An analysis of cooperation and conflict in students' collaborative explanations for phenomena in mechanics[1]

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Abstract : In this paper we present a method for analysing students' collaborative explanations for phenomena observed in mechanics experiments. Analyses in terms of the epistemology of the domain and the socio-cognitive processes which operate upon it are presented as a basis for analysing the influence of dialogue processes on explanation generation. The dialogue processes considered are those of maintaining a shared focus, and generating utterances in the context of high-level mutual interaction goals and complex propositional attitudes of speakers. We concentrate on analysing explanation generation in terms of two complex propositional attitudes - COOPERATION and CONFLICT. Definitions of these attitudes enable us to identify a number of strategies which students use in 'removing' conflict, and to assess the extent to which cooperation and conflict situations facilitate changes in their beliefs. This analysis is intended to contribute to a computer program for providing automatic guidance which facilitates explanation generation in the framework of collaborative computer-based learning in physics.

Keywords : explanation, physics, dialogue, collaborative learning, cooperation, conflict.

1. Introduction

Studying the micro-structure of the way in which students collaborate in constructing explanations is interesting from a number of points of view. In current educational practice, school students often work in pairs, particularly during experimental work in science subjects. However, teachers commonly have little detailed knowledge of what goes on during such sessions. They are usually surprised to find out, and experience in analysing such interactions with teachers can often have an important effect on their teaching. For didactic researchers, looking at pair work provides an opportunity to analyse the epistemological content of students' explanations [47]. In cognitive and social psychology itself, research in collaborative learning situations has been approached from the point of view of the rôle of "socio-cognitive conflict" [18] in cognitive development, and in terms of Vygosky's [51] theories of the rôle of language in learning, where adult guidance or the "scaffolding" provided by collaboration with more capable peers is viewed as an important factor in problem-solving. Given existing educational practice, this research has been applied to a new generation of computer-based learning environments which aim to facilitate collaborative work [28,9,41].

Our own research goals are defined in terms of a specific aspect of collaborative work : we aim to analyse dialogues between pairs of students in order to contribute to the design of a computational guidance system which can facilitate the development of explanations in the context of a computer-based collaborative learning environment in physics. Given learning hypotheses in existing research on the respective rôles of *cooperation* and *conflict* in cognitive development, our research concentrates on analysing the dialogue strategies and structures which learners use in these two situations, and how these strategies relate to the way in which

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collaborative explanations develop. In order to analyse such dialogue strategies, we need clear definitions of cooperation and conflict, which we provide in terms of *complex mental attitudes*. The principal attitudes of speakers upon which we base our definitions are those of *beliefs* and *goals*. For the purposes of our analysis, a belief is viewed as the attitude of an individual towards a proposition, which may express aspects of the domain - for example, (believes Hélène (red ball_1)) - or other attitudes - for example, (believes Hélène (believes Laurent (red ball_1))). Belief is defined operationally by its *dialogue function* : a belief in some proposition implies that the individual will be prepared to assert the proposition in dialogue and to *argue* for its acceptance. A goal is an attitude towards a proposition which describes a state of affairs, where the individual has a certain willingness to expend resources in achieving it. We also use the notion of *awareness* on the part of an individual towards attitudes, and the notions of *mutuality*, i.e. mutual belief and mutual goals. The definitions of cooperation and conflict in terms of these primitives are discussed in detail later in the chapter. As a preliminary we remark that cooperation is defined in terms of the performance of dialogue utterances which are viewed as contributing towards the achievement of a state of affairs which is a mutual goal. Conflict is defined in terms of awareness of belief in some proposition p, belief that the other speaker believes not-p, or the other speaker does not believe p, or some other proposition is believed to be inconsistent with p. These definitions enable us to describe how utterances which contribute to collaborative explanations relate to cooperative goals, and how successions of utterances transform mental attitudes towards a situation where the conflict situation no longer obtains.

At present we cannot claim any "cognitive status" to our analyses : we rather present research towards developing a new exploratory analysis method, which will be systematically applied to dialogue transcripts in further research. We attempt to apply the method not to dialogues in general, but rather to didactic dialogues between students of a specific age, with a specific problem to resolve. The research is being carried out in collaboration with other researchers[2], within the framework of a wider project which aims to study students' conceptions of energy. The problem chosen is one where pairs of students are asked to *interpret* phenomena observed in mechanics experiments, in terms of a specific concept in physics - that of *energy*. In order to perform this interpretation task, they must generate *explanations*. We now describe our theoretical approach to explanation.

There is a large research literature on explanation in cognitive science, which we can not review here. In order to describe our approach to explanation we identify :

(1) criteria for characterising research goals occurring in the literature ;
(2) recurrent theoretical terms used in analysing explanation ;
(3) a number of different theoretical approaches to explanation analysis.

(1) The two criteria which we use for characterising research goals are :

(i) the nature of the entity which constitutes 'the explanation' ;
(ii) the nature of the entity to be explained.

For example, Schank [42] views 'the explanation' as the individual understanding which results from the process of "intentional reminding", initiated by "expectation failure". The kinds of entities to be explained are physical, social and psychological events and processes. Such psychological preoccupations must be distinguished from research on the linguistic or communicative structure of 'the explanation' as a discourse [27].

(2) The following are recurrent theoretical terms in explanation research :

(2-1) explanation as *understanding* ;
(2-2) *difference* and/or *symmetry* between explanation actors (knowledge, belief, goals, points of view, rights or rôles in the interaction) ;

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[2] Prof. A. Tiberghien and F. Langlois, CNRS-IRPEACS.

(2-3) *coherence* of the explanation, at multiple conceptual levels, both 'internal' (an agent's view) and 'external' (coherence with another agent in explanation, with authorities, with the teacher, ...) ;

(2-4) *translation* between representational levels, from a description of the entity to be explained at one level to a coherent view at another level ;

(2-5) explanation as an *emergent* property of interaction.

(3) The theoretical approaches used analysing explanations include *epistemological* (the nature and structure of knowledge in specific domains) *socio-cognitive* (the socio-psychological processes which operate on domain knowledge to generate explanations) and *linguistic* (speech act, discourse structure) approaches.

