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# Favouring modellable computer-mediated argumentative dialogue in collaborative problem-solving situations

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**Abstract :** We describe an experimental Collaborative Problem-Solving (CPS) environment involving Computer-Mediated Communication (CMC), that is designed to favour the production of argumentative interactions and to enable the cognitive changes that they produce to be modelled. Our approach is based on defining a restricted set of psychological and logico-linguistic conditions for generation of argumentation, an original algorithm for optimising constitution of dyads for critical discussion and a computer-based environment that combines graphical and language-based problem-solving with CMC discussion. This approach enables us to study learners' solutions, justification structures and attitudes, before and after CPS activity, and thus to assess the role of argumentative interactions in students' changes in view. Corpus analysis showed that whilst the environment is successful in favouring argumentative interactions, it leads to increased awareness in students concerning the nature of their problem-solving task (in this case, modelling energy in physics) rather than an improvement in solutions or conceptual understanding.

## 1. Introduction

A central tenet of recent research on collaborative learning is that certain types of communicative interactions between learners can be associated with specific interactive learning mechanisms (e.g. [1]). In this paper we concentrate on the case of argumentative interactions between learners — interactions that involve the attempt to resolve expressed conflicts of opinions with respect to proposals, by verbal means (expression of justificational structures). A number of mechanisms by which these types of interactions could lead to conceptual change have been described (e.g. [2,3]) but a major problem remains: it appears that very complex and strict conditions are required in order for argumentative interactions to be produced by learners [4], especially in CMC situations [5].

Our research addresses two related problems: (1) understanding the conditions for production of argumentative interactions in CPS situations involving CMC, and (2) modelling the cognitive changes produced as a result of engaging in argumentative interactions. We propose a restricted set of conditions under which argumentative interactions can be produced, based on psychological and logico-linguistic studies of argumentation, and research on computer-mediated interactions in cooperative learning situations. These conditions form the basis for design and implementation of a computer-based environment, involving synchronous type-written CMC. Experimentation of the environment has enabled us to collect a corpus of argumentative interactions that is adapted to the validation of a cognitive model of argumentation in relation to cognitive change [6,7]. Our experimental CPS sequence involves encouraging students to express justifications and attitudes, automatically translating graphical problem-solutions into a linguistic form as a preparation for debating, automatic constitution of dyads

and generation of individualised texts describing the verbal conflict situation, and individual reconstruction of the agreed solution and justifications after CMC discussion. This approach enables us to study learners solutions, justification structures and attitudes, before and after CPS activity, and thus to assess the role of argumentative interactions in students' changes in view.

We describe design conditions and modelling constraints for argumentative interactions, then the computer-based environment whose design was based upon them, in the context of the experimental CPS sequence. We present and discuss results of a study where the learners' task was to elaborate simple qualitative models of energy ("energy chains", [8]). In conclusion we discuss the extent to which this experimental CMC situation has potential as a learning environment and how this tool could be applied to other types of CPS.

## 2. Design conditions and modelling constraints

Previous research on problem-solving dialogues between learners has confirmed what teachers have always known: students are not naturally likely to argue spontaneously with each other, at least with respect to the subjects taught in school. Interpersonal conflicts or individual contradictions are not sufficient to provoke the incidence of argumentation. Nonnon's work [9] partially explain this phenomenon: students will not be able to adopt sufficiently firm and opposed argumentative positions with respect to concepts that are not yet sufficiently mastered (since they are being elaborated, and learned). So it appears that, in certain situations, there will be a trade-off between conditions for collaborative learning and for engaging in argumentative interactions.

