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Negotiation in Collaborative Problem-Solving Dialogues†

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Abstract Understanding the detailed mechanics of collaborative problem-solving (CPS) is important from the point of view of peer-learning research in psychology and for constructing intelligent computer co-learners. However, little recent research has been based on detailed analysis of interactions, or of dialogues, in such contexts. We therefore describe an analysis-modelling approach based on viewing CPS in dialogue as a form of *negotiation*, at the level of the problem-solving domain itself. The approach is illustrated with extracts from a corpus of dialogues generated by students solving physics problems. On the basis of a model for negotiation as the search for agreement by successive refinement of offered propositions, we define and address two specific subproblems : describing the way in which offered partial solutions are related to previous ones in order to converge on an agreed solution, and identifying when and with respect to what the students are agreed. We describe a set of relations that occur between offered solutions at the domain-task level, discuss analysis of different forms of feedback on agreement, and argue that agreement should be analysed in terms of the joint attitude of "acceptance", rather than "mutual belief". We conclude that fundamental theoretical issues need to be addressed before such an analysis method can give rise to a model.

Keywords: collaborative problem-solving, dialogue, negotiation, belief, acceptance.

1.0 Introduction

Understanding collaborative problem-solving ("CPS") is important from a number of perspectives. However, as Barbieri & Light (1991) point out, despite an extensive research literature on peer interaction from Piagetian and Vygotskyan perspectives, "studies in collaborative learning at the computer usually do not go into a detailed analysis of the interaction" (p.3). One recent exception is the research of Roschelle et al (eg., Behrend, Singer & Roschelle 1988), where the approach was proposed of analysing the "Joint Problem Space", constructed by pairs of students working at a physics learning environment. In particular, this approach aimed to identify when students were collaborating and when they were not from analysis of conversational structures (for example, "collaborative completions" of utterances). As we discuss below, several more

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specific problems remain to be addressed. Artificial intelligence and education research has also recently shown interest in CPS in order to construct computer-based "co-learners" (Chan & Baskin 1988 ; Chan *et al* 1992 ; Dillenbourg & Self 1992), this being the longer term aim of the research presented here.

When students collaborate in problem-solving they may engage in dialogue in order to co-construct jointly agreed solutions. But how do they do this ? How do students co-construct solutions in dialogue, and how do they establish agreement with respect to them ? Initially the answers may appear obvious : each student proposes possible partial solutions, which are then accepted or not, and so the dialogue progresses towards an agreed solution. This is oversimplified in at least two ways. Firstly, joint solutions are not constructed by a simple accumulation of individually proposed statements since successive contributions "build on" previous ones in different ways (successive refinement). The question therefore arises as to how, precisely, students interrelate their contributions in order to co-construct solutions (let us call this the **co-construction problem**). Secondly, **feedback** with respect to acceptance and agreement is often implicit in dialogue, which thus poses the problems of identifying *when* students are agreed or not, on *what* precisely they are agreed and even what it *means*, theoretically, to be "agreed" in this context (let us call this the **agreement problem**).

We claim that viewing the processes of co-construction of problem solutions in dialogue as a type of **negotiation** can provide an approach to solving the above mentioned problems. In order to show this we shall draw on a corpus of dialogues generated by pairs of students solving simple mechanics problems in physics. The paper is structured as follows. After presenting an initial illustrative dialogue extract, an analysis of negotiation is developed. The two subsequent sections deal with analysis of specific aspects of negotiation processes, namely relations between contributions to problem solutions ("co-construction problem"), and the processes whereby agreement is established ("agreement problem"). The paper concludes with some implications for future models for CPS in dialogue.

2.0 An example

Our analysis method is being developed using a corpus of dialogues generated by students (aged 16-17 years) who attempted to solve simple mechanics problems in physics. The dialogues were recorded in schools in the Lyon region. The problem given was of an open-ended kind, not normally set in the curriculum, and was thus designed to provoke intensive discussion and to oblige the students to draw on and externalise their

conceptions of physics concepts (energy). The students were provided with experimental materials and asked to determine a property of balls of different substances that enabled their rebound behaviour to be interpreted and hence explained in terms of the concepts of *energy*. The students were asked to produce a single solution upon which they were agreed.

The following extract is taken from the middle of a face-to-face verbal dialogue (approximately 1.5 hours long). Prior to the extract, the students had allowed two balls of the same size, one made of rubber, the other of plastic, to fall at the same time from the same height. They agreed that the rubber ball had rebounded 5cm lower than the plastic one. S2 then put forward the explanation that the difference was due to the respective masses, S1 did not agree, and so they decided to consider what would happen in the simpler case of an inelastic impact.