The specific explanation problem which we consider incorporates these points as follows : (1) 'the explanation' is viewed as the *joint understanding* (2-1) which *emerges* (2-5) from their interaction. "Emergence" means here that participants' explanations (*re* individual mutual and individual beliefs concerning interpretation of physical phenomena) may only emerge during the course of the dialogue. This joint goal is explicit in the specific "social contract" of the interaction.

(2) The speakers must establish the internal and external coherence of their explanations (2-3) in terms of the concept of energy, and establish their relevance to the phenomena to be explained in terms of *intertranslatability* (2-4) with descriptions at an 'objects and events' level. They have *symmetrical* rights and high-level goals in the interaction (2-2), as distinct from a didactic interaction between teacher and student, but there may be *differences* in lower-level specific goals, and in knowledge and beliefs. This may lead to *conflict*. The emphasis of our analysis is therefore on these two interactional situations - COOPERATION and CONFLICT - and their rôle in explanation generation.

(3) We present analyses in terms of three theoretical approaches, which are closely linked : epistemological, socio-cognitive and dialogic. The epistemological analysis assumes a distinction between "everyday terms"[3] and "physics terms". For example, "big" is an everyday term, and "mass" a physics term. " Clearly, this distinction is contentious, and cannot be completely maintained, since terms such as "weight" may be used in either an everday or a physics sense. What it means for a term to be part of physics knowledge is determined by scientific communities (essentially, a Kuhnian view). We adopt a set of epistemological "levels" of analysis, where the syntax and semantics of physics is distinguished (see Tiberghien, this volume). The epistemological analysis essentially defines a *domain knowledge representation scheme*, upon which the *socio-cognitive level* analysis is based. Here we analyse the way in which students jointly intertranslate between different epistemological levels, in terms of schema theory, which we represent in terms of "socially-distributed production rules" [41]. The *dialogic analysis* in turn is based on the cognitive analysis : the aim is to describe how the cognitive processes of explanation generation of each student are influenced by their interaction, and how the joint explanation which emerges from the interaction develops. For example, students' explanation processes are influenced by the necessity to maintain a joint *dialogue focus* [30], by the requirements of managing *turn-taking* [43], and by the general requirements of cooperation [29], such as *relevance* of their utterances to joint goals [45]. Perhaps the most important influence on their explanation generation processes is the additional cognitive load imposed by the necessity to model the attitudes of the other speaker in the dialogue, in order to satisfy these other requirements.

To date there has been relatively little research on the influence of dialogue processes on explanation generation, nothwithstanding Ericsson and Simon's [22] recognition of the need for a model for language generation in studying verbal reports in protocol analysis. Exceptions are the work of Roschelle and his collaborators [9,41] on "transaction analysis" of collaborative learning in a physics microworld, and the research of Barnard and Erkens [10] on modelling the

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[3] Later we adopt a more technical definition of "everyday terms" as an "objects and events" representational level.

rôle of language production in problem solving. Roschelle *et al* have attempted to use analyses of turn-taking strategies used by students collaborating in the use of a physics learning environment (the "envisioning machine") to identify when students are really cooperating and constucting a "joint problem space". In our previous work [5,6] we described how turn-taking mechanisms relate to conflict and cooperation. In this chapter we concentrate principally on defining these complex attitudes and the way in which they influence the generation of utterances.

2. Empirical work

Dialogues were recorded and transcribed from children (n = 6) aged 17-18 years, working in pairs. The students were volunteers, working after school hours, with no precise time limit imposed on their activity. Each session turned out to be around 1 and a half hours long. Two observers were present (including their physics teacher), who made notes which were later used for clarification in dialogue analysis. The observers could intervene if the students appeared to be 'stuck'. In our subsequent analysis we consider one specific dialogue ("Hélène and Laurent"). The following problem was given in written form, introduced verbally by the teacher :

"We want to compare one of the properties allowing a distinction to be made between the substances of which the balls are made. For this, we will study their respective behaviours when they interact with the ground. We will interpret the phenomenon in terms of energy."[4]

The students were given a set of balls of different sizes and substances - rubber, steel, etc. - and also had other materials at their disposal - rulers, weighing scales, wooden planks. They had the possibility to ask for anything else they wanted. After a short introduction by the teacher to the objectives of the experiment, the students discussed together, with few interventions from the teacher.

The objective of the question posed to the students was that they should arrive at an idea of a property of the substance of the balls as the factor which explained their rebound properties, in terms of the "coefficient of restitution" :

vr1 = e.vr2
vr1 = v1 - v'1
vr2 = vé - v'2

v1, v2 velocities before impact
v'1, v'2 velocities after the impact
0<e<1
e=0 perfectly inelastic impact
e = 1 perfectly elastic impact

A 'correct' explanation for the rebound of the balls would be something like the following :

Explanation for the rebound of a free-falling ball in terms of Energy

At time the ball is released, t_0, system BALL/EARTH has POTENTIAL ENERGY = E_p = mgh.
As the ball falls there is a DISPLACEMENT of the FORCE (mg) through a distance h and there is WORK, which transforms the E_p of the system BALL/EARTH to KINETIC ENERGY = $^1/_2mv^2$. This energy is transferred to the system BALL

[4] All problem statements and dialogues appearing in this paper have been translated from the original French by the author. Originals are available on request.

When the ball impacts with the ground the system BALL transfers ENERGY (Mechanical Energy = PE + KE) to the system BALL/EARTH, some of which is converted into HEAT.
The system BALL now has less kinetic energy and so will rebound to a height less than the initial height.
The loss of energy (converted into HEAT) from t_0 to the final time at the highest rebound of the ball, is the difference between the PE of system BALL/EARTH at t_0
(= mgh) and the PE at the highest point after the rebound (mgh1 ; h1 < h).
KE is 0 in both of these cases.

In the explanation, physics terms are marked in CAPITALS, to distinguish their use in a physics sense from an 'everyday' sense - a very important point when considering students' conceptions. From students of this age we would not of course expect such knowledge ; but we would expect their explanations to involve the concepts of energy transfer and conversion, work, force and various forms of energy (potential, kinetic, mechanical).

In general, the dialogues follow the pattern of a student proposing an experiment - for example, dropping two balls and measuring the height of the rebound - then discussion on whether the right result had been found, followed by a period during which they discussed their explanations of the results, trying to relate them to concepts of energy with which they were familiar.