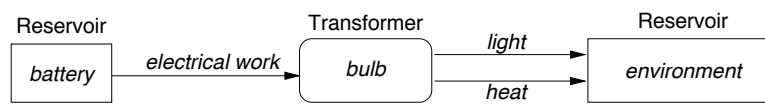
*Necessary conditions.* Our study of situations that can promote spontaneous<sup>1</sup> argumentative interactions between learners is structured by *psychological conditions* (C1-C4) concerning obstacles to the production of argumentative texts [4] and by *pragma-dialectical conditions* (C5-C8), derived from theoretical studies of argumentation [10]:

- C1. The concepts underlying the problem-solving task to be solved can be understood by participants.
- C2. The "debatability" of the task: participants can understand different positions with respect to the problem; they are able to 'step-back' in order to apprehend differences of attitudes and contradictions.
- C3. The communication situation (CMC interface) does is not an unsurmountable obstacle to the expression of opinions. For example, a type-written interface may be an obstacle for communicating graphical solutions.
- C4. The conceptual distance between the two conflictual theses is sufficiently wide and evident. If it is not the case, there are many non-argumentative way to 'dissolve' the conflict [3] (e.g. by finding a compromise or even a immediate retraction of one thesis).
- C5. A minimal common ground is shared, with respect to the topic to be discussed. This is a minimal condition for understanding each other.
- C6. A conflict of opinions has been openly declared, and understood: participants know their initial positions in the conflict.
- C7. Participants have enough arguments at their disposal, and commit themselves to the debate (they have *something to argue about*).
- C8. Individuals' "argumentativeness": participants want to resolve the conflict of opinions, whilst defending their own positions (*they want to argue*).

*Modelling constraints.* In order to experiment the potential of such a learning situation, attitudes and explanations have to be collected just before and just after discussion. In that case, it is possible to obtain a good representation of the participants' knowledge, of the attitudes they may have during the interaction and of the arguments they may use. This information

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1. By the term *spontaneous*, used in this context, we do not mean that the argumentation situation is completely 'free' or 'natural' since, precisely, we aim to constrain the situation so as to favour argumentation. Rather, we mean that the students *attitudes* towards conflicting proposals are genuinely their own, in contrast with cases where individuals or groups are asked (by the experimenter) to play the role of being in (dis)favour of a given view, and that no prior constraints are imposed on the nature of the students' dialogue.



**Figure 1:** The correct energy chain for the ‘battery–bulb’ problem

must be collected at the boundaries of the interaction (before it starts and after it finishes), yet this external intervention must alter neither the content nor the progression of the discussion.

The emergence of a critical discussion is predicted as soon as the appropriate dialogical attitudes (“pro”, “contra”) have been expressed and the communication between participants’ screens is established. This implies that dyads have already been constituted, i.e. which students will discuss together in pairs. Since the combinatory space that has to be investigated is very large (105 combinations for 8 students), *dyad constitution* that is based on analysis and comparison of individuals’ problem solutions *needs to be achieved by a computer*.

### 3. Description of the experimental collaborative-problem solving situation

*The choice of the problem-solving task* involves a crucial compromise : the main topic must be both *debatable* (condition C2) and *modellable*, i.e. it allows automated analysis and dyad constitution. The task chosen was qualitative modelling of energy, using *energy chains*, by highschool students (16-17 years old). Energy chains are composed by the following elements : *reservoirs* (that store energy), *transformers* (that transform energy) and *transfers* of energy (work, heat and light). This task also contains a fundamental syntactic rule : “*chains must start and finish by a reservoir ; these reservoirs must be different*”. The experimental situation students have to model is the case of a bulb connected to a battery by the mean of two conducting wires. The correct corresponding chain is given figure 1.

