

## **Relating characteristics of teaching situations to learner activities**

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**Abstract** This paper compares collaborative problem solving by learners sitting side-by-side with computer-mediated learning at a distance. Three aspects are studied: students' problem solving strategies and interpretation of the teaching situation, their use of components of the situation, and the cognitive processes involved in understanding domain knowledge, energy in physics. The analysis shows how situational characteristics affect the balance between discussion and construction activities, as well as the degree of salience of certain components of the situation. Furthermore, the simple and complex cognitive processes are not expressed to the same degree in side-by-side and distance cases. Implications of these results for the design of teaching situations are discussed.

*Keywords:* Cognitive processes; Distance collaboration; Teaching situations; Learning physics

### **Introduction**

This paper investigates changes in situational characteristics and students' joint knowledge construction when a teaching sequence for student pairs working side-by-side is transposed into a computer-mediated situation. Pairs of learners were studied as they solved problems working side-by-side using one computer, or through a network at a distance, each using one computer. In the latter case, students communicated by typing messages that could be seen in real time by their partner. In both situations, the students drew their solution on the computer using a specially designed interface (Devi *et al.*, 1996).

Whereas the *main difference* between these situations is the type of interaction allowed, the *common goal* in the design is students learning through collaboration. New technologies provide an interesting opportunity for investigating the variety of teaching situations which, nowadays, is greatly increasing. Thus,

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understanding of teaching situations with and without new technologies may be enhanced. From this perspective, the local interaction using the computer, the interpretation of the current situation, and the construction of social context have to be taken into account (Mantovani, 1996).

This paper describes a theoretical approach to collaborative learning and the characteristics of the corresponding teaching situations\*. A specific teaching situation in physics is introduced and, in particular, the qualitative modelling problems and the characteristics of the side-by-side and distance settings are examined. Finally, a qualitative comparison of three particular aspects of students' problem solving in the two situations, side-by-side and at a distance, is made in the light of the theoretical approach.

### Learning through collaboration

Peer collaboration, as described by Damon and Phelps (1989), should create an engagement rich in mutual discovery, reciprocal feedback, and frequent sharing of ideas. Aspects of collaboration that are expected to be conducive to learning are: using the partner as a resource (Baker & Bielaczyc, 1995), knowledge negotiation (Baker, 1994; Roschelle & Teasley, 1995), argumentation (Baker, 1996; Suthers & Weiner, 1995), and mutual explanations, in a manner analogue to self-explanations (Chi *et al.*, 1989; Chi *et al.*, 1994). Thus, although different theoretical notions exist (see also Koschmann, 1994), there seems to be an agreement that collaboration is conducive to learning.

The general hypothesis adopted is that learners construct their knowledge of a domain by action (physical or intellectual) from their previous knowledge. The case of learning in the experimental sciences was studied in this work where learning complex knowledge, such as physics, involves the acquisition of a meaning which allows for the interpretation (and if possible prediction) of a variety of experimental or everyday settings (Niedderer *et al.*, 1992; Vergnaud, 1990). This acquisition is strongly related to the students' way of processing knowledge and these cognitive processes, relating physics concepts to the objects and events of an experimental field, are thought to be a necessary prerequisite for learning, though they might not be sufficient. This is why, in order to compare teaching situations, there is a need to study students' problem solving processes, their final solution not being the main focus of interest for the research.

Depending on the situation, learners construct their own interpretation of what has to be done. Thus, students' problem solving has to be related to the characteristics of teaching situations. In this study, two main characteristics are distinguished. First, the type of *communicative interaction* allowed, which differs between the two situations. Second, the *media* used to convey knowledge, for example, written texts, drawings, videos, experimental apparatus. In this

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\* Editor's note: In this paper the term 'situation' is used in the specific sense of the 'theory of didactic situations' as, for example, in Brousseau (1986). Hence, the term 'teaching situation' is used even though *direct* instruction by a teacher is not expected. Some authors would use the term 'learning environment' to describe the software, apparatus and written notes which the learners use and with which they interact.

study, the media used were the same in both cases and it was the analysis of problem solving protocols during communication which was compared in the side-by-side and distance situations.