3. Analysis of cooperation

We adopt three approaches to analysing the rôle of cooperation in explanation generation :
(i) *epistemological* - in terms of the concepts and methods of physics, in comparison with concepts related to everyday experience ;
(ii) *socio-cognitive* - in terms of individuals' contributions to joint explanations with respect to domain knowledge;
(iii) *dialogic* - in terms of the processes of generation and understanding utterances in explanation dialogues.

The three approaches are clearly interdependent.

3.1 Epistemological analysis

In terms of this approach, we have analysed students' explanations both in terms of

(i) categories derived from scientific methodology, and
(ii) 'representational levels', identified from the referents used with respect to the experimental situation.

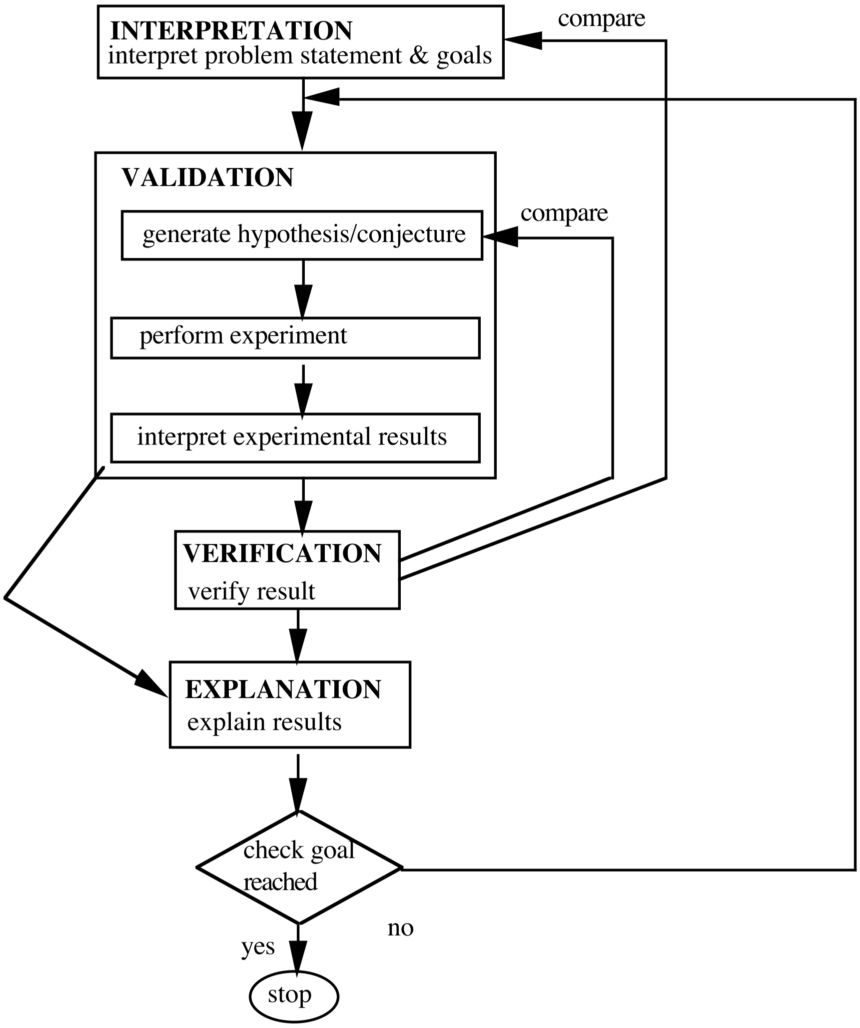
3.1.1 Analysis in terms of scientific methodology

The analysis categories used are derived from the scientific methodology as physicists conceive it - in some sense a *normative* description rather than what physicists actually do. We have represented the stages which occur as a "task analysis" [39] in figure 1. Brief definitions are as follows.

Problem interpretation.

This includes interpretation of the original written question, and the repeated references to the problem which the students made throughout the course of their problem solving. It is clear that the way in which a problem is represented influences crucially the way in which the problem can be solved.

Figure 1 : Task analysis for physics explanation dialogues in terms of elements of scientific method



Validation.

This term is used specifically for the case where an experimental hypothesis may be said to have been generated (whether stated explicitly or not), and this hypothesis is interpreted as confirmed or disconfirmed from an experimental result. There are therefore four subtasks to the validation task :

1 **hypothesis** and **prediction** formation ;
2 proposal and performance of and **experiment** to test the hypothesis ;
3 interpretation of the experimental **result** ;
4 the result is **interpreted** as a **confirmation** or disconfirmation of the hypothesis.

These stages occur rarely in their entirety in the dialogue considered. In the case of one or more steps being absent, although *no validation is said to have taken place,* we may nevertheless use some of the individual subtasks as analytical categories. *Interpretation of the result* is the activity of determining the result and its relationship with prior hypotheses (if any). As such it is distinguished from *explanation*, although it is clear that there are interrelationships between the two, as follows :

° the hypothesis derived will be influenced by interpretation of the previous results, and by its explanation in terms of energy (when one is given) ;

° previous hypotheses strongly influence perception of the result, in the case where no precise measuring instrument is available;
° the students are rarely clear about any of these stages - we rarely have the situation where they say explicitly "my hypothesis is ...", "the experiment will test this hypothesis and so on.

The following is an extract which illustrates some of these analysis categories.

<u>Example of validation</u>

H: the small one rebounded a bit more!
(result (Hélène) = "rebound different for balls of same materials")
L: well, its not very clear, eh?
wait, wait ....
L: the higher one, perhaps?
H: yes but that's not .... the small rebounded ...
L: the small one rebounded more! Now ......
H: yes, but it's, it's the same in fact, they're the same substances which they .... so that shows well, that when the same substance, the volume ... the volume acts no..... the volume,
(interpretation (Hélène) = "when the substance of the balls is the same, their difference in VOLUME is the cause of their different rebound")
or rather the mass
(interpretation (Hélène) = "when the substance of the balls is the same, their difference in MASS is the cause of their different rebound")

Verification

This is the students' activity of "checking" the acceptability of an experimental result with respect to their existing knowledge. This knowledge can be of various kinds [33,34], including references to :

° knowledge of physics ;
° the relationship between physics knowledge and experience ;
° mathematical knowledge (such as the sign of a value obtained from calculation) ;
° the 'didactical contract' (eg using all information in the question; "the teacher said so previously"), and
° the 'social contract' between the students.