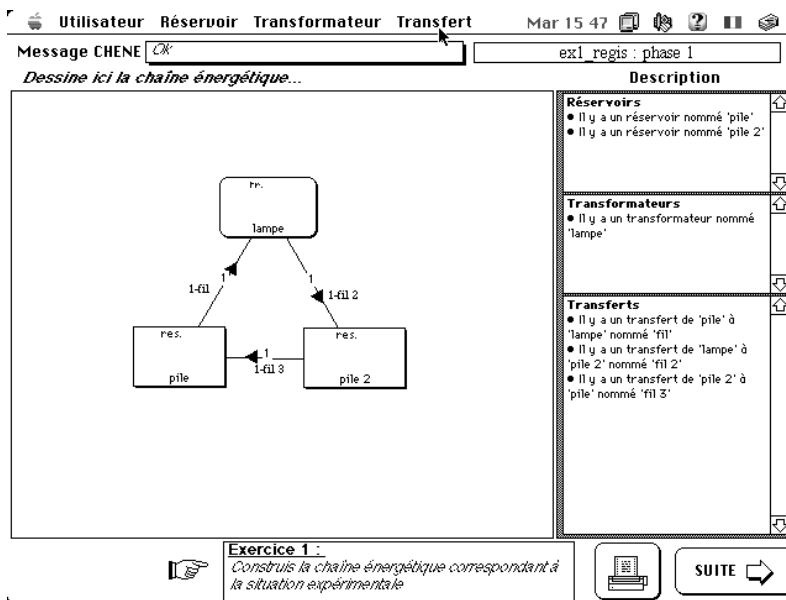
The choice of this task is grounded by the following facts. Firstly, students’ problem solving strategies are now well known for this task [11,12,13]. Secondly, the task implies a *wide knowledge space for debate*, since students have to their disposal several systems of explanation for this phenomenon, and therefore several conflicting positions may be held and discussed (the electrokinetic model proposes a very different solution to this exercise). Finally, this graphical task is well structured by syntactic rules applying to a small number of types of elements, which allows automated analysis of students’ solutions.

The experiment was carried out with 8 secondary school students of a same class, 3 boys and 5 girls. The successive phases of the experimental sequence are as follows (see table 1) :

*Phase 1 : Individual problem solving and attitudes.* On the first screen (see figure 2), each individual student must draw the energy chain that models the experimental situation (it consists of a battery, a bulb, connected by two electric wires from the labwork material). On this screen, two spaces are available : one graphical window where energy chain elements can be placed (these boxes and arrows can be manipulated from the menu bar) and one text window, updated by the system, that describes chains in a few sentences, as fast as they are elaborated. Students also have a quick access on the screen (as well as on a separate sheet of paper) to a description of the model (syntax and semantics of the chain components). Our fundamental hypothesis here is that *argumentation is a language-based activity* : our aim is thus to facilitate the transition between “semiotic registers” [14], from a graphically-based problem-solving activity, to language-based reflection and discussion. In addition, automated description of diagrams in a linguistic form provides a common way of describing the solutions, that may improve determination of the common ground prior to discussion.

**Table 1:** General progression of the experiment.

Phases		Achieved by	Screens
1.1	Individual problem-solving	Student	1
1.2	Expression of attitudes and explanations	Student	2a, 2b
2.1	Automated solution and attitudes analysis	System	
2.2	Dyad constitution	System	
2.3	Generation of conflict situation text, specific to each dyad	System	
3	Typed dialogue (CMC)	Dyad	3
4.1	Individual reconstruction of the agreed solution	Student	1
4.2	Expression of personal attitudes and explanations	Student	2a, 2b



**Figure 2 :** Computer environment for graphical construction of energy chains (left) with an automated description of its components (right).

On the second screen (see figure 4), students are proposed sentences (up to ten) by which the system describes their own solution. Each sentence is displayed in a separate text window, in a column, on the left hand side. On the right of each sentence, students successively find a local menu, from which one of five attitudes can be selected (see figure 3), then a text window, where subjects are invited to type explanations or justifications with respect to their attitudes. A third screen (not shown here), in principle identical to the previous one, displays *a more complex description of the solution*. It does not describe components separately, but rather “chunks” of the energy chain diagram (two connected boxes and their interconnections), in order to collect more global attitudes and *other types of explanations*. Our hypothesis here is that modelling involves global as well as element-to-element matching [13], so justifications for chunks may not be equivalent to the sum of justifications of their components.