Dialogue Extract 1[1]

(1) S1 : <...> so, what can we say if there's an inelastic impact ?
(2) S2 : well, that the energy ... all the energy ...
(3) S1 : well, that the kinetic energy is theoretically nil
(4) S2 : it's nil on arrival, in fact ...
(5) S1 : since ... since the object stops, in fact, ah yes, especially since there it doesn't move, uh ...
(6) S2 : it's nil at the start, and it's nil on arrival ...
... about energy ... yes, but at the moment of an inelastic impact, what is it that ...
(7) S1 : we've been doing that for a while now !
(8) S2 : but we've also ...
(9) S1 : wait ... inelastic impact, right, you've conservation of momentum, but ... the kinetic energy isn't conserved ! I think that's what we've seen ... the elastic impact, by contrast, both are conserved ...
(10) S2 : Yes, elastic impact, there's the total energy which is conserved...
(11) S1 : Yes
<...>

Due to the joint explicit agreement ("Yes") in (10) and (11), most observers would probably agree that at the end of this extract the students have reached some kind of agreement. But what are they agreed on ? One possible solution may be glossed as :

> "in the case of an inelastic impact, the kinetic energy is nil on arrival and nil at the start ; thus momentum but not kinetic energy is conserved ; in an elastic impact both are conserved".

However, we can not find an explicit statement of this "gloss" in the dialogue, nor is it a simple conjunction of several statements. In fact what seems to happen is that an initially stated partial solution (2-"the energy") is successively *transformed* or *refined* by both

[1] The extract has been translated by the author from the original French (see Appendix 1).

speakers in order to lead to a composite solution on which both students can agree. For example, (2) ("the energy") is refined in (3) ("the kinetic energy is nil") by restricting the concept of energy to a specific type of energy (kinetic) and by giving a specific value for it (nil). In (4) an additional relevant feature of the problem situation is added (nil on arrival), and so the refinement process continues. From an analytical point of view, therefore, we need some principled means for describing these "refinement" processes (the "co-construction problem"). We shall attempt to do this by *specifying types of relations between problem solution elements in dialogue.*

Given that our intuitions concerning agreement relate to joint explicit agreement (in 10 and 11), what can we say about the middle of this extract (2-9), where there is no explicit agreement of this kind ? For example, in (3) S1 completes S2's incomplete proposition : does this mean that S1 *accepts* S1's proposal, or not ? In this example we might want to say that a proposition concerning "kinetic energy" in some way *presupposes* acceptance of a previous one concerning "energy". The concept of presupposition is not without its difficulties in pragmatics ; however, even if a clear notion of presupposition was available, we can observe a large number of other cases where it is difficult to find a principled way of deciding what is agreed, how, and why, and what is not.

We can begin to address these issues by viewing collaborative co-construction of problem solutions in dialogue as a kind of **negotiation**, at the level of the problem-solving domain. The next section gives a sketch of an approach to analysing (and eventually modelling) negotiation that can be applied in this case.

3.0 Negotiation

3.1 Existing views

The rôle of negotiation and dialogue in learning has recently been invoked within a number of cognitive science approaches, both from a "traditional" AI and Education perspective, as well as within the "situated learning" paradigm. With respect to the latter, Seely-Brown, for example, states that Intelligent Tutoring Systems should aim to "... provide initially underdetermined threadbare concepts to which, through conversation, *negotiation* and authentic activity, a learner adds texture." [my italics] (Seely-Brown 1990). Within ITS research a recent approach called "Knowledge Negotiation" has emerged (see Moyse & Elsom-Cook 1992) that emphasises the need to incorporate negotiation mechanisms in tutorial dialogues, and to provide alternative "viewpoints" on the teaching domain and students' knowledge as a basis for them. This corresponds to an

epistemological shift, where knowledge is itself viewed as "negotiable", rather than fixed in the system, ready for eventual "transmission" to the student. However, little of this research describes negotiation processes themselves, and we therefore need to look to other domains where negotiation is a key concept - specifically, Distributed AI (DAI), language sciences and social psychology - in order to define an analysis and modelling approach. In DAI research the term "negotiation" is generally associated with resolution of *conflicts* (usually with respect to problem-solving resource allocation). We adopt a more general definition of negotiation (see Galliers 1989) where negotiation is a process designed to achieve agreement between agents, whether the initial starting point is one of conflict or whether it is simply one of 'absence of agreement' ("indifference" in Galliers' terms). In view of space restrictions here we shall concentrate on the most relevant language sciences research.