This last category is particularly interesting from the point of view of our research objectives in the modelling the influence of interaction between students. For example, they may accept a result as verified if they are agreed upon it. The following is an example of verification which occurs in this dialogue :

<u>Example of verification</u>

"L: I ask myself if we theoretically we shouldn't find a negative value. What we're interested in is the variation in energy. It's positive because at the start it's potential energy. It's greater on arrival."
(verification criterion = mathematical knowledge)

Explanation

We have previously described our point of view on the nature of explanation in this cooperative context. In terms of the epistemology of physics, explanation may be identified with respect to *physics terms used* - in our case, those relating to *energy*. The following is an example of explanation (physics terms marked in **bold** typeface).

<u>Example of explanation</u>

1 H: .... if , if the coefficient of absorption is a function of the **mass** ... the one which has a greater **mass** will have a greater **coefficient of absorption**.
2 L: yes ... but it will fall faster.
3 H: .... so, by ?? it rebounds lower ... but effectively there are the weights which are involved in **potential energy**...

This counts as an explanation both in terms of the physics referents used and in terms of the *position* of the utterances after interpretation of results.

3.1.2 Analysis in terms of representational levels

Analysis in terms of representational levels gives us some means of defining the explanation process itself, in contrast to *interpretation* of results, since utterances forming parts of explanations are expressed in terms of concepts related to *energy*, whereas *interpretations* and descriptions of results are usually expressed in terms of "objects and events" (for example "heavy", "weight", rather than "mass"). Explanation in this context can thus also be viewed in terms of *translation* between descriptions in everyday terms to descriptions in terms of physics. The explanation process is thus closely linked to that of development of the *problem representation* in problem solving tasks. Chi, Feltovich and Glaser [14] have described four "representational levels" in the creation of problem representations in mechanics :

Level 1 : physical objects, properties and problem statement referents ;
Level 2 : associative network structures for representations at level 1 ;
Level 3 : physics concepts and idealised objects ;
Level 4 : the syntax and semantics of physics equations.

In the following example we can analyse the way in which students cooperate in the process of 'translation' between levels (referents are in **bold**).

<u>Example : representational levels in collaborative explanation dialogues</u>

1."H: and uh, and we can say that .... wait, what are these...
2.L: ok, in fact we know that there is **conservation of quantities [level 3]** during movement...
3.H: look! this one's a lot **softer [level 1]** than that one, but that one is softer than the **steel [level 1]** one.
4.L: ah, ah yes.
5.H: so, the **steel [level 1]** rebounds more than the **rubber [level 1]** , uh, **yellow [level 1]** one there, and the **black [level 1]** one didn't rebound at all.
6.L: its not a matter of ..... of **density [level 3]** , I think, all the same, it's not the density.
7.H: good, the difference between the substance which the ball's made of!
8.L: yes, its the subst ..... yes!
9.H: ah! so, in terms of **energy [level 3]** , we can see that ...
10.L: right, hang on, support !
(throws ball)
11.H: hang on, because there's the .... if we release at a certain height, there's **potential energy** involved .....**[level 3]**
12.L: yes.
13.H: with the, the **weights [level 1]** , with the **mass [level 3]** .
14.L: could we say that there is conservation? ....no, because there are fr[ictions] ..... ok, right, if we ignore, we said we'd ignore air friction, right, in fact ....."

It should be noted that since a given term such as "weight" may be used at either level 1 or 3 (line 13 above), its interpretation is *context dependent*. Such translations work in both directions. At line 2 L describes the result in terms of a physics concept ; however, H is presently thinking of the result at level 1. At 9 H attempts to translate these descriptions into the physics term "energy", after both L and H have described the situation in terms of the properties of the balls. At 11, H is also contributes to the explanation at the same level. In 13 H makes a self-correction, in translating the everyday term "weight" into "mass", presumably because she knows that the former would not be consistent with a physics level description (it does not appear in the energy equations, but "mass" does). In accordance with well known results in physics education (see [19]) we observed that students generally 'dwell' on the objects and events level - the colour of the balls, their size, the floor - and make repeated attempts to relate these descriptions both to energy equations and the descriptions in the original problem statement.

3.2 Socio-cognitive analysis

The epistemological analysis provides the general domain content of students' explanations, upon which we may base a model for socio-cognitive processes in explanation. For *individual* students, these explanation generation processes have been described in the literature in terms of bottom-up and top-down mechanisms in *schema matching* [14]. We have attempted to apply this production rule analysis method to the complete dialogue between Laurent and Hélène (approximately 60 rules have been identified), with the objective of exploring how students cooperate in construction of explanations, at the level of the domain concepts used, derived from the epistemological analysis. In many cases it proved impossible to analyse such rules without recourse to both students in interaction. Roschelle & Behrend [41] term rules analysed in this way "socially-distributed productions". They argue that instead of viewing production rules as somehow "inside the head" of each individual student, a more fruitful approach is to analyse the way in which collaborative problem solving "takes place *between* the partners". In addition to the "collaborative completion" which they identify, where in effect a compound sentence is distributed across speaker turns, we identify various forms of *collaborative elaboration*. From these analyses we have identified the following phenomena :

1 collaborative completion of rule right-hand side (rhs) by the other student ;
2 collaborative elaboration of the rhs of rules by the other student ;
3 collaborative elaboration of the left-hand side (lhs) of rules.

The following are some examples.

Collaborative completion of rule right-hand side

"L: and kinetic, and in fact, the kinetic energy... it...	**IF kinetic energy is involved**
H: and well, it, it is nil at the start	**THEN kinetic energy is nil at the moment it is released**

Collaborative elaboration of the rule right-hand side

"L: so, what can we say if there's an inelastic impact?	**IF there is an inelastic impact**
H: um, well, that the energy, ... all the energy ..;	**THEN the energy ...**
L: well, the kinetic energy, is theoretically nil.	**the kinetic energy is nil ...**
H: it's nil on arrival, in fact"	**on arrival at the impact**

"L: what is it in ... in the characteristic of this	**IF one ball rebounds, and the other does not**
ball which is going to ...going to tell us that	**THEN characteristic which explains rebound is ...**
that one absorbs and that one rebounds?	
H: well, it's what we called the rigidity"[5]	**the rigidity**

Collaborative elaboration of the lhs

"L:ok, there's a total loss of velocity, which means that ...	**IF there is total loss of velocity and**
H: wait, wait, ... with their interaction, with the ground.	**there is interaction with ground**
L: so the ground absorbs eh...	**THEN the ground absorbs ...**

[5] Note that the students invented this term themselves - it was not part of taught knowledge.

