verb, but both seem to be concerned (Lydia in turn 1, Daphne in turn 22). They finally decide that they need a referee, i.e. their teacher, and neither of them commits to a particular verb. In a sense, they don't need to argue since they will be able to ask a person with more physics knowledge. Their common text contains a synthetic model description, containing only the verb to push:

> T1 pushes the A molecules, which in turn push the B molecules, which themselves go push the C molecules.

There is not much argumentation or explanation in this sequence, but an interesting result is the students' recognition of their need of more information.

QUANTITATIVE ANALYSIS

The quantitative analysis concerned the six pairs that worked with CONNECT at a distance. Two main sources of obstruction for the occurrence of epistemic dialogue have been recognized. The first source is the simultaneous execution of a main task such as constructing a solution or writing a text. Dialogue enters into competition with it: the more time and actions necessary for task execution, the less room there is left for dialogue, especially in distance situations (Tiberghien & de Vries, 1997). The second source is dialogue that concerns interaction and task management. The presence of dialogue in itself does not mean it can be categorized as epistemic. Epistemic dialogue enters into competition with management dialogue. The level of epistemic dialogue is generally low, less than 10% in our previous research on a task involving graphical construction of a solution (Baker & Lund, 1997). In the CONNECT environment, the main task *is* discussion, at least in the first phase, and therefore we consider that explanation and argumentation should take up at least 35% of the dialogue. In other words, we set the lower limit for the occurrence of epistemic dialogue to approximately one third of the entire dialogue. The CONNECT environment and task sequence were designed so as to limit interaction and task management to only two thirds of the dialogue. The costs of task actions versus dialogue on the one hand, and of management and problem solving versus explanation and argumentation on the other hand are measured in terms of the number of actions and the time spent. The quantitative analysis also involves the rate of students' recognition (opinion marks) of conceptual differences.

The amount of dialogue turns and task actions

Table 7 shows the balance between dialogue turns and task actions in each of the two phases in terms of both their frequency and their total duration. In the first phase, the task actions consist of the marking of opinions, and therefore we find a mean of at least 28 actions (7 lines x 2 texts x 2 students). Table 7 shows that they do not take up much time (about seven and a half minutes). In contrast, whereas in the same phase a smaller number of dialogue turns is observed, they actually take up most of the time (almost thirty minutes).

Table 7
Amount of dialogue turns and task actions in each phase (mean number of turns and duration)

		Type			
Phase		Dialogue turn		Task action	
1. Marking opinions and discussion	*N* of turns	24.7	38%	37.8	62%
	N of minutes	28.6	76%	7.5	24%
2. Common text production	*N* of turns	39.0	62%	21.7	38%
	N of minutes	23.9	64%	13.6	36%

Since conceptual differences supposedly have been sorted out, students are supposed to concentrate on writing a common text in the second phase. The task actions consist of adding sentences and editing. In this phase, frequency and duration show almost identical proportions in favor of dialogue turns (62% and 64%) as opposed to task actions (38% and 36%).

Students' recognition of their conceptual differences

The dyad constitution procedure assured that the dyads consisted of students having different models underlying their texts. Results showed that the students in fact most frequently agreed on each other's sentences; the Yes-Yes opinion pairs made up 69% of the cases. The second most frequently encountered combination was the other student (not the author of a sentence) putting a question mark (23%). These cases can be interpreted as requests for explanation. A clear conflict situation, a Yes-No opinion pair, was encountered only three times (4%). In the remaining cases, one student put a No and the other a question mark (2%), both put a No (1 case, 1%) or both put a question mark (1 case, 1%). Did the students mark with a No or with a question mark precisely those sentences that were representative of a conceptual model different from their own? A closer inspection of the opinion marks showed that in five of the six dyads, at least one of the two students did not explicitly agree with the partner's sentence that contained the defining characteristic of his or her student model (did not put Yes). The differences between conceptual models therefore were noticed in five out of six cases.

Level of explanation and argumentation

Table 8 shows the results of the analysis of the six dialogues. The dyads produced approximately the same number of statements during marking opinions and discussion (first phase) as during the production of the common text (second phase). The mean number of statements added up to a total of 36.8 and 45.2 respectively ($t(5) = -.79$, ns). The amount of explanation and argumentation produced in the first phase was high, 33% and 23% respectively. Even when taking into account that discussion in fact was the main task, the cumulated amount of explanation and argumentation (56%) is higher than we expected a priori (35%, binomial (221;.35), $p < .001$). The first phase of the task sequence itself did not involve problem solving, and the type of dialogue observed reflected this (problem solving dialogue: 3%). The fourth category contained management and involved 41% of the statements in the student dialogues.