Within some branches of language sciences, the notion of negotiation is viewed as *constitutive* of verbal interactions, to the extent that the shared meaning of utterances is itself the object of negotiation. Thus Edmondson (1981), for example, approaches the "indirect speech act" problem in terms of the idea of "strategic indeterminacy" of utterances : the illocutionary force of an utterance is not 'predetermined' in some way, but is rather intrinsically indeterminate, a fact that allows for *negotiation* of its joint understanding. Thus if X says "It's cold in here" (u1) when entering Y's appartment, the illocutionary force of u1 as an indirect request to put the heating on, a simple statement, etc. may be negotiated by X as a function of Y's response (eg. "Shall I put the heating on?" "No no, I ways only remarking"). From a cognitive perspective, Clark & Schaefer (1989) have expressed this interactionist view in terms of a *grounding criterion* : "... The contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for current purposes." (Clark & Schaefer, ibid, p. 262). The criterion is presented in critical opposition to most "computational speech act" models which, it is claimed, assume that the "common ground" in dialogue simply "accumulates" as the result of making the right utterance at the right time. Thus specific interaction structures occur - such as "episodes", "repairs", "collaborative completions", etc. - whose function is to assure grounding in these terms. The work of Roschelle and colleagues (op cit) was largely concerned with analysing such interaction structures, as a means of identifying when students were "really collaborating" and when they were not. They posed the problem of determining, from the interaction transcript, when a "Yes" indicated "agreement" (*qua* "collaboration") and when it meant simply "turn-taking". This is a specific case of our **agreement problem** stated earlier, in that a "turn-taking" "Yes" could correspond to negotiation of meaning (grounding) and a "collaborative" "Yes" to agreement. Negotiation of meaning has also been studied within the framework of a more general theory of **linguistic feedback** (Allwood et al 1991), as will be discussed later (§5). In this paper we concentrate on feedback at the **attitudinal level**

(agreement and acceptance) rather than on the level of understanding. It is clear, however, that the two are closely related since 'real' agreement (see Nivre, this volume) with respect to something presupposes joint perception and understanding of it.

3.2 A model for negotiation in CPS dialogues

Figure 1 represents a minimal schema for negotiation of problem solutions in dialogue. It is intended to define both a *genre* of dialogue (negotiative) as well as negotiative sequences in other forms of dialogue (we shall refer to both simply as "negotiations"), and to provide a general framework within which to pose specific research problems on the modelling of CPS as negotiation.

At the highest level, a negotiation is defined by four components : (1) an initial state ; (2) a final state ; (3) objects of negotiation (what is being negotiated ?), and (4) negotiation processes (leading from 1 to 2). The following are brief descriptions of each component, illustrated with respect to the corpus considered here.

(1) initial state The initial state has itself four main components : mutual goals, constraints on mutual goals, individual goals, and relations between individual goals. The **defining characteristic** of negotiations is the mutual goal of attaining agreement with respect to some set of propositions. There will usually be constraints on the mutual goal state in that the agents do not want to agree on any unrelated set of propositions : constraints with respect to coherence and consistency will operate, as well as domain-specific constraints. In the present case, the propositions must be statements of physics (theory of energy) and they must have explanatory links to an agreed set of propositions describing results. Non-necessary conditions for negotiations include specific individual beliefs and goals - for example, one or both agents may have the goal that all and only the propositions that they propose are to be in the final state (adversarial negotiation), or they may have no such goals (disinterested or "forensic" negotiation). Finally, there may be special and mutually understood relations between individual attitudes (**R a**) , such as various forms of **conflict**. Note that we do not regard such conflict as a necessary condition for negotiation (as is the case with much DAI research) : it is quite possible to have the mutual goals of negotiation for other reasons, as in the present case where reaching agreement is imposed as part of the task.

(2) a final state The final state is simply the state where the proposition of the mutual goal of the initial state obtains [(agree A1 A2 {p1,p2,...})]. In some cases this will be a predetermined finite set ; in other more open-ended cases (such as the problem considered here), the agents must be able to judge when the set is sufficient for common

purposes, and possibly when it is unlikely that they will be able to achieve further agreement. The initial state mutual goal may thus be viewed as a "persistent goal", in the sense of Cohen & Levesque (1990), that may be dropped when a reason for having the goal no longer obtains.

(3) objects of negotiation These are different types of propositions, referring to the domain of dialogue (atomic propositions), or attitudinal expressions (such as goals or beliefs). It is thus possible to extend negotiation 'backwards'- for example to negotiate engaging in a negotiation about goals to pursue. Note that this will rarely be done explicitly : often a negotiative dialogue is negotiated implicitly, simply by one agent beginning to negotiate. In the present case objects of negotiation are atomic propositions referring to the problem-solving domain (eg. "The black ball rebounded higher than the yellow one", "the mass explains the difference in rebound", etc.). Problem-solving *goals* may also be objects of negotiation (eg. "Let's do an experiment with ..."), but this is not our main concern here (see Baker 1992b).