H: yes
L: absorbs the impact! **the impact**

In this example, we also see collaborative elaboration of the rhs.

In all of these cases it is not easy to isolate *why* this collaboration takes place : is a right-hand side completed by another because the first student cannot complete it, or has the second student taken an opportunity (perhaps a hesitation on the part of the first) to *interrupt* and supply something relevant, which was not in fact what the first student would have said? A number of rhs of rules can be interpreted as calls to "action schemata" [14], being procedures for solving equations attached to problem schemata :

> "H: so, wait, it leaves with a velocity of nil at 1metre height, ...
> L: wait, the energy, the mechanical energy, uh, the mechanical energy is the potential energy plus the kinetic energy"
> [Hélène]
> **IF there is velocity and height involved**
> **THEN (...)**
> [Laurent]
> **THEN [apply action schema : calculate the mechanical energy by adding the potential energy to kinetic energy]**

Finally, we analysed one case where the student could clearly see that a particular schema applied, but did not articulate the conditions which led her to believe this to be the case:

> "H: I'm sure there's a proportionality somewhere...
> **IF (...)**
> **THEN there is proportionality involved**

The analysis which we have described forms the basis for a cooperative production rule model for explanation in this restricted domain. We now analyse students'propositional attitudes towards their representations of the domain in order to model the processes by which they generate utterances in a cooperative dialogue context.

3.3 Dialogue level analysis

At this level we aim to analyse how the specific utterances which students generate to express their explanations relate to the set of implicit assumptions of cooperative dialogues. One such feature is the managing of turn-taking [43]. Since this has been extensively analysed by Roschelle and Behrend [41] in similar dialogues, we concentrate here on analysis of individual utterances as *speech acts* [44], and attempt to describe the way in which they are generated from mental states such as propositional attitudes [24], in order to satisfy cooperative goals in the interaction. We also analyse *conflict* situations in terms of complex propositional attitudes, and specific kinds of utterances used in *argument.*

3.3.1 Analysis of cooperation

The general set of assumptions of speakers in cooperative interactions has been analysed by Grice [29] in terms of a set of "conversational maxims" for sincerity, informativeness, and so on. In our analysis we assume Perrault's [37] formalisation of a number of these maxims. We also assume the general "deliberative agent" architecture [26] underlying production system models, a set of propositional attitudes derived from general theories of rational agency and a set of utterance categories derived from computational speech act theory [17]. The analysis method consists of assigning the utterance categories, together with their propositional content to the dialogue, and showing how they may be generated from propositional attitudes together with representations of the high-level goals of the interaction. In the case of analysing conflict, we assign corresponding complex attitudes to the students at given points in the dialogue. A production system is currently being programmed which can generate some utterance types from representations of initial domain knowledge and attitudes of students. The agent attitudes used include *beliefs*, *intentions*, *goals*, *committments*, *preferences* and *wants*. There are of course many profound theoretical issues which are currently being addressed in agent theory, concerning the nature of belief and intention, for example. Rather than performing *a priori* analyses, our research strategy is to take existing formalisations and to successively refine them with respect to analyses of real dialogue protocols. Here we can only give a short illustration of the model currently being developed. The 'content' of propositions referred to in the analysis is derived from the previous epistemological analysis.

An important starting point for the analysis is the set of mutual goals which constitute the "social contract" between the students :

> L and H have the mutual goal that they will mutually believe that some set of propositions {p1, ... pn} explain a given set of results {r1, ... rn} (G1) for a given set of experiments {expt_1,....expt_n}, that they will agree upon these results (G2) and that the propositions be instances of some subconcept of energy (G3) :

Mutual goals

G1 : (mgoal L H (mbelief L H (explains {p1, ... pn}
(rebound_behaviour (result {r1, ... rn} {expt_1,....expt_n}))))).

G2 : (mgoal L H (mbelief L H ({r1, ... rn} {expt_1,....expt_n}))).

G3 : (mgoal L H (mbelief L H (instance {p1, ... pn} (subconcept energy)))).

The definition of mutual goals ("mgoal") is dervived from the work of Galliers [25] and Elsom-Cook [21] :

R1 (mgoal S1 S2 g) --> (goal S1 g) & (believes S1 (goal S2 g)) &
(goal S2 g) & (believes S2 (goal S1 g)).

We assume that the well-known infinite regress of mutual beliefs - (believes S1 (believes S2 (believes S1 .... - is stopped at the first level of embedding :

R2 : (mbelief S1 S2 b) --> (believes S1 b) & (believes S1 (believes S2 b)) &
(believes S2 b) & (believes S2 (believes S1 b)).

Let us now look at an example utterance pair :

Utterances	Analysis
"L: it rebounds all the same a bit lower ...	(INFORM L H p1) p1 : (result (lower_than (rebound ball_1) (rebound ball_2)))
H: yes, but with respect to the masses you can see that the steel one is heavier"	(EXPRESS H L (believes H p1))

Definitions of the categories INFORM and EXPRESS are derived from computational pragmatics : to INFORM some proposition is to ASSERT it with the intention that the proposition be believed by the hearer [37]. To ASSERT a proposition is to intend that the hearer believes that the speaker believes the proposition. EXPRESS is a category of utterances where the speaker communicates their *attitude* to some proposition, in this case, *belief*, [49]. We need to show how this utterance analysis can be derived from the goals, and from *reaction* to the other speaker's utterances. Assume that a focus mechanism selects p1 as the most relevant proposition, both in terms of other propositions in semantic memory and in terms of the high level goals [30]. From G3, R1 and R2, and a rule which states that the components into which a goal may be analysed are also goals

R3 : (goal S1 x) --> (goal S1 (subcomponents x)) we can derive

(goal L (believes H p1)) &
(goal L (believes H (believes L p1)))

Many other goals may be derived - such as that L should believe p1 - which are already satisfied. Now, if there are no other goals to which L is *committed* which L believes conflict with these goals, L may become committed[6] to them. Assume therefore that L is committed to these goals. If an agent is committed to a goal, then the agent *wants* to perform a dialogue action which it is believed will contribute to its achievement. Now, as a definition of INFORM we have :

R4 : (wants A1 (believes A2 x)) & (wants A1 (believes A2 (believes A1 x))) &
(believes A1 x)
--> (wants A1 (INFORM A1 A2 x).