Inspection of the sub-categories revealed that about half of the explanation statements concerned giving explanations, whereas the other half concerned receiving explanations, expression of (lack of) understanding, or asking for a confirmation of understanding. Regarding argumentation, the statements were almost equally distributed across the six sub-categories. The amount of statements in each of the sub-categories was low. Finally, the larger portion of the management statements concerned the interaction rather the task. In fact, interaction management was the largest category concerning 26% of the statements in the first phase.

Table 8
Type of dialogue in each phase (mean frequency and percentage)

Type	Phase 1 Freq.	Phase 1 %	Phase 2 Freq.	Phase 2 %
Explanation	**12.2**	**33**	**0.8**	**2**
Explicate	5.8	16	.2	0
Understand	6.3	18	.7	1
Argumentation	**7.0**	**23**	**2.3**	**6**
Thesis	1.2	3	.2	1
Attack	1.2	5	.3	1
Defense	1.8	5	.3	1
Concession	1.2	5	.2	0
Compromise	0.5	2	.3	1
Discuss outcome	1.2	3	1.0	2
Problem resolution	**1.5**	**3**	**19.3**	**42**
Proposing	0.0	0	6.0	14
Evaluating	1.5	3	13.3	28
Management	**16.2**	**41**	**22.7**	**50**
Interaction	10.2	26	17.3	38
Task	5.0	13	4.7	10
Off-task	1.0	2	.7	2
Total	**36.8**	**100**	**45.2**	**100**

The second phase dealt with writing the common text. As expected, statements in which problem solution elements were proposed or evaluated were more prominent than in the first phase ($t(5) = -3.82$, $p < .05$). Inversely, the amount of explanatory dialogue was lower than in the first phase ($t(5) = 3.54$, $p < .05$) both in absolute number and proportionally. The dyads also produced very few argumentation statements. Management was again an important category (no difference between phases ($t(5) = -1.08$, ns) and in particular management of the interaction.

CONCLUSIONS, DISCUSSION AND FURTHER WORK

This article focuses on epistemic dialogue as a vehicle for understanding scientific notions as well as on the conditions for the occurrence of such dialogue. In particular, it concentrates on epistemic dialogue produced in computer-supported collaborative learning environments. In the first sections, we further specified the necessary conditions for epistemic dialogue on the basis of existing literature. We claim that these conditions involve domain choice, task sequence (dyad constitution, prescribed activities), and computer support (task and communication structuring on the interface). Moreover, we described how these conditions can be satisfied through the concurrent engineering of the components of a specific learning situation, i.e. the CONNECT environment and task sequence. The empirical study then aimed at studying the occurrence of epistemic dialogue in relation to each of the components of the situation and the way in which knowledge and conceptions evolve in epistemic dialogue. Regarding these two points, we will now summarize the results of the qualitative and quantitative analysis of the dialogue produced in the CONNECT environment. We will also discuss some of the obstacles that may inhibit the occurrence of epistemic dialogue. Finally, we will discuss further work.

Conditions for and occurrence of epistemic dialogue

The first component of the CONNECT environment and task sequence concerns the topic of discussion. Within the scientific domain of physics, we chose a problem about sound for several reasons that were in fact corroborated by the qualitative analysis. Firstly, sound is a complex domain that can be understood at different levels of description (cf. Andy and Jerry: conceptual differentiation and use of analogy). Secondly, it has been shown that students commonly hold a variety of perspectives on sound phenomena (cf. Andy and Jerry: divergent mental models, conceptual differentiation and use of analogy). Thirdly, the everyday meanings of terms related to sound differ from their scientific meanings, and may also differ between individuals (cf. Andy and Jerry: multiple meanings). These reasons constitute both learning barriers *and* opportunities for debate. Our qualitative analysis thus showed episodes in which the occurrence of epistemic dialogue was closely related to levels of description, different perspectives and double meanings in the domain and as such may contribute to the development of conceptual understanding in that domain.

The second component relates to the task sequence itself, i.e. dyad constitution and prescribed activities. The dyad constitution procedure maximized the chances for students to have *different* conceptions and models. However, putting students together with differing viewpoints is not a sufficient condition. Students must notice their differences and want to discuss them. A close inspection of the opinion marks showed that model differences were noticed in five out of six cases. The high percentage of question marks as opposed to No's shows that students might not be prepared to explicitly disagree but rather will express the need for explanation. Noticing differences and even being prepared to request explanations for them does not necessarily mean, however, that students will actually proceed to discuss them (cf. Carol and Ellen: missed opportunities). In some cases, students will only discuss them when confronted with the task of writing a common text (cf. Andy and Jerry: addressing remaining differences).