**Description of the teaching situation**

The situation was constructed by the researchers for a specific purpose. The aim was for the learners to construct relations between two types of knowledge: their knowledge of the objects and events of an experimental apparatus and their knowledge of a physics theory/model text. This section describes the modelling problems given to the students and the characteristics of the side-by-side and distance settings.

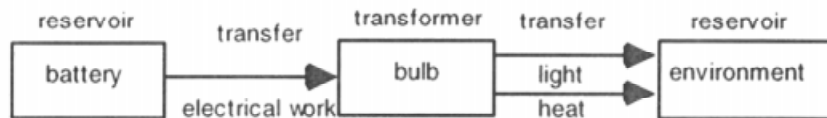
*The modelling problems*

The physics modelling problems were designed to help high school students (age 16-17) acquire conceptual knowledge through collaborative problem solving (Tiberghien & Megalakaki, 1995). They involved establishing relations between objects and events in the real world (e.g. battery, bulb, electricity), to concepts of the energy model and theory (reservoirs, transformers, transfers of energy).

The student pairs were asked to construct a chain for three experiments:

- battery — bulb — two wires;
- an object is hanging on a string which is completely rolled round the axle of a motor (working as a generator); a bulb is connected to the terminals of the motor; when the object is falling, the bulb shines;
- a battery is connected to an electrical motor; an object is hanging from a string, attached to the axle of the motor, which is completely unrolled at the beginning.

A correct solution to the first problem is shown in Fig. 1.



**Fig. 1.** Energy chain for the battery-bulb problem (expert solution)

The problems allow for both a one to one matching of elements or more complex matching. Students have to decide which part of the real world should be represented by which symbol in the model, and elaborate a meaning of the physics concepts in relation to the experimental apparatus.

*The side-by-side and distance situations*

The modelling problems have been studied in a variety of settings. Although not especially designed for this purpose, data from six side-by-side pairs and 11 distance pairs (second year of upper-secondary school, age 16-17) was used for comparison. The side-by-side pairs worked on one computer using *CHENE*, a program for constructing energy chains. The distance pairs worked in an electronic network using *C-CHENE*, a version of *CHENE* that allows text-based

distance communication (see Baker & Lund, 1997, pp. 175-193 in this issue, for a description of the interface). The available data are of two kinds: the dialogue between students (either transcriptions of video-recordings in the side-by-side case, or the record of the dialogue in the distance case), and the construction of the solution carried out on the computer (a record of the graphic actions) in both cases.

Whereas the communication channel is the main distinguishing characteristic, the situations are similar with respect to the media for conveying knowledge. These media involve the following components:

- the three successive experiments: battery-bulb, object-falling, and object-rising;
- the theory/model text on a sheet of paper, entitled 'energy model';
- the problem statement on a sheet of paper.

The problem statement was: *Use the 'energy model' to build the energy chain corresponding to the experiment.* Therefore, the students had to produce an energy chain for a given experiment with the theory/model sheet.

Whereas in the side-by-side case, student pairs had only one experimental setup and one text sheet; each student of the distance pairs had their own experimental apparatus and sheet. This led to a difference between the two situations in the possibility to designate an element of the experimental apparatus or the text sheet by gesture, and to show something to the partner by handling the experimental apparatus.

### **A qualitative comparison of the problem solving activities**

In the side-by-side cases, attention can be directed not only to human bodily orientation, gesture and facial expression, but also to the material environment (Pea, 1994). Whereas side-by-side interactions take place in a *rich common referential field*, interaction at a distance is much more limited. Clark and Brennan (1989) have described a variety of available resources and imposed constraints associated with the use of the computer as a medium for communication. Especially, the *processes* by which common ground is established and maintained between the two collaborating students will be highly influenced by the communication possibilities offered through properties of the interface (Dillenbourg *et al.*, 1996). Moreover, interfaces can be designed to limit the burden of interaction control activities and encourage other activities (Baker & Lund, 1997 — pp. 175-193 in this issue); Reinhard, *et al.*, 1997 — pp. 148-162 in this issue).