*Phase 2 : Dyad constitution.* Our aims are similar to those of Hoppe and colleagues (e.g. [15]) in that we also aim to constitute productive collaborative dyads in a CMC situation. However, our work differs from the latter in that our primary aim is to effect cognitive changes via stimulating a specific type of communicative interaction. An automated algorithm has been implemented for dyad constitution, so that discussions may start as soon as possible after attitudes have been expressed. The choice of the partners is achieved on-line, on the basis of the individual solutions, in order to put together subjects who manifested conflictual solutions, in a way that may give rise to potentially rich argumentation. Solutions are analysed, formalised and finally compared on the basis of the three following criteria in order to predict which pairs of students’ solutions would lead their authors to commit themselves to argumentation.

- (1) I’m sure it’s the case.
- (2) Yes, maybe
- (3) I don’t know.
- (4) Maybe not/yes.
- (5) I’m sure, it’s not the case.

**Figure 3 :** Five attitudes by which students express their commitment to elements of their solution.

- *conceptual obstacle* : students should be put together who did not solve the problem the same way. There are generally several ways (correct or not) to give a solution to a problem. Research on modelling tasks [8] show that students are strongly resistant to changing their views of the problem. Therefore, from this conceptual obstacle one can expect strong positions and entrenched commitments. In the specific case of energy modelling, there are three different ways of describing the problem (modelling levels, see [8]) : a raw description of the objects involved in the situation (objects level, e.g. arrows represent wires), an electrokinetic model (arrows represent current) and energy modelling (arrows represent energy transfers). Modelling levels are estimated on the basis of the labels given to components of the chain, and the number and direction of arrows. These are weighted by the *degree of commitment* to the corresponding sentences (expressed in phase 1.2).

Message CHENE

Pour chacune de ces phrases      donne ton avis      et explique quand tu le peux

Il y a un réservoir nommé 'pile'.	J'en suis sûr.	Car...le reservoir stocke l'energie
Il y a un réservoir nommé 'pile 2'.	J'en suis sûr.	Car...le reservoir final doit etre different du reservoir initial donc il en faut deux ...
Il y a un transformateur nommé 'lampe'.	J'en suis sûr.	Car...le transformateur transforme l'energie
Il y a un transfert de 'pile' à 'lampe' nommé 'fil'.	J'en suis sûr.	Car...le deplacement de charges ne peut se faire qu'avec un fil dit conducteur de courant electrique
Il y a un transfert de 'pile 2' à 'pile' nommé 'fil 3'.	Oui, peut-être.	Car...
Il y a un transfert de 'lampe' à 'pile 2' nommé 'fil 2'.	J'en suis sûr.	Car... il transporte l'energie du transformateur vers le reservoir
Il n'y a pas de réservoir nommé 'pile 2'.	Je suis sûr que si.	Car... le reservoir final doit etre different du reservoir initial

**Figure 4 :** Attribution of attitudes and explanations. For each sentence formulated by the system (left column) on the basis of the graphical solution, subjects are expected to express their attitude in the local menu (in the centre column) and to explain their choice in the reserved place, on the right.

- *normative obstacle* : a chain that does not conform to rules of the model (uncircularity and completeness) is expected to give rise to wellgrounded attacks from the opponent (there is a space of possible counterarguments).
- *solution correctness* : on the basis of the principle that a good solution is more convincing than a worse one, one must avoid putting together very unequal solutions, otherwise the worse solution could not compete against the better one. On the other hand, one should also avoid putting together two solutions that obtained a similar mark : they could be so close that there would not be any conflict left, which may lead to a negotiated compromise, rather than to potentially valuable argumentation. This score is calculated by the evaluation of differences between the current solution and the correct one (given figure 1).