One possible explanation lies in the tension between conditions for conceptually based learning and conditions for epistemic discourse (c.f. Nonnon, 1996). For the former, the concepts must be within the students' capabilities, but nevertheless need to be constructed or elaborated during the task sequence. For the latter, students' conceptions must be sufficiently elaborated, so that they are able to give or request an explanation, and/or to defend their viewpoints by argumentation. These sets of conditions are therefore clearly in conflict: how could one be sure enough of an idea currently being constructed in order to be willing to defend it? A second possible explanation for not engaging in epistemic dialogue relates to the social aspect of managing conflict (Traverso, 1998). Sharpening a cognitive conflict may sharpen an interpersonal social conflict and the students, as members of the same class, may not have wanted to pursue such an outcome. A third possible explanation lies in the nature of explanation and argumentation as social discourse practices that have to be learned (e.g. Voss & Means, 1991). Thus, it may have been that students did not have sufficient understanding of, and practice in, argumentation and explanation.

The third component is the task and communication interface and its insertion into the CONNECT sequence, which was designed to provide the preparation, the conditions, and the guidance for discussion. The preparation consisted of students writing an individual text (in class) that described the sound phenomenon. This was meant to initiate the construction of their own conceptual viewpoints. The display of individual texts and the students' opinion marking constituted the conditions and the guidance for discussion. These activities helped students gain an understanding of their partner's views, reflect upon them and compare them with their own (cf. Andy and Jerry: forging opinions). The instruction labels for each sentence on the interface gave direction to students' dialogue but with mixed outcomes (cf. Andy and Jerry: guided discussion, Carol and Ellen: missed opportunities, Daphne and Lydia: learning needs revealed). Thus, explanation and argumentation sequences have been shown to originate in the task and communication interface of CONNECT. However, students' dialogues also showed communicational burdens that hindered students' participation in epistemic dialogue. Firstly, even though we provided shortcuts for the students to use in managing their interaction, their dialogues revealed the burden of dialogue turns needed for interaction management (cf. Andy and Jerry: the burden of collaborative text writing at a distance). Secondly, the burden of executing task actions themselves, e.g. adding phrases to the common text, took time away from epistemic dialogue (cf. Andy and Jerry: communicating through text writing).

The quantitative analysis of the interactions of the six dyads was carried out in order to determine the extent to which the CONNECT situation favored dialogue rather than task activities, and explanation and argumentation rather than other types of discourse. Firstly, analysis of the interaction showed a prevalence of dialogue over task actions. We view this predominance as a positive outcome of the design of the interface and task sequence. Due to the burden of communication in a computer-mediated situation, task actions could well have prevailed over dialogue especially in the second phase. Secondly, analysis of the type of dialogue showed high percentages of explanation and argumentation compared to percentages found in previous research. So, whereas coordinating the interaction and the task still took up an important portion of a computer-mediated dialogue, these communicational burdens had only limited effects in the CONNECT environment. Moreover, there seem to be important differences depending on the activity that is carried out. Pure construction type activities demand more management due to the turn-taking not only between partners dialoguing, but also due to alternation of task and dialogue turns. The interplay of two partners and two possibilities for proceeding (I speak, you speak, I act, you act) renders the computer-mediated situation for construction activities a rather complicated one.

Epistemic dialogue and conceptual understanding

Once epistemic dialogue occurs, the question is how it may contribute to conceptual understanding of scientific notions. The Andy and Jerry interaction illustrates one of the ways in which this can take place, namely through conceptual differentiation resulting from the resolution of vocabulary ambiguities. The example “moving a lot” meaning either movement in terms of frequency or movement in terms of amplitude shows the importance of rendering explicit meanings behind words.

In contrast, Carol and Ellen’s case shows how an initially recognized conflict leads to epistemic dialogue, but does not reveal progress towards conceptual understanding. We qualified this as a missed opportunity. Instead of both exploring the differences between their models, Carol presents successive explanations of her own model seemingly with a goal of coinciding with Ellen’s model.

Another route towards conceptual understanding, present in the CONNECT data, is the recognition of a *lack* of understanding. In fact, it is not necessarily obvious that students realize just what it is they do not understand or that they realize that it is the appropriate moment to consult an outside source (for example their teacher in the Daphne and Lydia case). The arrival at such an impasse can be considered to be a positive outcome in the sense that the students have taken charge of their own pursuit of understanding.