The qualitative comparison reported here focuses on three aspects of the students' problem solving that might be influenced by the difference in communication channel:

- a comparison of the way in which students viewed the situation;
- the role of the components of the situation, i.e. the experimental apparatus on the one hand, and the theory/model text (both the sheet and its content) on the other;
- the way in which students processed domain knowledge, as far as it was explicitly expressed in their dialogue.

The following subsections each deal with one of these three aspects of students' problem solving.

*The situation as viewed by the students*

The first question concerns the interpretation of the situation constructed by the students: does it differ in the side-by-side and distance cases? To answer this question the students' strategies in the two situations were compared. by an analysis of the protocols used to establish the successive problem solving steps, i.e. students' successive aims in constructing a solution. This paper presents a comparison of two pairs who construct a similar solution for the first problem, a completely correct one (a distance pair with initials C-L) and one correct on the most difficult aspect, with a minor error (a side-by-side pair with initials P-M). In general, the number of correct solutions for the first problem was very low. These pairs with (almost) correct solutions were chosen deliberately because, in these cases, it is clear that the problem statement was well understood. This means that both student pairs were definitely dealing with the physics problem in a conceptual way and so observed differences in dialogue and construction sequences can be attributed to the students' interpretation of the situation. The problem solving steps were established by looking at either sentences that explicitly marked the beginning or end of a period, such as "OK, we're done, what else is there to do?", or sequences that represented the accomplishment of a subgoal in solving the problem (Hoc, 1987).

*The side-by-side situation:* For the pair P-M in the side-by-side situation, 175 dialogue turns were observed over a period of 20 minutes. The following problem steps could be distinguished:

| Step | Description   | Dialogue | Construction  |
|------|---|----------|---|
| 1.   | Discussion on the possible solution in terms of matching between elements of the experiment and those of the chain, construction of a reservoir   | 18 turns | 1 reservoir created                                   |
| 2.   | Construction of the chain. Only 1 reservoir and the transformer are named, but not the transfers.   | 36 turns | 1 reservoir,<br>1 transformer,<br>4 transfers created |
| 3.   | Discussion on the names to give to the transfers, and construction (name giving). The first 39 dialogue turns are discussion only, the remaining 17 deal with both discussion and construction. | 56 turns | 2 transfers named,<br>2 transfers deleted             |
| 4.   | Interruption of the researcher on technical aspects.  | 10 turns |   |
| 5.   | Questioning a reservoir from the rule of the text and construction. The first action to modify the solution is done after 24 dialogue turns.  | 55 turns | 1 reservoir and<br>2 transfers created<br>and named   |

In these steps, a prevalence of discussion over construction activities can be seen from the point of view of both the *order* of these activities, the students started by discussion on the possible solution, and *number* of turns within each type of activity, a large number of successive discussion turns were typical in the side-by-side situation. It appears that in the students' interpretation, the situation demands a discussion in order to agree on the matching between the

experiment and the elements of the chain by taking into account the rules given in the text. This is illustrated by the first 11 dialogue turns of this pair, shown in the following example which is representative of students' interactions in the side-by-side situation:

|    |   |   |
|----|---|---|
| 1  | P | The reservoir, it's the battery. No but we have to do a small drawing there   |
| 2  | M | You understand it, that's very good   |
| 3  | P | The reservoir, that's the battery since it stores energy  |
| 4  | M | Construct the energy chain [is reading the problem statement], the reservoir there stores the energy, so the reservoir there is |
| 5  | P | The battery   |
| 6  | M | The battery   |
| 7  | M | Transformer, that's the wires   |
| 8  | P | No, no, it is the transformer, it's the lamp, that transforms the electric, the electric  |
| 9  | M | Ah!   |
| 10 | P | Ah! into light  |
| 11 | M | Transfer it is the wires  |

At this point, the pair had already established a matching between the main elements of the experiment and those of the model even if, later on, they questioned it. This matching was established through verbal exchange without *any* construction.