The argumentative potential of each dyad is evaluated on the basis of the previous criteria, and an “argumentative score” is given. An optimisation algorithm investigates all possible ways of choosing  $n$  pairs in a group of  $2n$  subjects ( $(2n)!/2^n n!$  combinations), and retains the best configurations : no pair must be too weak, most of them must be maximal.

Once the choice of dyads is made, one must give specific instructions to each dyad that will lead to an argumentative interaction. In accordance with the rules of pragma-dialectics and our modelling constraints, instructions consist of a natural language description of the conflict situation and the following final phrase : “*Discuss together, each of you defending his/her own point of view, in order to find a common solution to the exercise*” (see figure 5). Whilst this does not, of course, mean that students’ will actually attain agreement, imposing this common goal motivates at least the necessity to engage in dialogue rather than to ‘agree to differ’. By the presentation of this text, essential elements of the common ground relating to the conflict situation are established, and positions are declared. Participants can not visualise their opponent’s diagram : they only have a partial description of it, in natural language. The students also have at their disposal their own solution diagram, on a separate sheet of paper.

*Phase 3 : CMC discussion of the solutions.* Once dyads have been constituted, the students sit in front of a computer, so that partners in a given dyad are back to back. Partners share the same computer screen across the network. The connection enables each student to observe all actions of the other on the shared screen, including text as it is being typed. The screen used for computer-mediated argumentation is divided in two parts (see figure 5). The upper part of the screen displays the description of the conflict situation, and the instruction phrase, described above. The lower part of the screen is dedicated to communication. Two personal spaces are displayed on both sides of a central dialogue history. Subjects communicate by the use of buttons in their personal space. Some buttons send short messages to the dialogue history : ‘Yes’,

**regis et Romain :**  
**Vous avez trouvé des solutions différentes,**  
**que l'on peut résumer ainsi :**

Regis pense qu'il y a un réservoir nommé 'pile' et un transformateur nommé 'lampe'.  
 Regis pense qu'il y a 1 transfert du réservoir 'pile' au transformateur 'lampe', nommé 'fil'.  
 Dans sa chaîne, Regis fait ensuite intervenir un réservoir nommé 'pile 2'.

De son côté, Romain pense aussi qu'il y a un réservoir nommé 'pile' et pense qu'il y a un transformateur nommé 'ampoule'.  
 Romain pense qu'il y a 1 transfert du réservoir 'pile' au transformateur 'ampoule', nommé 'file conducteur'.  
 Romain pense qu'il y a 1 transfert du transformateur 'ampoule' au réservoir 'pile', nommé 'file conducteur'.  
 Romain ne fait pas intervenir d'autres éléments dans sa chaîne.