So, L wants to INFORM H of p1. Choice amongst wanted actions is made according to a preference mechanism will evaluates the extent to which an action is likely to be successful in achieving the wanted goal. This involves reasoning about the propositional attitudes of the other speaker. We have described how a set of rules may be developed which relate attitudes to dialogue utterance types. We also require rules for updating the speaker's beliefs about the beliefs of the other, subsequent to performing an action, and for hearer's to infer attitudes from utterances of the other. Now assume that from the communicative context, the syntactic form of the utterance and its intonation contour [38], H is able to recognise it as a declarative sentence. From a combination of this and interpretation of the utterance in relation to high-level goals, H infers that L wants her to believe p1 and that L believes it (sincerity assumption :

R5 : (believes S1 (INFORM S2 S1 x)) -->
(believes S1 (want S2 (believes S1 x))) & (believes S1 (believes S2 x)).

Now we can assume that H does not believe p1 to be *inconsistent* with her beliefs, but not that she actually believes it. If she believes that L has INFORMED p1, she believes that L wants her to believe it and that L believes it (the reverse of R5). Since it is her turn, she first responds, then makes another declaration. So we have :

R6 : (believes S1 (wants S2 (attitude? S1 x))) -->
(wants (EXPRESS S1 S2 (attitude? S1 x))).

So L expresses her attitude (believes L p1) in the word "yes". We need to look at the wider cooperative context in order to determine whether the "yes" expresses the attitude of belief or not, since L could be simply 'taking her turn' in the dialogue. In this case, her response concerns the experimental result rather than its explanation ; since there is no evidence later in the dialogue to suggest that she does not believe this interpretation of the result, we assume this interpretation of her utterance. This illustrates one of the profound difficulties of this kind of analysis, and the necessity to consider the wider dialogue context.

We have not described all aspects of the model which we are developing - the focus mechanism, mechanisms for preferring wanted actions to others, what it means for goals to be inconsistent, and so on - but have rather given a short example to illustrate the approach. In the context of explanation, the most important question to be addressed is how and when agents are willing to adopt beliefs stated by others - whether they are believed to be inconsistent with their own or not. Our approach to this is based on existing work by Harman (1986). We also analyse the phenomenon of belief revision in terms of *conflict situations*.

3.3.2 Analysis of conflict

[6] We adopt a definition of commitment in terms of Cohen and Levesque's [16] definition of intention

The incidence of inter-individual conflict in problem-solving tasks has been argued to be a necessary condition for cognitive development, under certain specific conditions [18]. It is possible, therefore, that conflict and its resolution plays a constructive rôle in the development of cooperative explanations. Results from the study of "socio-cognitive conflict" on development are, however, inconclusive, and some research suggests that conflict is associated with *less* progress [11]. Our preliminary qualitative analyses suggest that the precise way in which conflict is dealt with may be important in determining the extent to which students' beliefs may change. Research on the formalisation of conflict resolution exists within the framework of "Distributed Artificial Intelligence" [46], where it has been approached from the point of view of specifying *negotiation protocols* for resolving goal conflicts and task allocation problems between distributed agents. Little of this research has addressed the problem of resolving conflicts in *beliefs* or *points of view*, which has rather been approached from the perspective of *argumentation* research. This has been concerned with identifying argument units and their interrelations [1], linguistic markers associated with arguments [20,36], grammars for understanding arguments [15], and with defining formal dialectics systems [8].

In our approach we characterise conflict and its resolution in terms of the model described earlier for cooperation at the dialogic level - in terms of complex propositional attitudes and the speech acts which they generate. We define several different kinds of conflict, which allows detailed analysis of the various ways in which conflict may be 'removed' or 'resolved'. We adopt definitions of conflict based on modifications of the research of Galliers [25] and Elsom-Cook [21] as follows.

Internal conflict is a notion of conflict within the beliefs of a single individual. It depends on the notions of *awareness* and *inconsistency* :

Definition of internal conflict

(believes A1 X1) & (believes A1 X2) & (aware A1 X1) & (aware A1 X2) &
(believes AI (inconsistent X1 X2))
--> (**int_conflict** A1 X1 X2).

[A1,A2 = agents, X1,X2 = propositions]

"Inconsistency" is not necessarily a matter of logical contradiction - it may relate to a more general *coherence model* of belief revision [31]. "Awareness" is modelled as focus of attention (Grosz & Sidner 1986) in working memory, within the general cognitive architecture. We have applied the notion of "spreading activation" [2] to modelling focus in tutorial dialogues [4,6].

External conflict concerns conflict between beliefs of two or more different agents. There are at least two different kinds - where some believed conflicting alternative proposition has been stated (ext_conflict_a"), and where a simple denial has been stated with no reason given ("ext_conflict_d"). Here we differ with Elsom-Cook [21], since these two different kinds need to be distinguished in the dialogues analysed.

Definitions of external conflict

(believes A1 X1) & (aware A1 X1) &
(believes A1 (believes A2 X2) & (aware A1 (believes A2 X2)) &
(believes A1 (inconsistent X1 X2))
--> (**ext_conflict_a** A1 A2 X1 X2).

(believes A1 X1) & (aware A1 X1) &
(believes A1 (believes A2 (not X1)) & (aware A1 (believes A2 (not X1)))
--> (**ext_conflict_d** A1 A2 X1).

These forms of external conflict may also be *mutual*, for example (and similarly for **m_ext_conflict_a**) :

Definition of mutual external conflict

(**ext_conflict_d** A1 A2 X1) & (**ext_conflict_d** A2 A1 X1)
--> (**m_ext_conflict_d** A1 A2 X1).