Further work

In conclusion, our work has demonstrated how different components of CSCL environments can play a role in favoring epistemic dialogue. We have highlighted the complex and interacting set of factors that are involved in enabling students to engage in such dialogues in a way that could lead to conceptual understanding and have described ways in which this can take place. Our future work will address the issue of defending opinions vs. constructing knowledge, focus on how to teach argumentation discourse practices, and explore how technology can help facilitate conceptual differentiation and recognition of learning needs, while working against the missed opportunity phenomenon. The integrated approach embodied in the CONNECT environment provides a promising way of exploring these complex issues in future research. Addressing these issues requires a broader understanding of how communication and information technologies can be embedded within discursive practices in educational settings.

ACKNOWLEDGEMENTS

This research was carried out during the time of the first author's stay as a Marie Curie Fellow (Training and Mobility of Researchers grant of the European Commission) in the COAST research team of the GRIC Laboratory in Lyon, France. We extend our warmest thanks to the students who participated in the study.

REFERENCES

Amigues, R. (1990). Peer interaction and conceptual change. In H. Mandle, E. De Corte, N. Bennett, & H. F. Friedrich (Eds.), *Learning and Instruction: European research in an international context. Volume 2:1 Social and cognitive aspects of learning and instruction* (pp. 27-43). Oxford: Pergamon.

Baker, M. J. (1991). the influence of dialogue processes on the generation of students' collaborative explanations for simple physical phenomena. In L Birnbaum (Ed.), *Proceedings of the International Conference on the Learning Sciences* (pp. 9-19). Evanston, Illinois.

Baker, M. J. (1996). Argumentation et co-construction des connaissances [Argumentation and co-construction of knowledge]. *Interaction et cognitions*, 1, 157-191.

Baker, M. J. & Bielaczyc, K. (1995). Missed opportunities in collaborative problem-solving interactions. In J. Greer (Ed.), *Proceedings of the World Conference on Artificial Intelligence and Education* (pp. 210-217). Washington, DC: AACE.

Baker, M. J. & Lund, K. (1997). Promoting reflective interactions in a CSCL environment. *Journal of Computer-Assisted Learning*, *13*, 175-193.

Baker, M. J. (1999). Argumentation and constructive interaction. In P. Coirier & J. Andriessen (Eds.), *Foundations of Argumentative Text Processing* (pp. 179-202). Amsterdam: University of Amsterdam Press.

Barth, E. M. & Krabbe, E. C. W. (1982). *From Axiom to Dialogue: A philosophical study of logics and argumentation*. Berlin: Walter de Gruyter.

Blaye, A. (1990). Peer interaction in solving a binary matrix problem: Possible mechanisms causing individual progress. In H. Mandl, E. De Corte, S. N. Bennett, & H. F. Friedrich (Eds.), *Learning and Instruction: European research in an international context, Vol. 2:1. Social and cognitive aspects of learning and instruction* (pp. 45-56). Oxford: Pergamon.

Blaye, A., Light, P., & Rubtsov, V. (1992). Collaborative learning at the computer: How social processes "interface" with human-computer interaction. *European Journal of Psychology of Education*, *7*, 257-267.

Chi, M. T. H., Slotta J. D., & Leeuw, N. de. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction*, *4*, 27-43.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science*, *13*, 145-182.

Chi, M. T. H., Leeuw, N. de, Chiu, M.-H., LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science*, *18*, 439-477.

Clark, H. H., & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 127-149). Washington, DC: APA.

Collet, G. (1996). *Apports linguistiques à l'analyse des mécanismes cognitifs de modélisation en sciences physiques* [Linguistic contributions to the analysis of cognitive mechanisms of modeling in physics]. Doctoral dissertation, Grenoble, INPG.

diSessa, A. A. (1982). Unlearning Aristotelean physics: A study of knowledge-based learning. *Cognitive Science*, *6*, 37-75.

diSessa, A; A. (1996). What do "just plain folk" know about physics. In D. R. Olson & N. Torrance (Eds.), *The handbook of education and human development* (pp. 709-724). Cambridge: Blackwell.

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's ideas in science*. Milton Keynes: Open University Press.

Golder, C. (1996). *Le développement des discours argumentatifs* [The development of argumentative discourse]. Lausanne: Delachaux & Niestlé.

Koschmann, T. D. (1994). Toward a theory of computer support for collaborative learning. *Journal of the Learning Sciences*, *3*, 219-225.