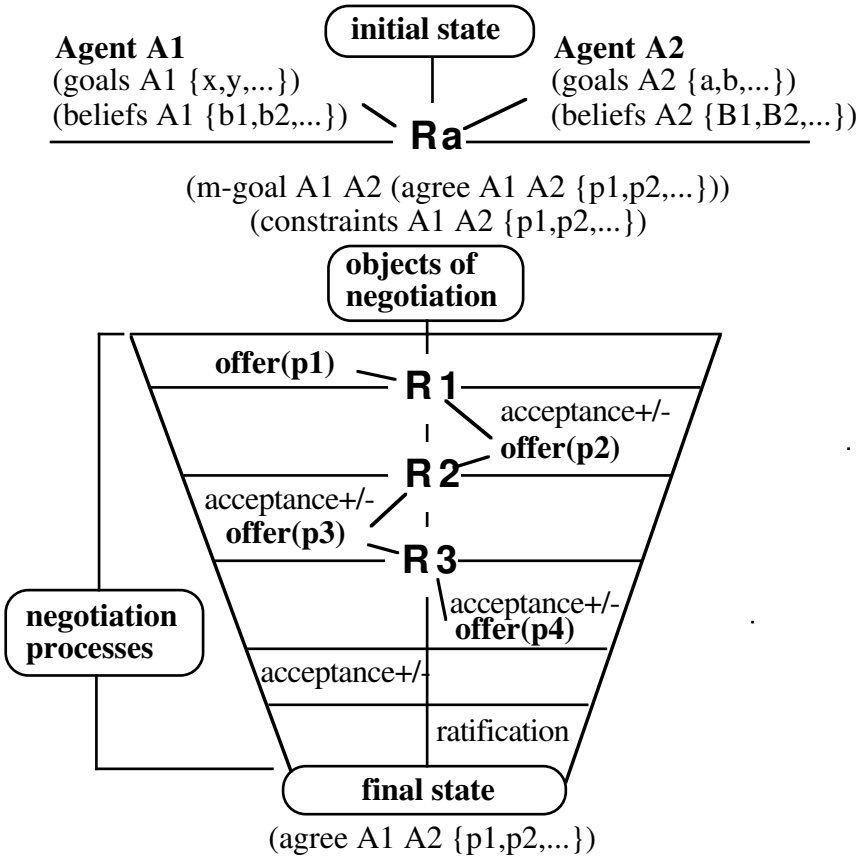

Fig. 1 Minimal schema for negotiations in CPS dialogues

(4) negotiation processes These include types of communicative acts or functions which may be realised jointly or singly by one or more utterances (offers and

acceptances/positive or negative), and specific relations between offered propositions (**R 1**, **R 2**, **R 3** etc.). Clearly, in a negotiation which is going to succeed, relations should be such that a proposition is finally offered which can be accepted, and this acceptance ratified (explicit acceptance of acceptance). As we shall see, the offer and acceptance functions are rarely explicit, both often being achieved by a single utterance. Finally, specific relations may arise during the negotiation process between agents' propositional attitudes, such as *conflict of avowed opinions* . Agents may attempt to resolve them by *argumentation* subdialogues.

On the basis of this general framework for negotiation, we can now define and consider our two main problems, both of which concern **negotiation processes** : the co-construction problem and the agreement problem. With respect to the first problem, we concentrate here on defining the types of relations between offered propositions (§4), and with respect to the second problem, we characterise "offer" and "acceptance/non-acceptance" functions of communicative acts (§5). As we shall see, the two problems are closely related, in that one way in which acceptance may be communicated is to relate one's new contribution to the previous one in a specific way.

4.0 Co-construction of problem solutions in dialogue

4.1 Types of relations in dialogue

An analysis of relations between utterances in problem-solving dialogues, treated as negotiations, will show how offered solutions are constructed as a function of previous ones in order to converge on agreement. There are four main types or levels of relations between dialogue units at different levels, as shown in Figure 2.

Domain-task relations obtain between propositions of the problem-solving domain that the dialogue is concerned with. For example, one proposition may "reformulate" another, it may give a supporting reason for it, etc. **Interactional** relations are those concerned with **coordination** or **control** of the dialogue (Bunt 1989). For example, utterance u2 may be an "interruption" of u1, it may be a repetition of it that serves a control function of confirming understanding (a feedback function), and so on. **Hierarchical-functional** relations are those which obtain between functional units (moves, communicative acts, ...), such as "adjacency pairs" at different hierarchical levels. Finally, **argumentational** relations are relate utterances in the context where speakers adopt "proponent" and "opponent" rôles in a "conflict of avowed opinions" (Barth & Krabbe 1982). They include different forms of attack, defence and concession.

Different types of relations may have different *ranges* ; for example, argumentational relations (in the sense understood here) apply only across interventions (turns), whereas domain-task relations apply within and across turns. It may be thought that interactional relations apply only, by definition, across turns. However, even an individual's utterance in verbal face-to-face dialogue may be viewed as an 'interactional achievement' (Kerbrat-Orecchioni 1990).