The process of conflict resolution is one example of *negotiation* [4,6], which we define as :

Definition of negotiation : the set of cognitive processes which generate a sequence of dialogue actions by two speakers, who possess the propositional postures of indifference or conflict with respect to one or more propositions, and one or more of whom possesses the goal of transforming the mutually shared posture to one of cooperation with respect to some proposition.

Note therefore that negotiation is not exclusively concerned with conflict resolution[7], nor with goal conflict [6], but may include the attempt to secure mutual belief from a position of indifference or absence of such. Note also that initial attitudes of speakers do not have to be symmetrical - one could believe conflict to exist and the other not, for example.

Consider now the definition of ext_conflict_a. This complex attitude ceases to be ascribed to an agent if any combination of the conjuncts in the definition is no longer ascribable (there are $2^4 - 1 = 15$ possibilities). For each specific conflict situation we therefore need to ascribe the appropriate conflict attitude, to describe which combination of conjunctive primitive attitudes no longer hold on conflict removal, and to describe the dialogue processes which led to this removal. As a preliminary means to exploring the viability of the analysis method, we have analysed conflict situations in the Hélène/Laurent dialogue. We can only give a few examples here, taken from a consecutive series of 39 exchanges near the beginning of the dialogue (one and a half hour duration). The definitions are presently rather simple, but prove adequate for analysing the phenomena observed here.

In a more complete analysis we would also need to make use of descriptions of dialectic moves in argument - support, counterclaim, etc. For example, in addition to analysing a specific utterance as an ASSERTION, we need to represent the fact that the utterance may be viewed as *supporting*, or *denying* some previous utterance. A method for analysis such phenomena may be derived from the work of Toulmin, Rieke and Janik [48] and Barth and Krabbe [8]. These do not constitute new speech act categories, but are rather *relations* between them [23]. There are different types of relations : speech acts may enter into an *explanatory* relation with the *propositional content* of others, but in the *justification* relation, what is justified is the entire act/proposition itself.

Conflict example 1 (p1, ... = propositions)

1 L: it rebounds all the same a bit lower, it's normal, but still ...
2 H: yes, but look, with respect to the masses, look you can see that the steel one is ... heavier
3 L: yes, but it's not a question of mass.
p1 : (explains "mass" (lower (rebound ball_1) (rebound ball_2)))
(ext_conflict_d L H p1)
4 H: well ; and , there's all the same potential energy involved, I'm sorry !
(ext_conflict_d H L p1)
(m_ext_conflict_d L H p1)
5 L: ...... ok, but if you've ...
6 H: if we re...
7 L: if you had a big steel ball, it would rebound ...

---

7 Sycara [46] restricts negotiation to "...the process of achieving compromise between conflicting goals".

8 H: if we release them at the same height, so that there's one which has a greater mass than the other, the one with the bigger mass, would have greater potential energy ...
9 L: yes, but ...
10 H: so, there will be more ...
11 L: do you believe that if, if you have an enormous rubber ball like that, which is a kilogramme, you believe it would rebound a lot ?
12 H: yes, but that's only valid in the case of a perfectly elastic impact.
13 L: right, ...
14 H: in fact, I think ...
15 L: perhaps we'd be better off thinking about that, because, a priori, it's simpler, given that it's an inelastic impact

The first conflict occurs at 3 and 4, where L denies H's (indirect) claim that the difference in rebound behaviour is explained by the *mass* of the balls. Since L does not propose an alternative explanation, this is analysed as **ext_conflict_d**, which, when recognised by H becomes **m_ext_conflict_d.** From our earlier analysis of conflict (**ext_conflict_d**), minimal attitudes of H and L are as follows :

Hélène : (believes H p1) & (aware H p1) &
(believes H (believes L (not p1)) & (aware H (believes L (not p1)))

Laurent : (believes L (not p1)) & (aware L (not p1)) &
(believes L (believes H p1)) & (aware L (believes H p1))

Our analysis therefore predicts that mutual conflict is transformed to individual conflict when any combination of the conjuncts for either H or L ceases to hold, and that mutual conflict is removed when any combination of conjuncts no longer holds in the complex attitude for each. In this case, it is difficult to see why L disagrees. H produces *support* for her beliefs by stating that potential energy is involved, to which L *concedes*. H then produces a further supporting argument (the greater the mass, the greater the potential energy and rebound), to which L again concedes, but produces a *plausible counter-argument* (counter example of large rubber ball , not rebounding much), to which H does not concede in the case of an inelastic rebound, but concedes in the case of a perfectly elastic rebound. So ; we are now in a situation where we might expect conflict to be removed by L conceding p1 in the case of a perfectly elastic rebound. This does not appear to be the case. The specific conflict resolution which occurs here is as follows :

- since L has produced no direct successful counterargument against H's argumentative support for p1, H *assumes* that L accepts p1 [(believes H (believes L p1))] ;
- as shown later in the dialogue, in fact (believes L (not p1))
- the *focus of attention* shifts to considering the case of elastic and inelastic impacts, so we have [(not (aware L (not p1))) & (not (aware H p1))]
- the *cognitive resources* which H and L are willing to use in resolving this conflict are *expended*, and so, they explicitly signal a focus shift (line 15 : " L: perhaps we'd be better off thinking about that ... ").

In this case, therefore, we observe that conflict may be 'removed' by :

° concentrating on related propositions with respect to which agreement occurs, thus no longer being aware of propositions with respect to which conflict occurred ;
° no longer being aware of conflict by focussing on a new topic introduced in the argument when cognitive resources are expended ;
° believing that the other implicitly agrees by assuming an argument to be convincing in the absence of effective counter-arguments to supports for other claims ;
° believing that the other implicitly agrees by assuming an argument to be convincing in the absence of alternative plausible claims.

Let us now consider a second example.