Kuhn, D., Shaw, V., & Felton, M. (1997). Effects of dyadic interaction on argumentative reasoning. *Cognition and Instruction*, *15*, 287-315.

Lave, J. (1988). *Cognition in practice*. Cambridge: Cambridge University Press.

Lemke, J. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex.

Linder, C. J. & Erickson, G. L. (1989). A study of tertiary physics students' conceptualizations of sound. *International Journal of Science Education*, *11*, 491-501.

Lund, K., Baker, M., & de Vries, E. (1997). *Teachers' analysis of and support for students' collaborative problem-solving activity: a study in a CSCL environment for understanding sound in physics*. Poster presented at the second international conference on Computer Support for Collaborative learning, Toronto, Canada [Online], abstract. Available: http://www.oise.utoronto.ca/cscl/posters.html [1999, February 11].

Maurines, L. (1998, January). Les élèves et la propagation des signaux sonores. *Bulletin de l'Union des Physiciens*, *92*, 1-22.

McCloskey, M. (1983). L'intuition en physique. *Pour la science*, *68*, 68-76.

Miller, M. (1987). Argumentation and Cognition. In M. Hickmann (Ed.), *Social and Functional Approaches to Language and Thought* (pp. 225-249). London: Academic Press.

Nonnon, E. (1996, December). Activités argumentatives et élaboration de connaissances nouvelles: le dialogue comme espace d'exploration [Argumentative activities and elaboration of new knowledge: dialog as an exploration space]. *Langue Française, 112*, 67-87.

Ohlsson, S. (1995). Learning to do and learning to understand: A lesson and a challenge for cognitive modeling. In P. Reimann & H. Spada (Eds.), *Learning in humans and machines* (pp. 37-62). Oxford: Elsevier.

Pea, R. D. (1994). Seeing what we build together: Distributed multimedia learning environments for transformative communications. *Journal of the Learning Sciences*, *3*, 285-299.

Perelman, C. & Olbrechts-Tyteca, L. (1988). *Traité de l'Argumentation* [Essay of argumentation] (5th ed). Brussels: Editions de l'Université de Bruxelles.

Robles, A., & Le Marechal, J.-F. (1996). *La propagation du son: Representation microscopique* [Sound propagation: a microscopical representation]. [Videotape]. Lyon: GRIC-COAST, CNRS-University of Lyon II.

Resnick, L.B., Salmon, M.H., Zeitz, C.M., Wathen, S.H. & Holowchak, M. (1993). Reasoning in conversation. *Cognition and Instruction*, 11 (3 & 4), 347-364.

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *Journal of the Learning Sciences*, *2*, 235-276.

Roschelle, J. & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. O'Malley (Ed.), *Computer supported collaborative learning* (pp. 69-97). Berlin: Springer Verlag.

Scardamalia, M. & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences*, *3*, 265-283.

Suthers, D. (1998). *Representations for scaffolding collaborative inquiry on ill-structured problems*. Paper presented at the annual conference of the American Educational Research Association, San Diego, California.

Suthers, D. & Weiner, A. (1995). Groupware for developing critical discussion skills. In J. L. Schnase & E. L. Cunnius (Eds.), *Proceedings of Computer Supported Cooperative Learning*, Bloomington, Indiana.

Tiberghien, A. (1994). Modeling as a basis for analyzing teaching - learning situations. *Learning and Instruction*, *4*, 71-87.

Tiberghien, A., & De Vries, E. (1997). Relating characteristics of learning situations to learner activities. *Journal of Computer Assisted Learning*, *13*, 163-174.

Tiberghien, A. & Megalakaki, O. (1995). Characterization of a modelling activity for a first qualitative approach to the concept of energy. *European Journal of Psychology of Education*, *10*, 369-284.

Traverso, V. (1998). Negociación y argumentación en la conversación familiar [Negotiation and argumentation in informal conversation]. *Escritos*, 17/18, 51-88.

Van Eemeren, F. H. & Grootendorst, R. (1984). *Speech acts in argumentative discussions*. Dordrecht-Holland: Foris Publications.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*, 45-69.

Voss, J. F. & Means, M. L. (1991). Learning to reason via instruction in argumentation. *Learning and Instruction*, *1*, 337-350.

Walton, D. N. (1992). *Plausible argument in everyday conversation*. New York: State University of New York Press.

Webb, N. M. (1989). Peer interaction and learning in small groups. *International Journal of Education Research*, *13*, 21-39.