Relation class	**Examples**
Domain-task	subclass, specific-value, reason, reformulation, identity, inference.
Interactional	Repetition, Interruption, Continuation, Floor-hold
Hierarchical-functional	Question-answer, affirmation-acceptance, offer-acceptance/rejection
Argumentational	Attack, counter-attack, protective defense, counteractive defense

Fig. 2 Classes of relations between utterances in CPS dialogues

Describing relations between dialogue units on different levels in this way highlights important differences with respect to the work of Mann & Thompson (1986) on **rhetorical relations**. It is not surprising that there should be differences since the latter work was developed for relations between segments in *texts* , although there have been attempts to extend this work to modelling dialogue (see eg. Daradoumis & Verdejo, this volume). The major differences are : (i) there are types of relations in dialogue which do not apply in texts, and (ii) between two segments in dialogue, relations on most or all of the levels described above will apply *simultaneously*, whereas in rhetorical relation theory, there is a single unique relation between two text segments (although different analyses may predict different single relations between segments). With respect to the first point, for example, argumentational relations in the specific (dialectic) sense in which we understand them, are quite unlike relations of "justification" in text (in a text the writer's goal is not to win an interactive argumentative game). More obviously, texts are simply not interactional. With respect to the second point, we consider (with many other writers) that dialogue utterances are *multifunctional* ; i.e. an utterance may perform a number of communicative functions, contribute to a solution, express argumentational opposition or agreement, etc. Analytically separable levels of analysis are therefore preferable in order to study subsequently their interaction.

We shall concentrate here on **domain-task relations** since they express how solutions themselves are co-constructed (an adequate treatment of other types of relations - argumentation, interaction structures, etc. - would require separate paper(s)).

4.2 Domain-task relations

In general, there are four main things that an agent participating in CPS can 'do' with a previously offered partial solution (C1), thereby establishing a specific relation with the new (C2) contribution : (1) C2 can describe **foundations** for C1 (explanation, reasons for and against); (2) C2 can **expand** C1 (add a new relevant feature of the concrete situation described, draw inferences from it, categorise it, state its superclass); (3) C2 can **contract** C1 (give it a specific value, subtract a proposition from the set described, state a specific subclass) and (4) C2 can be **neutral** with respect to the content of C1 (it may be a reformulation, have identical content, be an alternative or opposite case). These actions correspond to classes of domain-task relations[2], shown in Figure 3.

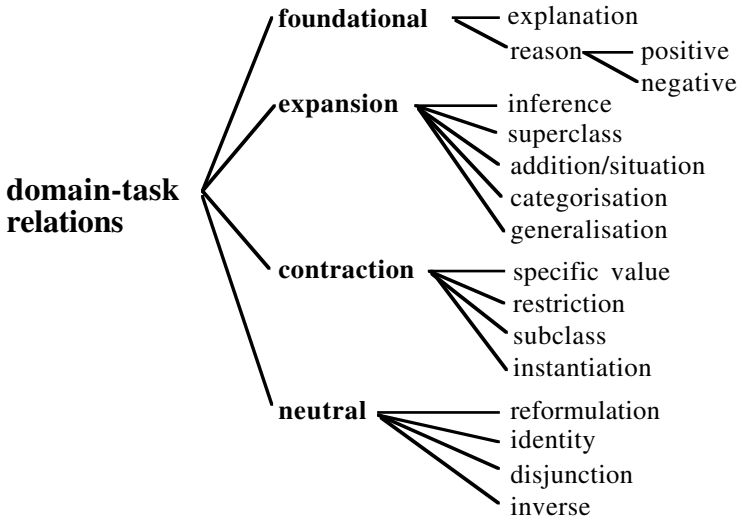

Fig. 3 Classes of domain-task relations in CPS dialogue

It must be noted that an utterance which establishes a specific relation with a previous one at the *domain-task* level, will also establish a relation (perform a function) at other levels. For example, "identity" relations often occur at the end of sequences, as **repetitions** (interactive level), or summaries of what has been said and agreed, offered for the

[2] Some of these classes of relations are similar to "coherence relations" in text described in the earlier work of Hobbs (1982).

confirmation of the other. Or again, **negative reasons** (domain-task) may, of course, occur as **attacks** at the argumentative level, although this is not necessarily the case (negative reasons may be given without argumentation taking place). We do not have space here to discuss each specific relation in detail here, and so shall simply give one example of their use in analysing Dialogue Extract 1, shown earlier (Fig. 4). From the graphical layout of Figure 4 we can see how the jointly agreed partial solution was co-constructed, at least at the level of the domain. It may be described as : in (2) adds a new description (add-sit) of the situation described in (1), and then generalises this ; (3) contracts (2) to its subclass, then gives a specific value for this class, etc., and so on. Note that **higher-order relations** do occur, but have not been marked here. For example, (2-9) may be viewed as an explanation for (1).