Conflict example 2

28 H: yes, elastic impact, there's the total energy which is conserved.
29 L: yes ...
30 H: yes, but there's the friction ... of the air !
p2: (explains (friction air)
(result (not (same (rebound ball_1) (rebound ball_2)))))
31 L: oh, I don't think its especially the air friction which invervenes ...
(ext_conflict_d H L p2)
32 H: but yes, otherwise it would rebound to the same height !
(m_ext_conflict_d L H p2)
p3 : (same (rebound ball_1) (rebound ball_2)) [stated earlier in dialogue]
p4: ((((not p2) --> p3)) & (not p3)) -> p2)
33 L: no ! ...
(ext_conflict_d L H p4)
34 H: but yes !
(m_ext_conflict_d L H p4)
35 L: ... it's the loss at the moment of impact ...
p5: (explains loss_at_impact
(result (not (same (rebound ball_1) (rebound ball_2)))))
36 H: that's the same ... that's really a sort of friction also. It's a form of friction, either with the ground or with the air
(ext_conflict_a L H p5)
p6: (equivalent loss_at_impact (friction air))
37 L: yes, but after all, air friction in comparision with friction ... no, no, what you call ground friction is by contrast negligable !
(ext_conflict_a L H p6)
38 H: ah well .... yes

This is a complex sequence. What we have in effect is a succession of conflicts, with only the final one resolved by explicit acknowledgement. Even in this case we cannot assume that H's "yes" implies that they genuinely adopt L's point of view. It divides into two phases : 28-34, where conflicting propositions are simply *denied*, and 35-38 where alternative propositions ("counterclaims") are proposed. Each of the conflicts have conjuncts in their definitions concerning awareness and belief in the conflicting propositions. Both of these are involved in resolution of these conflicts - i.e. the speaker who 'won' the last conflict resolution (L) assumes that H no longer believes the conflicting propositions, since he believes this last argument to be *won*, and neither student is now *aware* of the original propositions with respect to which conflict took place. Therefore, L assumes that winning an argument means that L and H are agreed on some proposition p_x, that p_x is inconsistent with some other proposition p_y, that this belief in inconsistency will be shared by H, and finally that this will lead to H dropping their belief in p_y.

With respect to the possible effects of conflict in the evolution of students' explanations, it is clear that their explanations do not evolve as effectively as they might since : learners have a tendency to 'remove' conflict rather than to 'resolve' it. We summarise the ways in which students remove conflict as follows :

focus shifts
- focussing on related propositions with respect to which there is agreement ;
- focussing on the most recent conflicts ;
- focussing on recent concluded local arguments ;
- (focus shifts may sometimes be occasioned by *exhaustion of cognitive resources* when conflict is not resolved after a certain time).

belief revision assumptions
- believing that a 'won' local argument implies belief revision ;
- believing that an unsupported alternative claim implies acceptance of their own claim ;
- believing that absence of an alternative claim implies acceptance ;

lack of clarity

- students' understanding of their own arguments and beliefs, as well as of those of the other, is unclear, which leads to an unclear understanding of the conflict situation (the propositions with respect to which conflict takes place).

Assumptions concerning belief revision and mechanisms for shifting focus are therefore important elements in explaining students' conflict resolution strategies in this domain.

It is understandable that conflict between students tends to be *removed* rather than *resolved* and that beliefs are not genuinely revised in such conflicts : in the absence of an arbiter, such as a human teacher, there is no direct *legitimisation* of their beliefs, although students do employ various strategies for *validating* and/or *verifying* their results and explanations [33,34], with respect to their own knowledge, and aspects of the general "didactic contract" ("all information in the question is relevant", "the teacher said so", etc.). We can therefore hypothesise a clear role for the use of AI techniques for generating automatic guidance for facilitating students' explanations. We believe that the following kinds of adaptive guidance may be useful with respect to resolving students' conflicts :

- identification of reasonable and unreasonable arguments ;
- identification of propositions with respect to which conflict takes place ;
- clarification of the beliefs of each student ;
- identification of dialogic or argumentative relations between propositions stated ;
- recapitulation and reinforcement of argument conclusions ;
- indication as to when an argument is worth pursuing or not.

What this amounts to is the claim that the generation of effective negotiated explanations between students requires a system for providing guidance or tutoring on *how to argue*. Providing automatic guidance of this kind within the context of cooperative computer-based learning environments needs to be situated within a more general cognitive simulation of explanation and argument in dialogue.

4. Conclusions and further work

In this paper we have described an integrated approach to analysing students' cooperative explanations. The method is intended to take the influence of the dialogue processes on explanation generation into account, and to produce an analysis which can form the basis of a computationally tractable model for providing automatic guidance for cooperative explanation generation. Our present concern has been to define a set of suitable analysis methods, which will be systematically applied to further dialogue protocols in further research. Such an enterprise is interesting in its own right, but a precise analysis may also help us to define reasons why explanations do not develop effectively, and thus a rôle for computer-based education in the context of collaborative computer work.

Our qualitative analysis suggests that <u>cooperation is more constructive than conflict</u> in the evolution of students' explanations. In their search for agreement, students may settle on explanations which neither would have generated alone. In the absence of confirmation and legitimisation, students often do not pursue the most fruitful directions amongst those which have been stated. There is therefore a clear need for guidance in *cooperative* contexts. We also argued that <u>students in fact rarely *resolve* conflicts</u>, since they either focus on subclaims upon which there is agreement, change focus to the most recent conflicts, assume that the conflict is resolved if the most recent sub-argument chain is 'won', or simply give up. Conflict itself is rarely clearly understood, which leads to 'softening' its perception. Students could therefore benefit from guidance in 'sharpening' their understanding of each other's beliefs and claims, and in indicating when a conflict is worth resolving. We therefore propose the following rôle for computer-based guidance.

The learning context considered is *computer-based distance education*, where each student has access to a mechanics learning environment for the problem we desribed. Within the environment, students can communicate their explanations in cooperation and conflict situations to each other. We shall use a deliberately *restricted* interface for communication, which forces students to clearly state the utterance and proposition units of their explanations and arguments. Such a tool has been described for arguments by VanLehn [50]. Forcing students to express themselves in this way should eliminate some of the ambiguity of the conflict situation derived from natural language interaction. Within the system, a computer 'monitor' program will generate guidance for both students by explaining the utterances and beliefs of each to the other, indicating which cooperative explanations are worth pursuing, and which conflicts are worth resolving. It may also need to provide new information in order to do so, using a domain model, the elements of which are provided in our analyses at the epistemological and socio-cognitive levels. These are our ambitious long-term research goals, for which the analyses presented provide good theoretical and empirical bases.

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