**Discutez ensemble, en défendant chacun votre point de vue, afin de trouver une solution commune à l'exercice.**

regis		Romain																				
<div style="border: 1px solid gray; padding: 2px; margin-bottom: 5px;"> <input type="text" value=""/> </div> <table border="1" style="width: 100%; border-collapse: collapse; font-size: small;"> <tr> <td style="text-align: center;">Oui</td> <td style="text-align: center;">Non</td> </tr> <tr> <td style="text-align: center;">D'accord ?</td> <td style="text-align: center;">Pas d'accord</td> </tr> <tr> <td style="text-align: center;">Pourquoi ?</td> <td style="text-align: center;">Parce que...</td> </tr> <tr> <td style="text-align: center;">J'y vais</td> <td style="text-align: center;">Vas-y, toi</td> </tr> <tr> <td style="text-align: center;">Coucou !</td> <td style="text-align: center;">On a fini ?</td> </tr> </table>	Oui	Non	D'accord ?	Pas d'accord	Pourquoi ?	Parce que...	J'y vais	Vas-y, toi	Coucou !	On a fini ?	<div style="border: 1px solid gray; padding: 2px; margin-bottom: 5px;"> <input type="text" value=""/> </div> <div style="border: 1px solid gray; padding: 2px; margin-bottom: 5px;">             regis : romain me reçois tu ?              Romain : Oui              regis : moi aussi je te reçois              Romain : que penses tu de mon montage ?              regis : c'est pas tres concluant              Romain : Pourquoi ?              regis : car selon moi ,il doit y avoir 2 réservoirs              Romain : dans un circuit avec une pile il y a forcément un seul reservoir!              regis : oui je suis totalement d'accord           </div>	<div style="border: 1px solid gray; padding: 2px; margin-bottom: 5px;"> <input type="text" value=""/> </div> <table border="1" style="width: 100%; border-collapse: collapse; font-size: small;"> <tr> <td style="text-align: center;">Oui</td> <td style="text-align: center;">Non</td> </tr> <tr> <td style="text-align: center;">D'accord ?</td> <td style="text-align: center;">Pas d'accord</td> </tr> <tr> <td style="text-align: center;">Pourquoi ?</td> <td style="text-align: center;">Parce que...</td> </tr> <tr> <td style="text-align: center;">J'y vais</td> <td style="text-align: center;">Vas-y, toi</td> </tr> <tr> <td style="text-align: center;">Coucou !</td> <td style="text-align: center;">On a fini ?</td> </tr> </table>	Oui	Non	D'accord ?	Pas d'accord	Pourquoi ?	Parce que...	J'y vais	Vas-y, toi	Coucou !	On a fini ?
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**Figure 5 :** CMC environment shared by the subjects of the same dyad. The upper part displays the conflict situation, whereas the lower part is dedicated to communication. On both side of the dialogue history (in the centre) subjects are provided a personal panel for the formulation of communicative acts. A free text typing window can be called by clicking on the balloon. The other buttons send key messages directly to the dialogue history.

'No', 'I agree' ... Other buttons like the balloon, 'Because...' open a pop-up text window where free text can be typed. The students send their messages by hitting the TAB key. In this case, their message is added to the bottom of the dialogue history. The CMC part of this interface was based on previous research carried out within GRIC-COAST [5].

*Phase 4 : Individual reconstruction of the agreed solution and attitudes.* Once students decide that the debate is closed, they call the experimenter to disconnect the screen sharing. Subjects come back to the initial graphical and textual environment for energy chain construction (see figures 2 and 4). They are expected to rebuild the energy chain on which they agree at the end of their discussion. As in the first phase, their chain is analysed and descriptive propositions are proposed by the system, on which subjects must express their own attitudes and give explanations. The design rationale of this phase was to access the degree of agreement reached in the discussion, by comparing it with the chains drawn subsequently by individual students of the same dyad. This also enables access to the explanations given for new components of the chain, and the reasons why proposals were accepted or not.

## 4. Results

*General results.* Although students communicate using a typewritten interface, predominantly dialogal and argumentative interactions were produced. Interventions were relatively short, synchronously written and read, with free turn-taking. The average amount of time spent on argumentation attains 84 mutual understanding and students entered freely into argumentation as soon as the discussion started. This shows that CMC did not prevent communication of graphical solutions (C3) and that the common ground (including the specific conflict description) was adequately established (C5-6-8). Argumentation evaluation. The two most conflictual argumentation dialogues were obtained with dyads having the greatest conceptual and normative difference. The poorest argumentation dialogue was obtained with the dyad for which initial solutions were very similar. In that case, students had some trouble in perceiving the conflict and reviewed all elements to check their agreement. This corroborates the distance condition (C4) and the criteria used in our dyad constitution algorithm for obtaining conflicts that may be solved by argumentation.

*Attitudes and arguments.* One can observe a good continuity of attitudes and arguments across the activities (before, during and after discussion): students did not adopt different attitudes with respect to a given proposition when they are in a discussion or alone in front of the screens 2a and 2b (figure 4). This indicates a perhaps surprisingly strong link between

individual (private) and dialogical (public) forms of reasoning. Similarly, justifications given in phases 1.2 and 4.2 are used as arguments during the discussion. This shows that screens 2a and 2b are well designed for collecting the relevant information about students' knowledge and for argumentation modelling. The comparison of the two individual visions of the agreed solutions (phase 4) shows that students genuinely reached agreement on a common solution. The only differences that remained were relative to elements that were not debated.