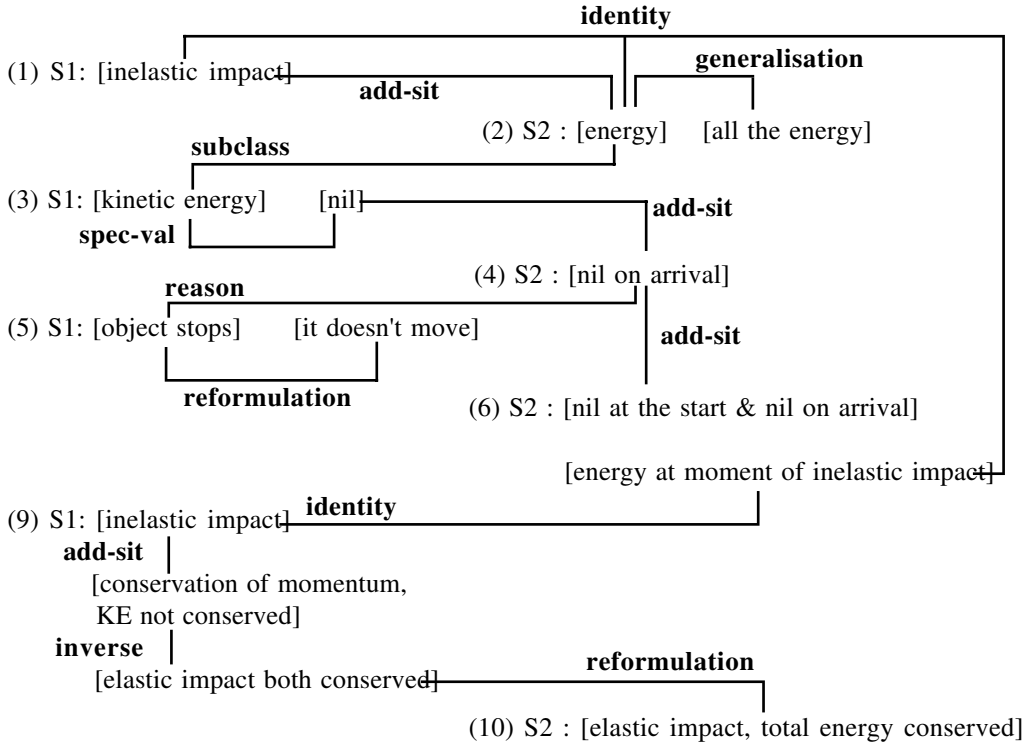

Fig. 4 Analysis of domain-task relations in Dialogue Extract 1

Even for such a short extract a quite complex picture emerges of joint problem-solving, where students build on the solutions of the other, on their own previous solutions, and develop their own contributions to a greater or lesser extent. Analysis of this kind can thus help us to give precise answers to more specific questions relating to co-construction, such as **who contributed the most ?** and **to what extent are the students collaborating ?** (rather than resolving in parallel). We can answer this to some

extent by counting relations to self and to other across turns, and within turns, as shown in the table below.

Number of domain-task relations for Dialogue Extract 1

		S1	S2	
To self :	within turn	4		1
	across turn	0	2	
To other (across turn)		3	4	
TOTAL			**7**	**7**

For such a small extract the figures are not of course significant ; we can however remark that in this extract S1 develops his own solution to a greater extent than S2, and that S2 builds on his own previous contributions more than S1.

Finally, we may ask to what extent these relations may generalise to other domains. We have not yet applied the defined relations to other collaborative tasks since the analysis approach is currently under development. However, it seems that such very general classes as "inference", "explanation", etc. are likely to apply elsewhere, and that specific domains and tasks will emphasise one type of relation rather than another. In the task we consider here, a number of the relations have a special significance. The students' task is effectively one of **modelling**, to the extent that they must select relevant facts in the experimental situations, and "translate" them into a language of physics terms (see Greeno 1989 ; Tiberghien 1993 ; Chi, Feltovich & Glaser 1981). The **reformulation** relation is thus very important, since students must take descriptions of the experimental situation at an "objects and events" level, and translate them into physics terms. For example "weight" becomes "mass". The **addition-situation** relation is also important since this corresponds to enumeration of relevant facts in the experimental situation. The general point to be made is that in specific domains, specific types of relations can be reinterpreted in the light of an available **cognitive model** for problem solving.

5.0 Agreement in dialogue : feedback, belief and acceptance

In the previous section we described sequences within which initially offered partial solutions are successively refined towards (explicit) agreement. Such sequences at the **transaction** level (Moeschler 1985) are typical of this corpus (and of other corpora).

CPS dialogues may thus be analysed as **iteration**s on solution elements, where the 'output' agreed solution of one negotiation sequence may be input to further sequences. In order to identify when interlocutors are agreed, and thus on what they are agreed, we need some way of analysing the way in which **feedback** on the level of the attitudes "**agreement**" or "non-agreement" is communicated. There are two main cases to be addressed : **explicit agreement** and **implicit agreement**. Both presuppose some notion of what agreement is, so this will be dealt with first.