*The distance situation:* For the distance pair (C-L), a total of 34 dialogue turns was observed over a period of about one hour. The problem solving steps in the distance situation were the following:

| Step | Description   | Dialogue | Construction   |
|------|---|----------|--|
| 1.   | Construction of the chain with matching between elements of the experiment and the chain. The first five dialogue turns deal with who will start constructing.  | 12 turns | 1 reservoir, 1 transformer, 1 transfer created and named                                 |
| 2.   | Questioning of the solution with reference to a rule of the text, followed by construction by one student (C), with 2 remarks and a question from the other (L). In the last turn, C asks L to express his opinion on the construction. | 12 turns | 2 transformers, 1 reservoir, 3 transfers created and named (1 transformer gets deleted). |
| 3.   | Construction by L since he doesn't quite agree. A question from C and a justification from L.   | 9 turns  | 1 transformer deleted, 2 transfers created   |

In these steps, a prevalence of construction over discussion activities can be seen from the point of view of both the *order* of these activities, the students started by constructing a chain, and the *number* of turns, construction sequences were long, and discussion involved only a few turns for establishing agreement only *after* construction. It appears that for the students, the situation demanded the mere construction of the chain, and how to accomplish it. In the following example, representative for students' interactions in the distance situation, the

first five dialogue turns show how this student pair interpreted the situation:

|    |   |   |
|----|---|---|
| 1  | L | Hi Christophe, shall we do the energy chain right away?                                   |
| 2  | C | Hi Laurent! Yes, we can start. We have to agree in order to know who does what            |
| 3  | L | I can do the reservoir and the transformer if you want                                    |
| 4  | C | OK, after that, it will be up to me   |
| 5  | L | Yes, I start immediately  |
|    | L | <b>[R battery] (T bulb)</b>   |
| 6  | L | That's it, I finished. Are you happy with what I did?                                     |
| 7  | C | Yes I 'm happy. I'll do the transfer now  |
|    | C | <b>[R battery] — Tr (T bulb)</b>  |
| 8  | C | How do you want to name it?   |
| 9  | L | I think it should be named electrical wire, but I'm not sure                              |
| 10 | C | Me neither, what's more, if you look at your sheet, on transfers, it says electrical work |
| 11 | L | Well then, it's OK, you can put that  |
|    | C | <b>[R battery] — Tr <i>electrical work</i> (T bulb)</b>                                   |

At this point, the pair had established a matching similar to the side-by-side case, but it was obtained merely through a construction. The matching (the battery is a reservoir, the bulb is a transformer) is not explicitly expressed in their discussion.

In conclusion, in the side-by-side case, the students explicitly discussed the problem before constructing the solution, whereas in the distance case, students constructed an individual partial solution and proposed it to their partner.

*Students' use of the components of the situation*

As already described, in both the side-by-side and the distance situation, the student pairs had experimental apparatus which they could handle and a text (an information sheet). Typical examples, taken from side-by-side and distance pairs solving one of the three problems, illustrate the key points.

*The experimental material.* As mentioned in the section on the characteristics of both situations, the use of the experimental material could not be the same in students' interactions. A video transcription of a side-by-side pair for the second problem (falling-object) nicely illustrates this point.

M handled the experimental material and used gestures as an argument in itself and S's answer took into account what she saw; she disagreed with M's idea of a reservoir which would fill when lifted up. This type of interaction never appeared in the distance situation. Such an interaction would require students to verbalise their actions with the experimental apparatus, which is not impossible, *a priori*, but up to now it was never observed. A specific study would be necessary to investigate under what conditions such verbalisation can happen.