*Evolution of the solutions.* Discussions did not necessarily lead to finding better or even newer solutions. Only one dyad agreed on a radically new solution, the three others agreed on slight modifications of one of the initial solutions. This can be explained by the systematic use of normative arguments (one refers to a rule of the model to attack and reject a solution), rather than more constructive arguments that could lead to completion of an unsatisfactory solution. However, producing better energy chain solutions is not the most important point here: this task is only a means to an end, that of enabling students to gain a better understanding of both the concept of energy and the nature of modelling in science. From analysis of the corpus, there was evidence that students had gained a more refined understanding of the nature of the modelling task in which they were engaged, rather than of the concepts underlying it.

*Learning.* The potential of this experimental situation as a learning environment is based on the cognitive activities carried out by learners at different stages of the experiment. In phase 1, students have to solve the problem with two very different types of knowledge representation: graphical diagrams and natural language [16,17]. Since they are expected to shift from one to another, they may reach a very stable solution, taking benefit of the reasoning induced by the representations: graphics facilitate elaboration of solution and the application of rules; natural language, that has a more restricted focus, stimulates reflection and critical analysis, emphasised by the activities of attitude expression and explanations.

During the discussion (phase 3) students are confronted with an alternative point of view: they have to represent the other's solution to themselves, in order to evaluate its validity. Students manage quite well with this task, specifically with formal arguments (the most efficient but also the easiest to find). Confrontation with a different solution does not necessarily lead them to produce solutions that are based on deeper conceptual understanding.

If learning may not necessarily be achieved *during* discussion, on the basis of observing the group discussion and correction session with the teacher subsequent to our experimental sequence, we would make the following conjecture, to be explored in further research: argumentative discussion in the situation described here can create a state of *receptive critical awareness* of the problem-solving domain in students. Such a state of awareness may be important in learning, or in learning to learn, on a much longer-term basis.

## 5. Conclusions and perspectives

This paper presented an experimental CMC situation that was designed for favouring production of argumentative interactions between learners and for modelling relations between those interactions and specific types of cognitive changes. We described an experimental study that has produced satisfactory qualitative results on a restricted group of learners: predominantly argumentative interactions were spontaneously produced in a way that led to better understanding of the nature of the modelling task, rather than better solutions and/or conceptual understanding. An experiment with a larger group of learners is planned for completing the validation of this protocol, including the dyad constitution algorithm, and for supporting our main research project: cognitive modelling of argumentation dialogue.

Success in the spontaneous production of argumentation dialogue depends essentially on the degree of commitment of students to their solutions, and on the conceptual distance between their points of view. In the corpus collected during the experiment presented in this paper, students' solutions were too similar and very much constrained by the electrical model. Further experiments will aim to constitute more argumentative dyads by giving students more information on the energy chain model, so that they can understand more precisely what type of modelling activity is expected from them.

Extending this experimental technique to other types of collaborative problem-solving tasks could also be a way of extending its field of validity. Such an extension could begin with other types of problem-solving tasks involving modelling activities or graphical representations, which would enable automated analysis to be carried out. The dyad constitution



algorithm would then need a general problem solver, that could determine discriminate the values for the three criteria : *conceptual opposition* (i.e. the various ways of resolving the problem); *normative opposition* (i.e. evaluating which rules were applied and which were not) and a procedure for evaluating the *degree of correctness* of the solution. Nevertheless, it is clear that spontaneous production of argumentation dialogue does not only depend of the efficiency of the previous algorithm, but essentially on the nature of the topic that is to be debated : there must be something to be debated.

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