After a long (in AI terms) preoccupation with "knowledge representation", research on computational models of language and communication has more recently given a privileged position to the epistemic attitude of "belief", beginning with the work of the "Toronto School" (notably Cohen & Perrault 1979 ; Allen & Perrault 1980 ; Cohen, Morgan and Pollack 1990). Thus the illocutionary point of an "inform" communicative act is the addition of a belief to the hearer's set of propositional attitudes to the effect that the speaker believes the expressed proposition, and so on. A natural extension of this approach would be to analyse the primitive "agree" in Figure 1 as a **mutual belief** with respect to a set of propositions (part of the "common ground" established in dialogue). Leaving aside technical problems associated with mutual attitudes (such as infinite regression), we would make the following claim : **the propositional attitude of "belief" alone is inadequate for modelling attitudes of speakers in dialogue.** We do not have the space to argue fully for this claim here, and so shall give a brief summary of the general view adopted.

Consider the case of a completed argumentation sequence in dialogue. In such a case there is no *a priori* reason why the "loser" should adopt a *belief* with respect to the proponent's argued thesis. We should rather say that the "loser" has **conceded** the statements advanced. Dennett (1981) describes this situation as follows :

"... somebody corners me and proceeds to present me with an argument of great persuasiveness, of *irresistible* logic, step by step. I can think of nothing to say against any of the steps. I get to the conclusion and can think of no reason to deny the conclusion, *but I don't believe it* !"
(Dennett 1981 p. 308).

A more 'mundane' case is that where a sequence simply reaches *closure* - a state which may imply nothing more for speakers than "it is unlikely that we can progress further together on this point, the solution is acceptable enough as far as it goes at present". In general, therefore, we are obliged to admit a larger set of attitudes associated with dialogue, including **belief**, **opinion**, **concession**, **committment** and **acceptance**. We adopt the approach of analysing **agreement as joint acceptance**. In Cohen's (1992) terms, "acceptance" of a proposition differs from belief in that "Belief is a disposition to feel, acceptance a policy for reasoning" (op cit, p.5). We would argue that this provides a

more plausible analysis of students' attitudes in CPS dialogues to the extent that students accept offered partial solutions as part of a common reasoning process, rather than (primarily) adopting beliefs with respect to them during the dialogue. We describe acceptance as "joint" rather than "mutual" since we adopt the following view : what is *said* is important in collaborative dialogue, not what is *believed* ', i.e. "acceptance" of a proposition means making some utterance that is mutually understood to give feedback on acceptance (such as "Yes" or "Ok" : see Allwood et al 1991), and "joint acceptance" simply means that utterances of this kind have been made by both interlocutors.

The above discussion indicates an approach for dealing with explicit feedback on agreement (*qua* acceptance). It is restricted to the simple (and prevalent) case where **positive** feedback is given with respect to utterances that have **positive polarity** (Allwood et al 1991). As Allwood and co-workers have shown, *explicit* feedback expressions (such as "yes","mm","no","ok") are "highly dependent on context for a precise determination of their meaning" (op cit p. 13), and specifically on the polarity, mood (speech act) and information status of preceding utterances. As we describe below, the *relation* between the information 'content' of an utterance (u1) and the information content of one that follows it (u2) is also important in determining the type of *implicit* feedback communicated. This establishes a close link between the two main problems considered here.

We now consider *implicit* agreement *qua* acceptance. Why is joint acceptance signalled explicitly at the end of Dialogue Extract 1 (10-11) whereas it may be viewed as signalled implicitly throughout (2-9) ? Consider the following three interventions from the above Dialogue Extract 1 :

<...>
(2) S2 : well, that the energy ... all the energy ...
(3) S1 : well, that the kinetic energy is theoretically nil
[implicitly accepts (2) 'as far as it goes ...']
(4) S2 : it's nil on arrival, in fact ...
[implicitly accepts (3)]
<...>

Intuitively we want to say that in uttering (3), S1 accepts (2) "as far as it goes" (i.e. "it is acceptable that the *energy* is ...but we can say something even more specific, about *kinetic* energy"), and that in uttering (4) S2 accepts (3) implicitly, since (4) has a specific content (domain-task) relation with (3) (it "builds on" (3) and does not contradict it). How can we give substance to these intuitions ? There seem to be three main possibilities, which we can only sketch here.

The first possibility is to show how "offers" can communicate acceptance by characterising them as **communicative functions** (Gazdar 1981 ; Bunt 1989). Thus, following Edmondson (1981) offers can be viewed as **conditional acceptances** : an

offer with respect to a proposition p1, realised by agent A1 directed towards A2 in dialogue, updates the epistemic states of A1 and A2 with (at least) the element :

((accepts A1 p1) if (accepts A2 p1)) ;

or as Edmonson (op cit) puts it, a "propose" (offer) illocution expresses "I will if you will" (p.142).