|     |   | Verbal transcription  | Gesture                                  |
|-----|---|---|--|
| 155 | M | Well yes, that is a reservoir because as long as it is going down. In fact, it is a certain quantity  | M (looks at S) touches string and object |
| 156 | S | But the force, it didn't exist before, therefore there is reservoir of nothing  |  |
| 157 | M | Yes, there is, besides, to euh, you see, fill the reservoir (laughs)  | M raises the object                      |
| 158 | S | (laughs)  |  |
| 159 | M | We'll just have to lift that. Yes, yes, no, I'm not kidding   | M lifts the object again                 |
| 160 | S | Well  |  |
| 161 | M | Yes, there you go, I lifted the reservoir up to about there, I can lift it even more, and then, there I'm supplying it. Well in fact, I would have dropped it and | M lets the object fall                   |
| 162 | S | No, the reservoir, it is manufactured, there, it is the battery which is manufactured   |  |

*Use of the text:* Two aspects should be considered: the physical use of the text sheet and the way in which students took the content of the text into account. On the first, the difference between the side-by-side and the distance situation is comparable to the difference regarding the use of the experimental apparatus. Whereas a student could see the partner reading the text in the side-by-side situation, this was not possible in the distance situation. However, unlike the case of the experimental material, some verbalisation of the action of reading in the distance situation was observed. For example in the battery-bulb problem, C in CE (intervention 4): *"do as you think is best, start and take control, but I've not finished reading the sheet"*, or M in MC (intervention 13): *"Look at the sheet, we have to construct a transformer, I think"*. So, the sheet as a component of the situation was explicitly referred to a number of times.

On the second aspect, a phenomenon in the distance situation that never occurs in the side-by-side situation can be seen. One pair of students constructed a chain based only on the text, and did not refer to the experiment (or at least not explicitly). In fact, as in previous examples, these students started by constructing the chain consisting of reservoirs, transformers and transfers *without* referring to the objects of the experiment as they were asked in the problem. Here is an example in which R starts by constructing a reservoir named energy. Then, they wonder how to proceed.

|    |   |  |
|----|---|--|
| 7  | R | I believe there has to be 3 transformers with a transfer each      |
| 8  | G | OK, you do the transformers and I do the transfers?                |
|    | R | [R <i>energy</i> ] (T) (T) (T)                                     |
| 9  | R | Do you know how to name them?                                      |
| 10 | G | By the way, how do you know that there must be three transformers? |
| 11 | R | Because there have to be 3 transfers                               |
| 12 | G | Why?   |
| 13 | R | Read the sheet   |

In this case, in the students' interpretation, the situation mainly asked for the construction of a chain following the rules given by the text; and did not demand the establishment of a match between the elements of the experiment (objets and events) and the elements of the text. This type of interpretation of what was asked for in the problem statement did not occur in side-by-side situations.

The comparison between the two situations shows that, although the components of the situation were objectively similar, the way in which students interpreted them was modified (Brousseau, 1986). In the distance situation, the text seemed to be much more salient than the experiment. This phenomenon can be interpreted as an example of a general tendency in school science teaching: the experiment is easily undervalued by comparison with written text which has the status of 'correct' knowledge to be learnt. The distance student pairs, physically working in isolation, were apparently more inclined to hold on to the text rather than referring to the experiment in solving the problem. The side-by-side pairs, in their face-to-face collaboration, did not seem to be affected by this tendency. In the distance situation, this phenomenon can also be attributed to the similarity of the written form, that is the text and the students' communication. The fact that the students communicated with typed messages might have enhanced the usage of the written text.

#### *Processing of domain knowledge*

Tiberghien and Megalakaki (1995) discussed the cognitive processes involved when students establish relations between the objects and events of the experiment and the elements of the energy model given in the text. Here, only five categories are used:

1. simple matching of an element of the experiment to an element in model, e.g. "*the reservoir is the battery.*";
2. as 1. with an explanation or a justification, e.g. "*the reservoir stores the energy, then it is the battery. In the battery there is the energy, do you agree?*";
3. matching a structure in the experiment to a structure in the model, e.g. "*the bulb will be another transformer and the wires transfers.*";
4. as 3. with an explanation or justification, e.g. **P**: "*I would have thought that the reservoir would be the motor and the object together.*" / **F**: "*What do you mean the motor and the object?*" / **P**: "*the motor and the object that turns the motor. Then after, we'd put the bulb and after that we'd put the environment.*";
5. mixing the elements of the experiment and the model in a single explanation, e.g. "*The object is the reservoir. . . The object produces energy. Do you agree? The object falls and this produces energy which goes through the motor and arrives at the bulb. And the light bulb lights up.*".