The second approach is to combine an analysis of offers in terms of communicative functions with our analysis of domain-task **relations** between successively offered propositions. For example, if we have the following utterances and (minimal) updates of knowledge states of both agents :

(u1) A1 : (offer A1 p1) [=update => ((accepts A1 p1) if (accepts A2 p1))]
(u2) A2 : (offer A2 p2) [=update => ((accepts A2 p2) if (accepts A1 p2))]

given certain values for the relation R between p1 and p2 (such as that p2 *presupposes*[3] p1), we can derive from u2 :

((accepts A2 p1) if (accepts A1 p1)).

This puts the agents in the somewhat curious situation where each will accept a proposition if the other will (!). Now, in subsequent utterances this process of joint conditional acceptance can continue, thus building up a **stack** of propositions. Our model therefore predicts that the stack build-up will stop when each agent makes an *explicit non-conditional acceptance* ; and this is precisely what occurs (the joint explicit acceptance described earlier, also shown as explicit acceptance / ratification in Figure 1). The remaining problem is to provide a rigorous analysis of how specific domain-task relations between utterances function with respect to implicit feedback. We leave this problem for future research.

There is a third relevant approach to analysing acceptance, that has been described by Hamblin (1971) and Mackenzie (1981, 1985). The approach consists in positing a dialogue rule for updating a "committment slate", whereby *acceptance is assumed* with respect to a statement in the absence of explicit **denial** or **retraction**. As Mackenzie (1985) puts it "... in this [dialogic] game silence means assent." (p. 333). This approach has been developed with respect to highly idealised mathematical models for dialogue, consisting of successions of logical statements (see also Barth & Krabbe 1982). The

[3] We recognise that invoking the notion of presupposition introduces a large number of theoretical problems (see Levinson 1983). Our aim is simply to indicate other areas of research in pragmatics that are relevant to the problems considered here.

problem is that in real dialogues, denial or retraction is not always explicit. This approach is therefore of some application, but requires extension to take into account specific relations between utterances in the type of dialogue considered here and the rôle of implicit and explicit feedback.

6.0 Conclusion

This paper has been concerned with two main problems that arise in analysis and modelling of dialogues produced in the context of CPS : (1) modelling how joint solutions are co-constructed, and (2) determining when students are agreed and with respect to what. Our responses to both problems are situated within a more general model of CPS in dialogue as *negotiation*, the principal defining characteristic of which is the mutual goal of achieving agreement with respect to a set of propositions. Thus, our approach to addressing the first problem was to define a set of relations between offered partial solutions at the domain-task level, as they converge towards agreement. This enabled us subsequently to address one specific part of the second problem - that of analysing the implicit feedback communicated (acceptance-non-acceptance dimension) by an offered proposition that follows another. In this case, our hypothesis is that the kind of feedback communicated depends on the content relation between the offers. With respect to the second problem we described how problem solutions are co-constructed within iterative transaction units, 'punctuated' by the kind of joint explicit acceptance described by Allwood and co-workers (op cit). Finally, we described the necessity to extend the range of epistemic states incorporated in communicative act models, beyond "belief" to "acceptance", "opinion" and "concession". Such a project requires exploration of the logical properties of acceptance, to an extent which has been performed for knowledge and belief.

The analysis model has not yet been systematically applied to the whole corpus, largely because a number of important and difficult theoretical issues remain to be addressed. The relations and feedback elements described have, however, proved sufficient for analysing one case study (dialogue of one and a half hour's length). It is therefore not yet clear to what extent the relations described will extend to other domains, although we may make this conjecture given their highly general nature. Note that we have not considered analysis of argumentation sequences in this paper, although their rôle in conceptual change is clearly important (see Baker 1991,1992a).

A number of theoretical problems remain for further research, the most important of which include : communicative act models based on acceptance rather than belief ; a thorough explanation of the logical properties of acceptance ; and the detailed analysis of

the rôle of content relations in implicit acceptance. Given that progress can be made in these directions, the negotiation-based analysis approach described here does appear promising as a means of increasing our understanding of collaborative problem solving in dialogue.

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Appendix 1

Original of Dialogue Extract 1

(1) S1: donc qu'est ce qu'on peut dire si il y a un choc mou ?
(2) S2: bein que l'énergie ... toute l'énergie ...
(3) S1: bein que l'énergie cinétique à priori est nulle !
(4) S2: elle est nulle à l'arrivée, enfin ...
(5) S1: puisque ... puisque l'objet s'arrête, enfin, ah oui, surtout là il ne bouge pas ah ...
(6) S2: elle est nulle au départ, et c'est nulle à l'arrivée... d'énergie ... oui mais lors d'un choc mou, qu'est ce que ...
(7) S1: ça fait un moment qu'on l'a fait ça !
(8) S2: mais on a aussi ...
(9) S1: attends ... choc mou, bon t'as conservation de la quantité de mouvement mais ... l'énergie cinétique ne se conserve pas ! je crois que c'est ça qu'on a vu ... choc élastique par contre, les deux se conservent ...
(10) S2: oui, choc élastique, il y a l'énergie totale qui se conserve

(11) S1: oui
<...>