These examples are all taken from *side-by-side* situations, see Tiberghien and Megalakaki (1995) for the complete analysis. In the *distance* situations, these categories are not often observed (see also Hesse *et al.*, 1995).

No explicit verbal occurrences of simple matching in distance situations were detected in the dialogue analysis. This is not surprising given their strategy of successive construction without discussion. These student pairs accomplished

matching by constructing an element, naming it, and asking for agreement only afterwards. This means there was no necessity to express what was matched, and why it was matched.

Moreover, in the distance situation, no interventions falling into category 2 were found. An adequate indicator is the number of times that the verbs "to store" and "to transform" were used in the dialogues. Collet (1996), in a linguistic analysis of the words in the energy chain domain, described how these verbs served as an engine for justification, and provided a potential control for a proposed matching. In the side-by-side situation, for the battery-bulb problem, student pairs used the verb "to store" zero to two times, and the verb "to transform" three to five times. The verbs were used when students explained a simple matching. They explicitly verbalised the similarity of behaviour between an element of the model and a real object, e.g. both a battery and a reservoir 'store', and both a bulb and a transformer 'transform'. However, in the distance situations, students *never* used the verb "to store" in their dialogue and only two pairs used the verb "to transform" but only once.

An analysis of the problem solving interactions of a number of distance pairs showed that the interventions described by the five categories are in fact rare, and whenever they are present, they can be classified in one of the three categories with more complex relations (Hesse *et al.*, 1995).

Thus, as is shown in Baker and Lund (1997 - in this issue), the cost of making ideas explicit in the distance situation is high. In this data, only the most complex cognitive processes appeared in the distance dialogues. It may be concluded that, although both simple and complex processes are necessary for problem solving, only the complex ones need to be expressed explicitly by the students; the simple ones may remain implicit.

## Conclusion

This comparative study illustrates several points. First, the relative weight of discussion and graphical construction is influenced by the characteristics of the situation. Second, the degree of salience of the components of the situation, such as the experiment and a written text, varies. The text is much more salient than the experiment in the distance situation. Third, although *a priori* simple cognitive processes are easier to express than the complex ones, both appear in the side-by-side dialogues, and only the latter appear in the distance dialogues. Thus both types of process seem to be necessary, but only the *explicitation* of complex cognitive processes can be seen as indispensable to collaborative problem solving.

An explanation lies in the framing effect of using the computer which might encourage actions more than discussion. Although there was a computer in both situations, in the distance case, the students were alone in front of their computer and this strongly constrained the students' view of the situation. In the distance case, the situation becomes one of mainly constructing a graphical representation rather than a joint elaboration of the concepts involved and discussion seems to be the first to suffer. Tasks which are predominantly verbal

would probably suffer less from these effects (Dillenbourg *et al.*, 1996; Andriessen *et al.*, 1996).

The comparisons made in this study lead to important implications for the design of teaching situations in the experimental sciences. The discussion activities, which are very important for learning, are extremely dependent on the students' view of the situation. A carefully designed situation should favour discussion without demanding special effort, or should make discussion a necessary condition in the solution process. Another implication is related to the role played by the experimental materials. Its importance is easily diminished, and its mere presence in the situation is not a sufficient prerequisite for students to take them into account. This means that teaching situations have to be designed that, through the problem statement or the introduction of a need for verification, compel students to consider the experiment in the problem solving process (Bécu-Robinault, 1997). In fact, transposing a situation designed for students collaborating side-by-side to a distance collaboration can disclose the specific role of its components, and guide the future design of both side-by-side and distance settings.

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